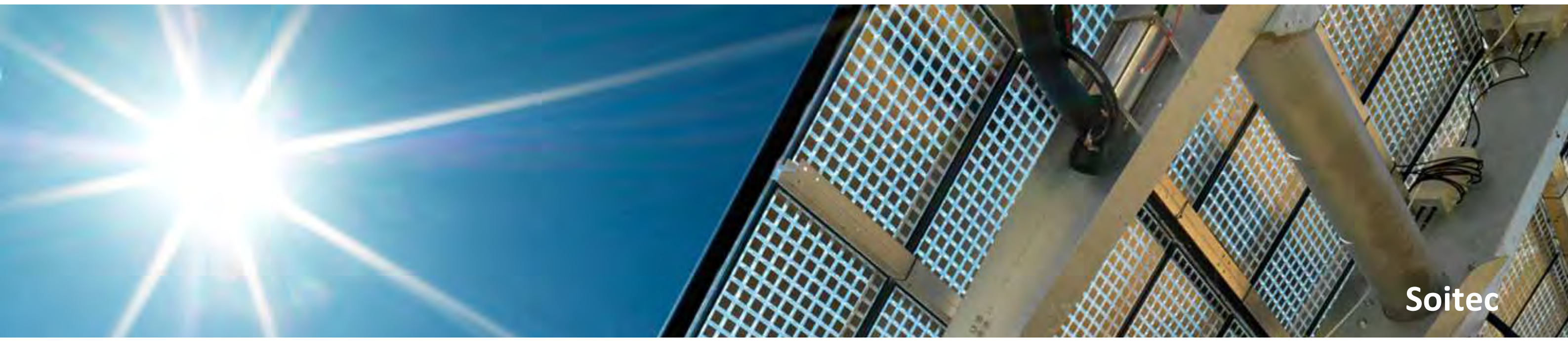
PVTRIN Training course

Handbook for Solar Installers

www.pvtrin.eu



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INTRODUCTION

Solar power can create thousands of jobs.

In 2010, the European PV industry directly employed over 150,000 people. According to the Advanced Scenario of the European Photovoltaic Industry Association (EPIA), 3.5 million full-time jobs in the global PV sector will have been created by 2030; half of which will focus on system installation and maintenance. In the European Union (EU), the PV industry could employ 465,000 people by 2015, 900,000 by 2020, and as many as 1,000,000 by 2040.

The application of PV technologies will require highly-qualified technicians for PV installation, repair and maintenance. Furthermore, the main agents in the sector (manufacturers, developers, investors) seek certified skills and quality assurance in all phases of a PV installation (design, installation and maintenance). However, a shortage of skilled workers may weaken projected growth in the PV market.

It is therefore obvious that quality installations call for skilled technicians and appropriate training. Certification schemes add a further quality assurance that the installer possesses the capability (organisation, competence and equipment) to complete PV installations in a safe and effective way. Currently, the availability of certification schemes for PV installers varies greatly between Member States. Many countries have not validated certification schemes and although training courses for PV installers are often available, these courses have different eligibility requirements and qualifications.

Among its other objectives, the EU Renewable Energy Directive (2009/28/EC) obliges Member States to set up mutually recognized certification schemes. In response to the challenges of this sector, appropriate training systems and certification schemes -to validate the competence of the installers- need to be developed, in order to ensure the efficient installation and operation of the PV systems that are installed.

Within this context, the scope of the European PVTRIN initiative, supported by the Intelligent Energy Europe programme of the European Commission, focuses on the development of an appropriate training and certification scheme for technicians involved in the installation and maintenance of small-scale PV systems. PVTRIN aims to establish the basis for the adoption of a mutually recognised certification scheme in EU Member States. As part of the PVTRIN activities, appropriate specific training materials have been developed to help technicians gain additional knowledge and skills. This will enable their successful participation in training programmes to gain higher levels of qualification, based on the requirements of the RES Directive and relevant national regulations.

The PVTRIN scheme will offer installers:

- High quality training courses: to advance in their profession and to update their knowledge and technical skills

- Flexible training opportunities: an e-learning platform, “24/7” technical assistance, useful technical guides and practical training material and tools
- Employability: recognition and competitive advantage in the profession, based on a certification scheme that follows acknowledged quality standards
- Mobility: certification that provides a “passport” to the EU job market.

The PVTRIN Handbook for Solar Installers has been designed to cover the key areas of knowledge, skills and competences for technicians who wish to participate actively in PV installation and the maintenance of small-scale PV systems. Based on a task analysis of the PV system installation process, agreed during the PVTRIN scheme development with the key stakeholders, the manual covers the following topics:

1. Solar energy basics
2. Design principles
3. BAPV and BIPV
4. Installation-Safety
5. Maintenance and troubleshooting
6. Case studies-best practices
7. Example installation of a small scale PV in building
8. Quality management and customer care

The scope of this publication is designed to equip PV installers with practical knowledge and best practice recommendations; it also presents a number of useful references and encourages the installer to acquire a deeper understanding of all the critical aspects in efficient design, installation, troubleshooting and maintenance of a PV system.

This Handbook should be used as supporting document that provides theoretical knowledge, in order to help trainees -along with a number of selective supplementary resources and tools- better prepared for the certification examination. It references other key publications and standard texts applicable to PV projects, and should therefore be treated as a supplement and used in conjunction with these other references and tools. The training process includes theoretical and practical training units combined with appropriate levels of self study.

Trainees should be aware that in-depth knowledge of the information that is presented, which includes an understanding of National Regulations and relevant legislations, as well as appropriate field experience, are generally required for the successful completion of the PVTRIN certification process.

Important note:

The Handbook is not intended to be either exhaustive or definitive and cannot guarantee to cover all possible situations in depth. It has been prepared on the basis of current knowledge of the relevant technology, quality standards, security practices and regulations. Technicians are advised to exercise their own professional judgment and to consult all current building regulations, health and safety codes, standards and other applicable guidelines, as well as up-to-date information on all the materials and products that they may use.

SOLAR BASICS 1

1. SOLAR BASICS

1.1. Solar Photovoltaic (PV) Energy

1.1.1. The sun as an energy source

The sun is the most important source of energy for all natural processes on Earth. It is a vital source of energy for the survival of all plant and animal species and provides heat for many critical processes such as photosynthesis.

Modern methods of energy production on Earth use solar energy, in the everyday sense of the word – in either a direct or an indirect way. Indirect forms of solar energy are biological material from the past that has been transformed into fossil fuels (oil and coal), as well as wind power, hydropower and bio-energy.

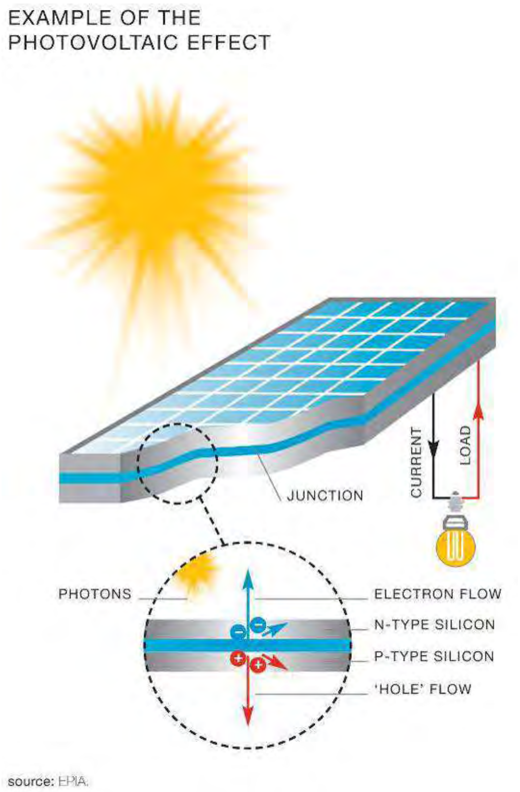
Solar photovoltaic installations generate a electric energy direct form of solar energy.

1.1.2. What does PhotoVoltaic (PV) mean?

Photovoltaic (PV) systems contain cells that convert sunlight into electricity. Inside each cell there are layers of semi-conductive material. Light falling onto the cell creates an electric field across the layers, causing electricity to flow. The intensity of the light determines the amount of electrical power that is generated by each cell.

A photovoltaic system can operate in the absence of bright sunlight and can generate electricity on cloudy and rainy days from reflected sunlight.

FIGURE 1.
EXAMPLE OF THE PHOTOVOLTAIC EFFECT. (Source: EPIA)



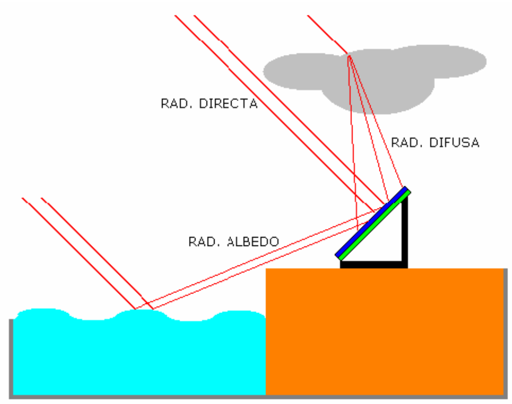
1.1.3. Solar irradiance (radiation)

Large quantities of statistical data on solar energy availability are gathered globally. For example, the US National Solar Radiation database has collected data for 30 years on solar irradiance and meteorological conditions from 237 sites in the USA. The European Joint Research Centre (EJRC) also collects and publishes solar irradiance data from 566 sites in Europe.

It is important to distinguish between the following five different types of solar irradiance data (3TIER,2011):

- Direct Normal Irradiance (DNI): the amount of solar radiation received per unit area by a surface that is always held at a perpendicular (or normal) angle to the rays that fall in a straight line from the position of the sun at any given position in the sky.
- Diffuse Irradiance (DIF): the amount of radiation received per unit area by a surface (not in a shaded or in shadows) that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere or reflected off the ground and may arrive from all directions.
- Albedo Irradiance: A third type of radiation called albedo, is direct or diffuse radiation, reflected from the soil or nearby surfaces (snow, lakes, building walls, and so on).

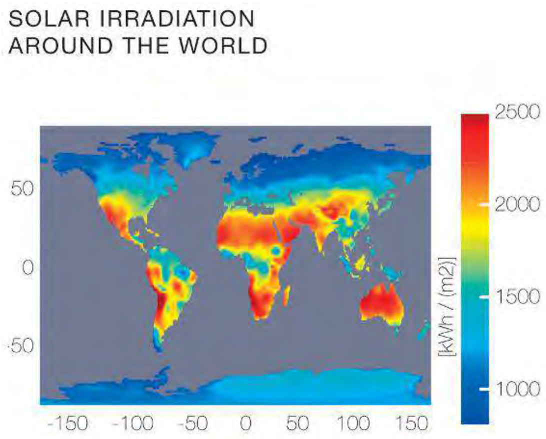
FIGURE 2.
TYPES OF SOLAR IRRADIANCE. (Source: Tknika, 2004)



- Global Horizontal Irradiance (GHI): the total amount of shortwave radiation received from above by a horizontal surface. It includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DIF).
- Global In-Plane Irradiance: the total amount of radiation (both DNI and DIF) received from above by an inclined surface.

The irradiance data that is used will vary according to the type of PV system in use. PV systems should be designed in such a way that they capture as much sunlight as possible. Their orientation and inclination are therefore of critical importance. As a consequence, global in-plane irradiance is suggested for power output calculations.

FIGURE 3.
SOLAR IRRADIATION AROUND THE WORLD. (Source: Gregor Czisch, ISET, Kassel, Germany, 2007)



1.1.4. Angle definition

A good understanding of the sun's path is necessary to estímate solar irradiance levels and the resulting yields of a PV system.

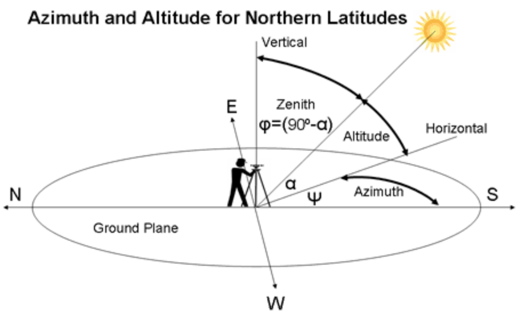
At any place on Earth, it is possible to identify the sun's position in terms of solar elevation and **solar azimuth**. Generally, a PV installer will define the south as $\gamma = 0°$ and indicate the angles to the east and west with a negative and a positive sign, respectively. Following this definition, the East is given as $\gamma = -90°$ and the West as $\gamma = 90°$.

1.1.5. Solar altitude and spectrum

The **solar elevation angle α** is measured from the horizontal, the value of which will alter with the daily course of the sun and annual seasonal changes. The value of this angle has, among other parameters, an impact on the solar irradiance level.

As it passes through the Earth's atmosphere, solar irradiation is deflected by contaminant particles and pollutants and is absorbed by molecules in the air. As a consequence, it has a lower irradiation level when the sunlight reaches the PV system.

FIGURE 4.
SOLAR AZIMUTH AND ALTITUDE. (Source: www.mpoweruk.com , 2011)



Air Mass (AM) caracterises the thickness of the atmosphere through which the sunlight has to pass to reach the ground. AM = 1 when the solar elevation is perpendicular to the Earth (α = 90°). This value corresponds to the solar elevation at the equator at noon during the spring equinox, and never occurs under latitudes in Europe.

The relationship between solar elevation α and air mass is defined by the following: AM = 1/sinus(α).

For Europe, an air mass factor of 1.5 is used as the average annual value, but an air mass of 4 is reached during December, when the sun is at a flatter angle.

1.1.6. Ground reflection

An albedo value should be used to calculate irradiance on an inclined plane, to take into account the reflectivity of the surrounding area. The albedo value depends upon the properties of the ground. For a reflective surface like snow, the albedo can reach a level as high as 0.9. In general, an albedo value of 0.2 can be assumed.

1.1.7. Measurement of solar radiation

Solar irradiation can be measured directly by using pyranometers and photovoltaic sensors or indirectly by analysing satellite images

Pyranometers are high precision sensors using a thermocouple measuring the temperature difference between an absorber surface and the environment. These types of devices are very accurate, but slow to respond because they work on a thermal basis. Measurement accuracy of 0.8% can be achieved on an annual average.

PV sensors are based on a calibrated solar cell and are less accurate than pyranometers due to their intrinsic spectral sensitivity. However, their advantage is that they cost significantly less than pyranometers. Their annual average accuracy is in the region of 2% to 5%. PV sensors in conjunction with data loggers are often used for monitoring larger PV systems.

FIGURE 5.
SSR 11 SOLAR RADIATION SENSOR (PYRANOMETER). (Source: Hukseflux, 2011)

1.1.8. Enormous potential

There is more than enough solar irradiance available to satisfy global energy demands. On average, each m^2 of land on the Earth is exposed to enough sunlight to generate 1,700 kWh of energy every year using currently available technology. The total solar energy that reaches the Earth's surface could meet existing global energy needs 10,000 times over.

While only a certain part of solar irradiance can be used to generate electricity, this 'efficiency loss' does not, unlike fossil fuels, actually waste a finite resource.

Where there is more sunlight, more power can be generated. The sub-tropical areas of the world offer some of the best locations for solar power generation. The average energy received in Europe is about 1,200 kWh/m^2 per year (GHI). This compares with 1,800 to 2,300 kWh/m^2 per year in the Middle East (GHI).

EPIA has calculated that Europe's entire electricity consumption could be met, if just 0.34% of the European land mass (an area the size of the Netherlands) were covered with photovoltaic modules. International Energy Agency (IEA) calculations show that if 4% of the World's very dry desert areas were used for PV installations, then total global primary energy demand could be met.

There is enormous untapped potential. Large areas such as roofs, building surfaces, fallow land and desert could be used to support solar power generation. For example, 40% of the European Union's total electricity demand in 2020 could be met, if all suitable roofs and façades were covered with solar panels (Sunrise project 2011)

1.2. PV System

The key parts of a solar PV energy generation system are:

- Photovoltaic cells and modules to collect sunlight,
- An inverter to transform direct current (DC) to alternate current (AC),
- A set of batteries and charge controller for stand-alone PV systems,
- Other system components.

All system components, excluding the PV modules, are referred to as the Balance of System (BOS) components.

1.2.1. PV cells and modules

The solar cell is the basic unit of a PV system. Cells are connected together to form larger units called PV modules. Thin sheets of EVA (Ethyl Vinyl Acetate) or PVB (Polyvinyl Butyral) are used to bind cells together and to provide weather protection. The modules are normally enclosed between a transparent cover (usually glass) and a weatherproof backing sheet (typically made from a thin polymer or glass). Modules can be framed for extra mechanical strength and durability.

FIGURE 6. PV MODULE CELL CONNECTION. (Source: Tknika,2004)

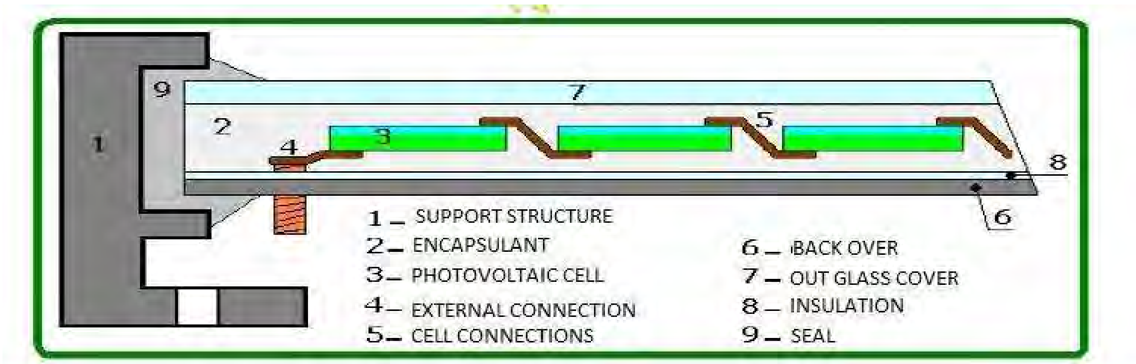
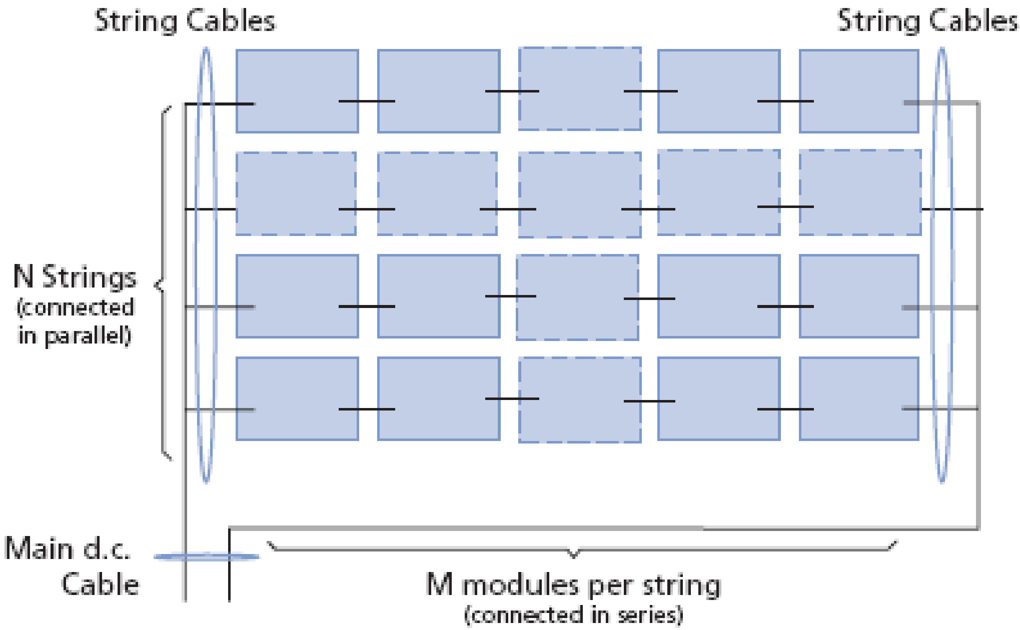


FIGURE 7. SOLAR POWER SYSTEM CONFIGURATIONS. (Source: DTI, 2006)



Modules can be connected to each other in series (known as a string) to increase the total voltage produced by the system. The strings are connected in parallel so as to increase the total system current.

The power generated by PV modules varies from a few watts (typically 20 to 60 Wp) up to 300 to 350 Wp, depending on the size of the module and its technology. Low wattage modules are typically used for stand-alone applications, where power demand is also generally low.

Modules may be sized for quick installation on any potential site. They are robust, reliable and weatherproof. Module producers usually guarantee a power output of 80% of the Wp, even after 20 to 25 years of use. The working life of a module is typically in the region of 25 years and may even last for more than 30 years.

1.2.2. Inverters

Inverters convert DC power generated by a PV module to AC power. This makes the power output compatible with the electricity distribution network and most common electrical appliances. An inverter is essential for grid-connected PV systems. Inverters are available in a wide range of power classes from a few hundred watts (normally for stand-alone systems), to several kW (the most frequently used range) and even 2,000 kW (central inverters) for large-scale systems.

1.2.3. Batteries and charge controllers

Stand-alone PV systems need to store energy for future use in a battery. The two standard types in widespread use are lead-acid or lithium-ion batteries. New high-quality batteries, designed specifically for solar applications are now available with a working life of up to 15 years. The final duration of a battery depends on its management.

Batteries are connected to the PV array via a charge controller. The charge controller prevents the battery from overcharging and from discharging. It can also provide information on the state of the system and enable metering and payment in relation to electricity consumption.

1.2.4. Other system components

In addition to the modules and inverter, a large number of other system components can be added to the system. All these components are known as the Balance of System (BoS). The most common components are mounting structures, tracking systems, electricity meters, cables, power optimisers, transformers, combiner boxes, switches, etc.

1.3. PV Technologies

PV technologies are classified as first, second or third generation. First generation technology is the basic crystalline silicon (c-Si). Second generation includes Thin Film technologies, while third generation includes concentrator photovoltaics, organics, and other technologies that have yet to be commercialised on a large scale.

1.3.1. First generation (Crystalline silicon technology)

Crystalline silicon cells are made from thin slices (wafers) cut from a single crystal or a block of silicon.

The type of crystalline cell depends on how the wafers are produced. The main types of crystalline cells are:

- Mono crystalline (mc-Si),
- Polycrystalline or multi crystalline (pc-Si),
- Ribbon and sheet-defined film growth (ribbon/sheet c-Si).

The most common cells are 12.7 x 12.7 cm (5 x 5 inches) or 15 x 15 cm (6 x 6 inches) and produce 3 to 4.5 W – a very small amount of power. A standard c-Si module is made up of about 60 to 72 solar cells and has a nominal power ranging from 120 to 300 Wp depending on size and efficiency.

The typical module size is 1.4 to 1.7 m², although larger modules are also manufactured (up to 2.5 m²). These are typically utilised for Building Integrated Photovoltaic (BIPV) applications.

Crystalline silicon is the most common and mature technology representing about 80% of the present-day market. Between 14 and

22% of the sunlight that reaches the cells are turned into electricity. For c-Si modules, efficiency ranges between 12 and 19%.

1.3.2. Second generation (Thin films)

Thin-film modules are constructed by depositing extremely thin layers of photosensitive material on to a low-cost backing such as glass, stainless steel or plastic. Once the deposited material is attached to the backing, it is laser-cut into multiple thin cells.

Thin-film modules are normally enclosed between two layers of glass and are frameless. If the photosensitive material has been deposited on a thin plastic film, the module is flexible. This creates the opportunity to integrate solar power generation into the fabric of a building (BIPV) or end-consumer applications.

Standard Thin Film modules have lower nominal power (60 to 120 Wp) and their size is generally smaller. However, there is no common industry agreement on optimal module size for Thin Film technologies. As a result they vary from 0.6 to 5.7 m² depending on the technology. Very large modules are of great interest to the building sector as they offer efficiencies in terms of handling and price.

Four types of Thin Film modules are commercially available:

Amorphous silicon (a-Si)

The semiconductor layer is only about 1 μm thick. Amorphous silicon can absorb more sunlight than c-Si structures. However, a lower flow of electrons is generated which leads to efficiencies that are currently in the range of 4 to 8%. An increasing number of companies are developing light, flexible a-Si modules perfectly suitable for flat and curved industrial roofs.

Multi-junction Thin Film silicon (a-Si/μc-Si)

Multi-junction Thin Film silicon consists of an a-Si cell with additional layers of a-Si and micro-crystalline silicon (μc-Si) applied to the substrate. The μc-Si layer absorbs more light from the red and near-infrared part of the light spectrum. This increases efficiency by up to 10%. The thickness of the μc-Si layer is in the order of 3 μm, meaning thicker but also more stable cells.

Cadmium telluride (CdTe)

CdTe Thin Films cost less to manufacture and have a module efficiency of up to 11%. This makes it the most economical Thin Film technology currently available.

Copper, indium, gallium, (di)selenide/(di)sulphide (CIGS) and copper, indium, (di)selenide/(di)sulphide (CIS)

CIGS and CIS offer the highest efficiencies of all Thin Film technologies. Efficiencies of 20% have been achieved in the laboratory, which are close to the levels achieved with c-Si cells. The manufacturing process is more complex and less standardised than for other types of cells. This tends to increase manufacturing costs. Current module efficiencies are in the range of 7 to 12%.

1.3.3. Third generation photovoltaics

Concentrator photovoltaics (CPV)

Concentrator photovoltaics (CPV) utilise lenses to focus sunlight on to solar cells. The cells are made from very small amounts of highly efficient, but expensive, semi-conductor PV material. CPV cells can be based on silicon or III-V compounds (generally gallium arsenide or GaA).

CPV systems use only direct irradiation. They are most efficient in very sunny areas which have high amounts of direct irradiation.

The concentrating intensity ranges from a factor of 2 to 100 suns (low concentration) up to 1000 suns (high concentration). Commercial module efficiencies of 20 to 25% have been obtained for silicon based cells. Efficiencies of 25 to 30% have been achieved with GaAs, although cell efficiencies well above 40% have been achieved in the laboratory.

The modules have precise and accurate sets of lenses which need to be permanently oriented towards the Sun. This is achieved through the use of a double-axis tracking system. Low concentration PV can be also used with one single-axis tracking system and a less complex set of lenses.

Other third generation PV

After more than 20 years of research and development, third generation solar devices are beginning to appear on the market.

Many of these new technologies are very promising. Organic PV cells represent an exciting development. These include both fully organic PV (OPV) solar cells and hybrid dye-sensitised solar cells (DSSC).

Third generation technologies that are beginning to reach the market are called “emerging” and can be classified as:

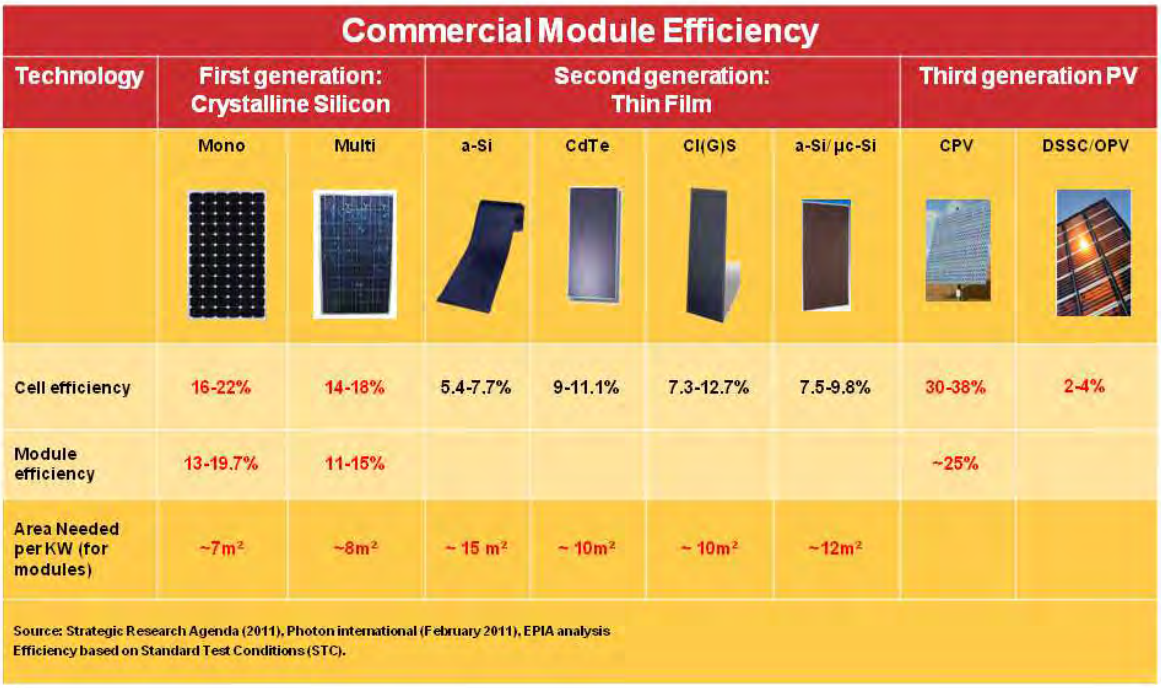
- Advanced inorganic Thin Films such as spherical CIS and Thin Film polycrystalline silicon solar cells.
- Organic solar cells which include both fully organic and hybrid dye-sensitised solar cells.
- Thermo-PhotoVoltaic (TPV) low band-gap cells which can be used in Combined Heat and Power (CHP) systems.

Third-generation PV products have significant competitive advantages in consumer applications, because of their substrate flexibility and ability to perform under dim or variable lighting conditions. Possible application areas include low-power consumer electronics (such as mobile phone rechargers, lighting applications and self-powered displays), outdoor recreational applications, and BIPV.

In addition to the above-mentioned third-generation PV technologies, a number of novel technologies are at present under development:

- Active layers can be created by introducing quantum dots or nanotechnology particles. This technology is likely to be used in concentrator devices.
- Tailoring the solar spectrum to wavelengths with maximum collection efficiency or increasing the absorption level of the solar cell. These adjustments can be applied to all existing solar cell technologies.

FIGURE 8. OVERVIEW OF EFFICIENCY OF PV TECHNOLOGIES. (Source: EPIA 2011, Photon International, February 2011, EPIA analysis)



Commercial Module Efficiency

Technology	First generation: Crystalline Silicon		Second generation: Thin Film				Third generation PV	
	Mono	Multi	a-Si	CdTe	CI(G)S	a-Si/µc-Si	CPV	DSSC/OPV
Cell efficiency	16-22%	14-18%	5.4-7.7%	9-11.1%	7.3-12.7%	7.5-9.8%	30-38%	2-4%
Module efficiency	13-19.7%	11-15%					~25%	
Area Needed per KW (for modules)	~7m²	~8m²	~ 15 m²	~ 10m²	~ 10m²	~12m²		

Source: Strategic Research Agenda (2011), Photon international (February 2011), EPIA analysis
Efficiency based on Standard Test Conditions (STC).

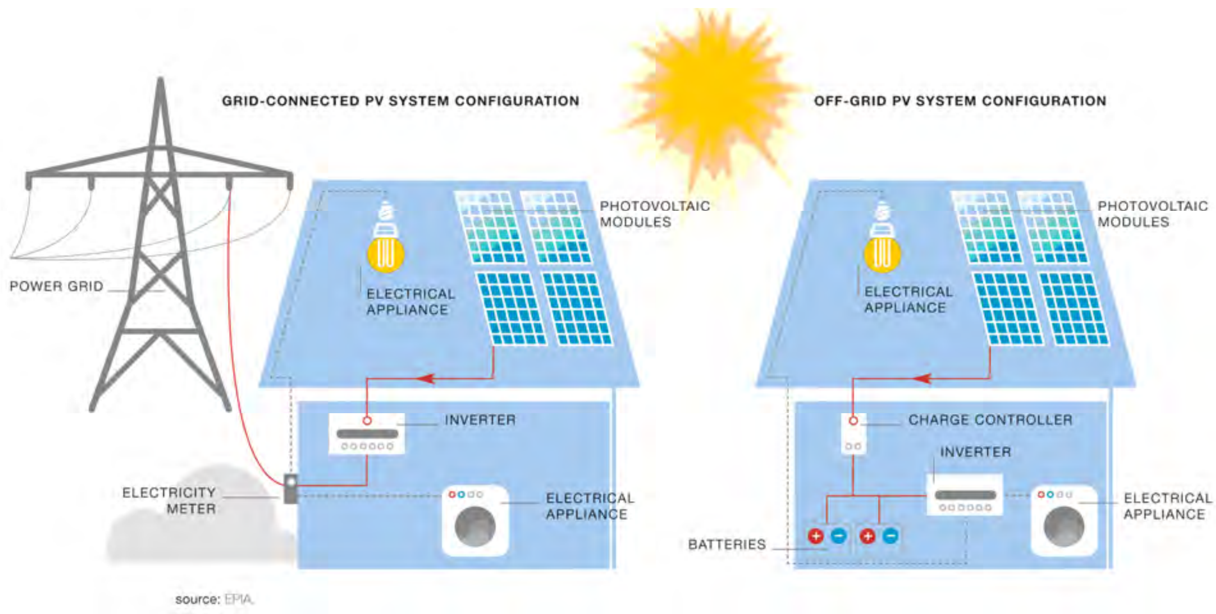
1.4. Types of PV systems and Applications

PV systems provide clean power for small or large applications. Many installations are already generating energy around the world in individual homes, housing developments, offices and public buildings.

Today, fully functioning solar PV installations operate in both urban and remote environments, where it is difficult to connect to the grid or where there is no energy infrastructure. PV installations that operate in isolated locations are known as stand-alone systems. In built areas, PV systems can be mounted on top of roofs (known as Building Adapted PV systems – or BAPV) or can be integrated into the roof or building façade (known as Building Integrated PV systems – or BIPV).

Modern PV systems are not restricted to rectangular and flat panel arrays. They are flexible and may be curved and shaped to the design of the building. Innovative architects and engineers are constantly finding new ways to integrate PV into their designs, creating buildings that are dynamic, beautiful and provide free, clean energy throughout their working life.

FIGURE 9. DIFFERENT CONFIGURATION OF SOLAR POWER SYSTEMS. (Source: EPIA)



1.4.1. Grid-connected systems

When a PV system is connected to the local electricity network, any excess power that is generated can be fed back into the electricity grid. Under a FiT regime, the owner of the PV system is legally entitled to payment for the power generated in this way. This type of PV system is referred to as being 'on-grid.'

Most solar PV systems are installed on homes and business premises in developed areas. By connecting to the local electricity network, owners can sell their excess power, feeding clean energy back into the grid. When solar energy is not available, electricity can be drawn from the grid.

Solar systems generate Direct Current (DC) while most household appliances utilise Alternating Current (AC). An inverter is installed in the system to convert DC to AC.

+Large industrial PV systems can produce enormous quantities of electricity at a single point respectful of the environment. These types of electricity generation plants can produce from many hundreds of kilowattshours (kWh) to several megawattshours (MWh).

The solar panels for industrial systems are usually mounted on frames on the ground. However, they can also be installed on large industrial buildings such as warehouses, airport terminals or railway stations. The system can make double-use of an urban space and put electricity into the grid where energy-intensive consumers are located.

TABLE 1.
TYPICAL TYPE AND SIZE OF APPLICATIONS PER MARKET SEGMENT FOR GRID-CONNECTED PV SYSTEMS. (Source: Solar Generation VI, EPIA and Greenpeace)

Type of application	Market segment			
	Residential <10 kWp	Commercial 10kWp-100 kWp	Industrial 100kWp-1MWp	Utility-scale >1MWp
Ground-mounted			X	X
Roof-top	X	X	X	
Integrated to façade/roof	X	X		

1.4.2. Stand-alone, off-grid and hybrid systems

Off-grid PV systems have no connection to an electricity grid. An off-grid system is usually equipped with batteries, so power can still be used at night or after several days of low irradiance. An inverter is needed to convert the DC power generated into AC power for use in appliances.

Most standalone PV systems fall into one of three main groups:

- Off-grid systems for the electrification of rural areas,
- Off-grid industrial applications,
- Consumer goods.

1.4.2.1. Off-grid systems for rural electrification

Typical off-grid installations bring electricity to remote areas or developing countries. They can be small home systems which cover a household's basic electricity needs, or larger solar mini-grids which provide enough power for several homes, a community or small business use.

1.4.2.2. Off-grid industrial applications

Off-grid industrial systems are used in remote areas to power repeater stations for mobile telephones (enabling communications), traffic signals, maritime navigational aids, remote lighting, highway signs and water treatment plants among others. Both full PV and hybrid systems are used. Hybrid systems are powered by the sun when it is available and by other fuel sources during the night and extended cloudy periods.

Off-grid industrial systems provide a cost-effective way to bring power to areas that remain unconnected to existing grids. The high cost of installing cabling makes off-grid solar power an economical choice.

1.4.2.3. Consumer goods

PV cells are now found in many everyday electrical appliances such as watches, calculators, toys, and battery chargers (for instance embedded in clothes and bags). Moreover, services such as water sprinklers, road signs, lighting and telephone boxes often rely on individual PV systems.

1.5. Benefits of PV technology

PV technology exploits the most abundant source of free power from the Sun and has the potential to meet almost all of mankind's energy needs. Unlike other sources of energy, PV has a negligible environmental footprint, can be deployed almost anywhere and utilises existing technologies and manufacturing processes, making it cheap and efficient to implement.

1.5.1. Environmental footprint

The energy it takes to make a solar power system is usually recouped by the energy costs saved over one to three years. Some new generation technologies can even recover the cost of the energy used to produce them within six months, depending on their location. PV systems have a typical life of at least 25 years, meaning that each panel will generate much more energy than it costs to produce.

1.5.2. Improving grid efficiency

PV systems can be placed at the centre of an energy generation network or used in a decentralised way. Small PV generators can be spread throughout the network, connecting directly into the grid. PV systems may be connected to batteries, in very remote areas where grid connections would be too expensive.

1.5.3. Making cities greener

With a total ground floor area of over 22,000 km2, 40% of all building roofs and 15% of all façades in the EU of the 27 are suitable for PV applications. This means that over 1,500 GWp of PV could, in theory, be installed in Europe, which would generate about 1,400TWh annually, representing 40% of total electricity demand by 2020. PV can seamlessly integrate into the densest urban environments. City buildings running lights, air-conditioning and equipment are responsible for large amounts of greenhouse gas emissions, if the power supply is not renewable. Solar power will have to become an integral and fundamental part of tomorrow's positive energy buildings.

1.5.4. PV jobs

The sector needs a diverse and qualified workforce to meet the challenge of this market expansion. Close to 220,000 people were employed in the solar photovoltaic industry at the beginning of 2010. This number includes employment along the entire value chain world-wide: production of PV products and equipment needed for their production, development and installation of the systems, operation and maintenance, as well as the financing of solar power plants and R&D.

While manufacturing jobs could be concentrated in some global production hubs, the downstream jobs (related to installation, operation and maintenance, financing and power sales) are, for the moment, still mainly local.

PV will provide an increasing number of jobs during the next decades. To estimate the employment potential, one can use an assumption of 30 jobs per MW installed resulting in a forecast of 1.7 million jobs worldwide by 2020. However, the need for quality installations calls for skilled labour and appropriate education, especially for qualified and certified installers. Electricians, roofers, and other construction workers bring their knowledge together in a new kind of job description that might be called the "solar installer".

1.5.5. No limits

There are no substantial limits to the massive deployment of PV. Material and industrial capability are plentiful and the industry has demonstrated its capacity to increase production very quickly to meet growing demand. This is evident in countries such as Germany and Japan that have implemented proactive PV policies.

1.6. Exercises

1.6.1. Solar Photovoltaic (PV) Energy

1. For the city of Chania (ϕ=35,3) calculate the monthly average total solar radiation on a tilted panel ($\beta=10^o$ and $\beta=55^o$) facing south in December and in June. For the calculations pick as representative the 10^{th} of each month. Which is the optimum tilt (10^o or 55^o) if the PV system will operate only in winter? The panel's albedo is 0.25. Use the values in TABLE 2.

TABLE 2.
INDICATIVE MONTHLY VALUES

Month	Average monthly Clearness index (k)	Monthly average total solar radiation on a horizontal surface (kWh/m^2)	Number of days
January	0,4	62	31
February	0,45	80	28
March	0,49	124	31
April	0,56	167	30
May	0,62	212	31
June	0,63	220	30
July	0,64	225	31
August	0,64	203	31
September	0,61	159	30
October	0,52	116	31
November	0,5	71	30
December	0,42	53	31

2. Which of the following irradiance parameter is the most important when calculating the PV system power output:
   a) The Direct Normal Irradiance (DNI)
   b) The Diffuse Irradiance (DIF)
   c) The Albeldo Irradiance
   d) The Global Horizontal Irradiance (GHI)
   e) The Global In-Plane Irradiance

3. A PV cell is made of :
   a) A conductor material
   b) An insulator material
   c) A semi-conductor material

4. What is the principal role of the inverter in a PV system:
   a) To prevent the batteries from overcharging and discharging
   b) To convert DC power generated by PV modules to AC power

1.6.2. PV system

1. Which material is not used as an encapsulant in a PV module?
   a) PVB
   b) PVC
   c) EVA

2. Usually, the module producers guarantee a power output of 80 % of the Wp after:
   a) 10 to 15 years
   b) 20 to 25 years
   c) 25 to 30 years

1.6.3. PV technologies

5. Which cell technology is not part of the first generation?
   a) Cadmium Telluride solar cells
   b) Mono crystalline silicon solar cells
   c) Ribbon crystalline solar cells

6. What are the common characteristics of a first generation solar cell?

a) 22.5 cm² and 4.5 Wp
b) 1.7 m² and 250 Wp
c) 20 m² and 3000 Wp

7. A thin-film module is generally smaller than a crystalline silicon module.
   a) True
   b) False

8. Which technology has achieved the highest efficiency in laboratory among the thin-film technologies?
   a) a-Si
   b) a-Si/μc-Si
   c) CIGS
   d) CdTe

1.6.4. Types of PV systems and applications

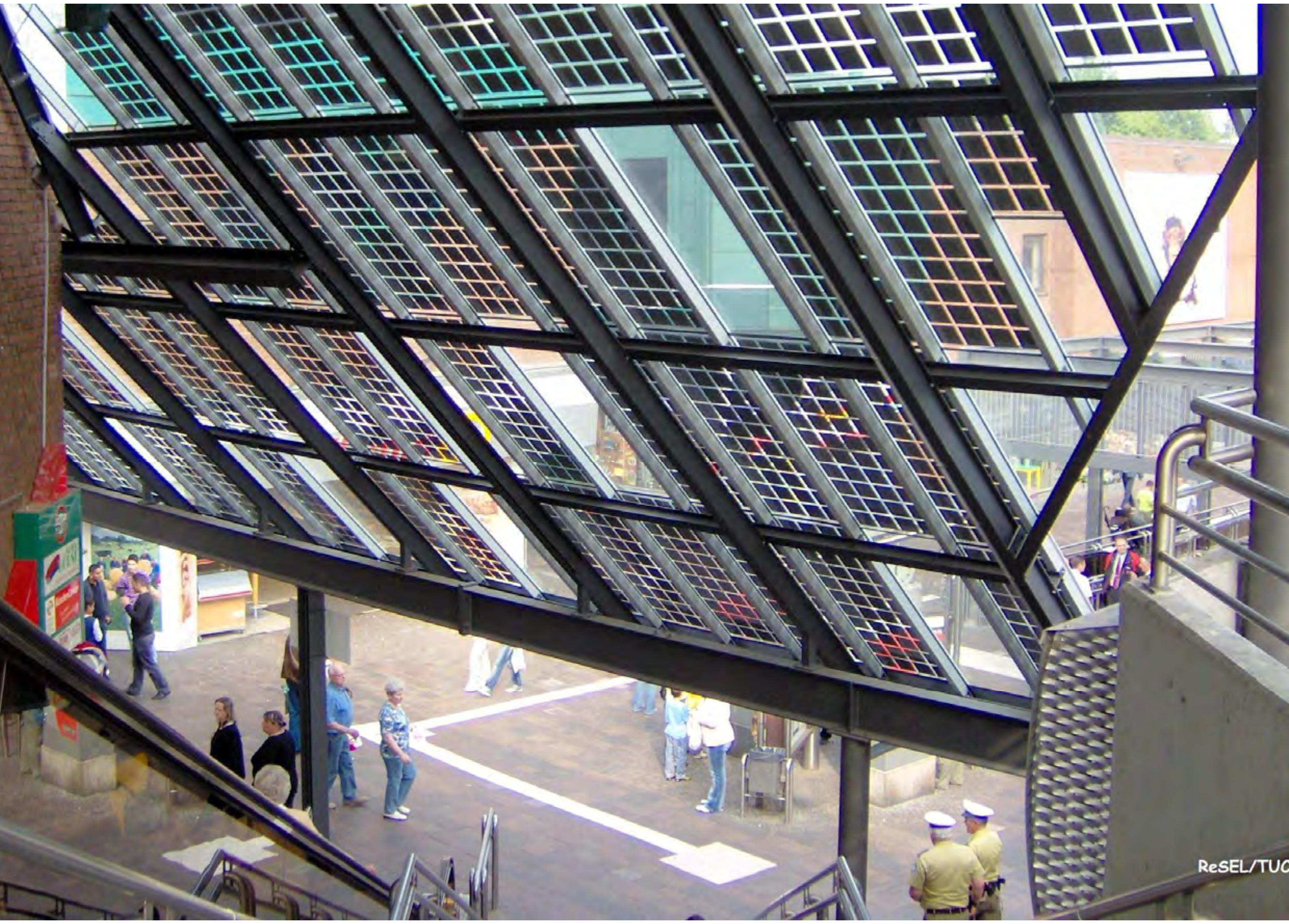
9. A grid-connected installation consists of three components:
   a) Generator, storage battery and power supply.
   b) Generator, converter and power supply.
   c) Generator, converter and storage battery.

10. Off-frid PV systems are always small home systems.
   a) True
   b) False

1.6.5. Benefits of PV technology

11. PV will never produce an important part of the final European electricity consumption because there are not enough roofs available.
   a) True
   b) False

DESIGN PRINCIPLES 2

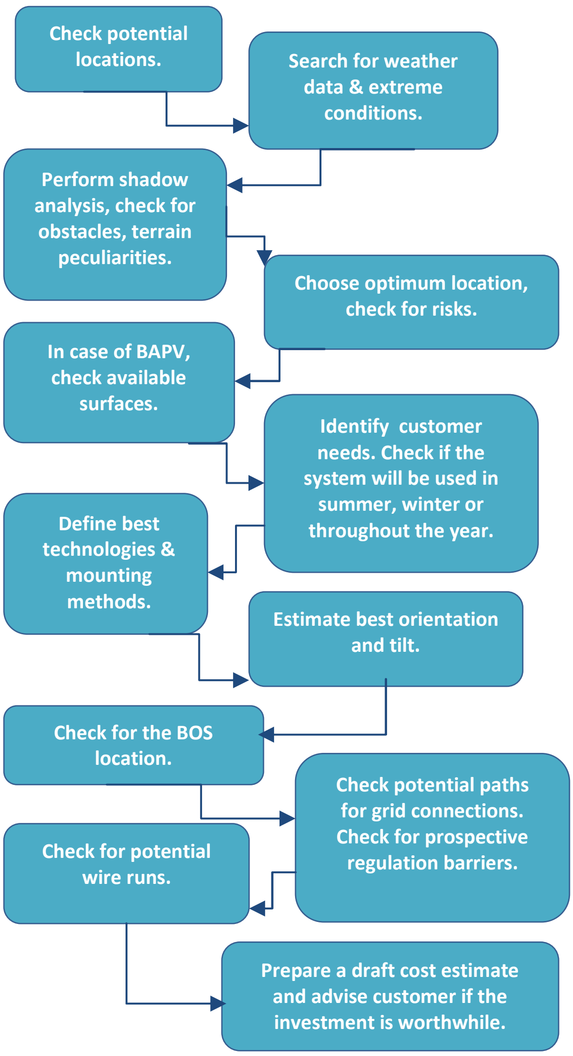


2. DESIGN PRINCIPLES

2.1. On Site Visit

Before starting the planning and design of a PV system, the installer should conduct a site visit and check whether the site is suitable or not for the installation. The installer should have maps, inclinometer, solar siting device, camera, tape measure and compass to complete this task (SEIS, 2006). Depending on the location and the conditions, safety gears may also be required.

FIGURE 10.
STEPS ON A SITE VISIT (Source: ReSEL TUC)



During the site assessment the installer should collect information that will be used to estimate the output of the system and its cost. Information should be detailed on the following issues:

- the available surface area,
- the potential location of the array,
- possible location of auxiliary equipment,
- the wire runs,
- shading,
- terrain features (ground mounted PVs),
- orientation, inclination angle in case of a roof applied PV system.

If the roof structure appears to be inadequate to support the PV array the installer should ask for the advice of an engineer.

Health and safety risks to be considered

During the onsite visit the installer should examine possible health and/or safety risks that may occur during installation of the PV system. The installer should check for ways of accessing the site when working at heights and identify possible risks such as falling objects. Moreover, when considering the wire runs, the installer should decide on appropriate equipment, in order to safely connect the system to the grid. In case of slippery glazed tiles or damaged roofing, a decision should be taken over whether the roof is appropriate for the installation. These safety measures must be followed at all costs when working on roofs. The PV installer should also bear in mind the prevailing weather conditions and avoid installing the system on icy or windy days, if installation presents difficulties.

2.1.1. Customer needs

The installer should have a clear picture of customer needs, before deciding whether the installation is feasible and starting to design the system.

During the first on-site visit, the installer should discuss important issues with the customer concerning the amount of money expected to be spent on the system, existing subsidies or Feed-in-Tariff (FIT) schemes and the size of the system. The selected system should meet the owner's needs and expectations.

The installer should be prepared to answer any questions about the proposed system and to provide alternative choices based on various factors including site considerations and customer needs.

Some frequently asked questions are:

- What is PV?
- How does a solar cell work?
- What are the advantages & disadvantages of PV system?
- Is my site/roof suitable for a PV system?
- What is the lifetime of a PV system?
- How much energy will the PV system produce per year?
- What happens to the power supply on cloudy days?
- Do PV systems have a high operating cost?
- What kind of maintenance is required?
- Are there any available grants, tax reductions or FITs?
- What is the payback period?

2.1.2. Climate conditions

The more solar radiation and the more uniformly it falls on the array, the higher the efficiency of the system. Site location is of great importance for system efficiency; northern zones have less solar energy available than southern zones (FIGURE 11). Solar maps, illustrating the solar potentials at different European locations, are available from the Photovoltaic Geographical Information System (PVGIS).

PV systems shall be designed to withstand all weather conditions, such as lightning, wind up to 80 miles/h, and extreme temperatures; conditions that may gradually reduce the energy productivity of the system.

PVs are more efficient at lower temperatures, so they should be installed at a distance from roofs, ground etc. in order to be ventilated.

FIGURE 11.
SOLAR RADIATION IN EUROPE (Source: PVGIS, 2011)

2.1.3. Shading

On-site visits involve the assessment of whether and to what extent the location of the PV system will be shaded. Shading may be one of the most important environmental parameters and one of the most critical parameters for energy loss in a PV array (PVResources, 2011). A detailed description of the surroundings is required to perform the shading calculations.

Shading is crucial especially between 08:00 and 17:00. A minimum of six hours of un-shaded operation is required for optimal system performance (PVResources, 2011).

An un-shaded surface can only be found if the ground is flat and no obstacles are nearby. In case objects (trees, electricity poles, buildings etc.) are far away from the potential PV field, it may be assumed that there will be no shading. However, in most cases, various objects exist in the surrounding area that cannot be removed (Quaschning & Hanitsch, 1998).

In a large number of BIPV systems in Europe, shading leads to annual yield reductions of between 5% and 10% (Drifa et al, 2008).

Potential shading sources can be trees and bushes, neighbouring buildings and self-shading by the building itself in case the PV is sited in urban areas. Even small obstacles such as chimneys, satellite dishes, telephone poles etc. should not be neglected during site assessment. Different optimization techniques may be used to minimize the influence of PV array shading, if it cannot be avoided (PVresources, 2011).

When the PV system is sited in a field, the most common cause of severe shading is a tree or a group of trees (DTI, 2008). Shading depends on the height of the tree, the distance from the array and the direction of the tree with respect to the array. Trees that are between east and south-east or between west and south-west of the array will cause greater problems than those to the south, since the sun is lower in the sky in those directions (DTI, 2008). If possible, the trees should be restricted in height so that they do not shade the array.

Partial-shading of even only one cell of a 36-cell module can significantly reduce its power output. PV Cells are connected in series; such that a cell that fails to function properly will result in reduced power for the whole array. Even if half of a cell is shaded, the result is proportionally the same as if half of a row is shaded. The decrease in power will be the same and proportional to the percentage of the shaded area (Sunglobal, 2011).

In addition, the PV module may be damaged due to shading, if too many cells are connected in series. This type of damage can be avoided, if bypass diodes are used (Wenham et al, 2007).

Types of shading

Shading of PVs can be categorised by the following categories:

- temporary,
- resulting from the location,
- self-shading,
- resulting from buildings (DGS, 2008).

Temporary shading may be owing to fallen leaves, snow, air pollution and dirt. The losses caused by this type of shading are estimated at 2-5% and may be overcome through proper arrangement and angle of the panels. The effect of this type of shading can be further reduced by cleaning the PV array with water. A 15^{o} tilt ensures that the solar panel will remain free from temporary shading.

Shading, resulting from the location, is caused by surrounding objects; obstacles of this type range from tall trees to neighbouring buildings. The PV installer has to identify if there are any obstacles which will shade the array and should examine whether shading can be avoided by moving them. However, if this is not possible the shading effect can be minimized, if taken into account during the initial design stage.

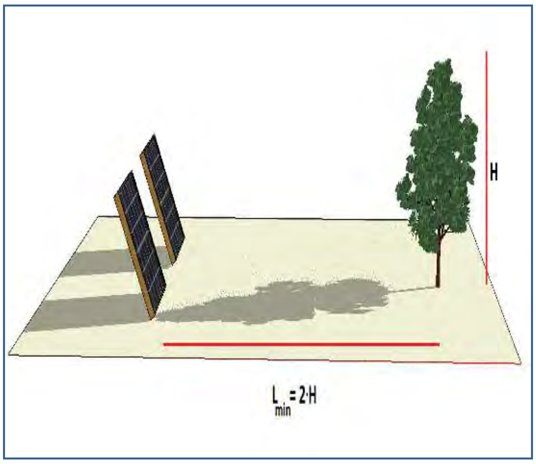
In any case, the installer may advise the customer on how to avoid this type of shadowing (e.g. to trim the trees causing the problem).

FIGURE 12.
SHADING FROM NEIGHBOURING OBSTACLES (Source: Energia e Domotica, Flickr, 2011)

As a rule, at a lower tilt angle, there is less shading and the area can be better exploited. However, in that case, the solar yield drops throughout the year. For this reason, a tilt angle of 30° is usually chosen at Central European latitudes (Solarpath, 2011).

Based on the height of the obstacle, draft estimation of the minimum distance (L_{min}), so that the PV will not be shaded, is presented in the following figure (FIGURE 13).

FIGURE 13.
MINIMUM DISTANCE OF PVS FROM OBSTACLES TO AVOID SHADING (Source: ResEL, TUC)



In this case (Kirchensteiner, 2010):

$$L_{min} = 2 \times H$$

H: the height of the obstacle

Lmin is calculated for the Winter Solstice.

Based on the thickness of the object d, the optimum distance L_{min} can be calculated using the similar triangle relations of the sun tangents which touch the object (FIGURE 14). The optimum distance L_{opti} from the modules is determined as:

$$L_{min} = \frac{(L_S + L_{min}) \cdot d}{d_S} \approx \frac{L_S \cdot d}{d_S}$$

L_s: distance Earth to sun = 150x10^6 km

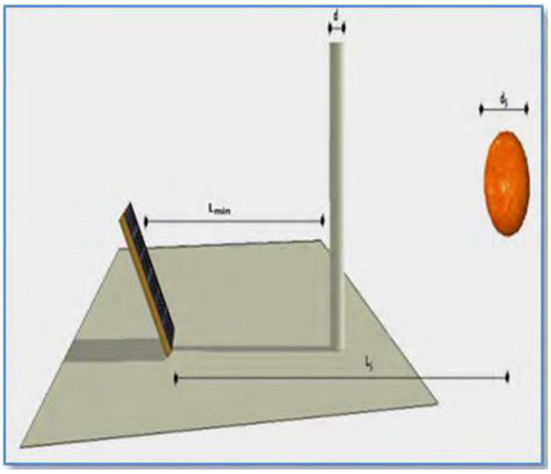
d_s: (diameter of sun = 1.39 x 10^6 km

d: diameter of the obstacle, m.

The previous equation can be simplified to:

$$\frac{L_S \cdot d}{d_S} = 108 \cdot d$$

FIGURE 14.
L_{min}, BASED ON THE THICKNESS OF THE OBJECT (Source: ResEL, TUC)



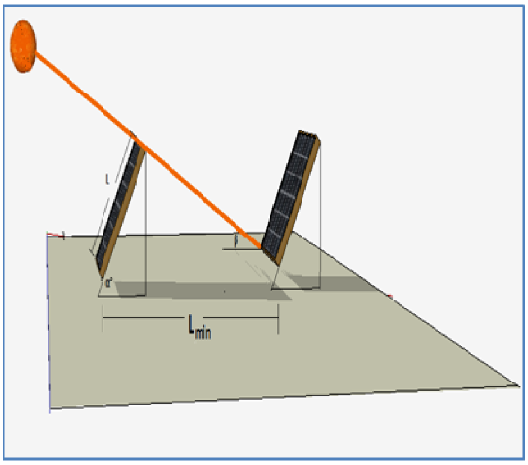
PVTRIN INSTALLER CERTIFICATION

Self-shading of a PV array is usually a designer fault. The installer has to minimize shading losses through optimisation of the tilt angles and the distances between the module rows.

An easy way to calculate the minimum distance between arrows is presented below (Kirchensteiner, 2010).

It is recommended that the spacing between rows should avoid shading between 09:00 and 15:00 at the Winter Solstice. At that date the sun is at its lowest angle (e.g. about 23^o in Greece).

FIGURE 15.
MINIMUM DISTANCE BETWEEN ARROWS (Source: ResEL, TUC)



The minimum distance Lmin (FIGURE 15) is estimated by the following equation.

L_{min} = (sina/tanβ+cosa) x L

The estimation of whether a site is appropriate or not, may also performed with the help of a solar map of the region under investigation, a compass and a sextant for measuring heights in degrees.

The following steps should be followed:

Step 1:

Stand in the middle of the proposed field.

Step 2:

Using the compass locate the East.

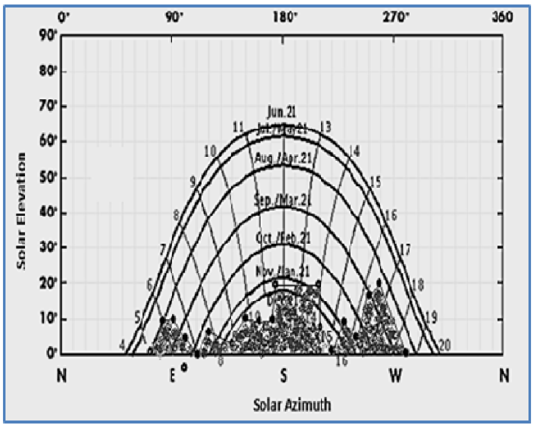
Step 3:

Using the sextant measure the height of each obstacle.

Step 4:

Note the height of each obstacle on the solar map, (FIGURE 16)

FIGURE 16.
SUN ORBIT DIAGRAM WITH SURVEYED SURROUNDINGS (Source: ResEL, TUC)



Step 5:

The installer rotates 15^o degrees, with its back to the north, and repeats steps 5, 3 and 4 until it faces the west.

Step 6:

The spots are connected on the solar map and the area under the line is shaded. A suitable area for a PV system should not be shaded between 09:00 and 15:00.

2.1.4. Array orientation and tilt

Orientation of the PV array is one of the most important aspects of site assessment.

Most PV systems are mounted in a fixed position and cannot follow the sun throughout the day. In that case, the optimal orientation in the northern hemisphere is due south.

The highest efficiency of a PV module is achieved when its surface is perpendicular to the sun's rays. In the northern hemisphere, the sun rises to its greatest height at noon on the Summer Solstice and sinks to its lowest angle at noon on the Winter Solstice. These elevations vary in accordance with the latitude of each location.

PVs should be tilted toward the sun's average elevation, equal to the latitude of the array's location, to capture most of the solar energy throughout the year.

However, for off-grid systems designed to perform best in winter, the array should be tilted at an angle of latitude (ϕ) + 15^o. If the array is designed to perform best in summer, then the array should be tilted at an angle of latitude (ϕ) – 15^o (TABLE 3).

TABLE 3.
OPTIMUM TILT FOR THE PV PANEL (NORTH HEMISPHERE) (Source: Markvart & Castafier, 2003)

β = ϕ	Throughout the year
β = ϕ + 15^o	Performs best in winter
β = ϕ - 15^o	Performs best in summer
β = ϕ - 15^o	In humid climate areas, solar radiation is diffused because of water droplets in the atmosphere (the PV panel faces the sky and a larger amount of diffuse radiation is received)
β = 5 - 10^o	In areas with a latitude of less than 20o around the equator
β = 0^o	In areas with very little sunshine in order to exploit diffuse radiation

If the PV array is mounted on a building where it is difficult for the panels to face the South, then it can be oriented towards the East or West but under no circumstances towards the North as its efficiency will then be very limited (NCSC, 2001).

For better results, the installer may consult one of the software packages presented in chapter 2.3.

2.1.5. Mounting methods

2.1.5.1. Building Mounts

The most common mounting methods (NABCEP, 2009) are:

a. Integrated mounting

The PVs are integrated into the building and are referred to as BIPV (Building Integrated Photovoltaics, see chapter 3). BIPV are usually constructed along with the building elements, although in some cases they may be built later. Integral mounting is where the modules are integrated into the roofing or exterior of the building itself. Three areas of the building where PV modules can easily be integrated are as follows:

- the roof,
- the façade,
- the sun screening components.

-

FIGURE 17.
PV PANELS FOR SUN SCREENING. (Source: ReSEL, TUC, 2010)

b. Rack mounting

PV panels are based on a metal framework, which allows easy attachment and detachment of the panels. In most cases, panels are mounted above and parallel to the roof surface. The rack mount is usually offered with the panel, by the PV manufacturer.

FIGURE 18.
PV MODULES ON INCLINED ROOF (Source: Flickr, Sun Switch, 2011)

c. Stand-off mounting

The panels are supported by a frame built ontop of the roof. The difference between stand-off and rack-mount PVs is that the angles can be adjusted. Usually, the PV panels are not parallel to the roof.

This type of mounting may not be aesthetically acceptable; however the efficiency of PVs on stand off mounting is higher than on rack mounting.

Some types of building mounted PVs (e.g. solar tiles) are not as efficient as other solutions, as PV cells are more efficient at lower temperatures and when they are suitably ventilated; the installer has to make allowance for sufficient space at the back of the module. At the system design stage, the installer should, as far as possible, search for ways to reduce overheating. As a general rule, roof mounted systems should have at least 50mm free space beneath them (NABCEP, 2009).

In the case of stand-off mounted PVs, air circulation behind the modules will reduce the PV module operating temperature, making them more efficient.

FIGURE 19.
PANELS MOUNTED ON A FLAT ROOF (Source: Flickr, Entersolar, 2011)

2.1.5.2. Ground Mounts

In rural environments, ground mounted PVs are erected. Ground-mounted PV systems involve a steel or aluminum frame, fixed to a concrete foundation on the ground. The requirements of the frame are to provide a rigid attachment that will resist gravitational waves, wind or impact forces.

In this case, fencing is often required to protect the panels from vandalism. The planning process should ensure that fencing will not create any further shading.

The advantage of ground mounted panels is that they may be easily oriented directly to south, at the optimum tilt angle, resulting in more efficient installations and maximum energy production throughout the year. Panels are easier to maintain and may, if required, be replaced.

However, ground mounted panels are more expensive than roof-mounted panels because of the cost of concrete posts and rigid frames. Furthermore, these systems suffer from visual pollution.

Solar trackers are often used to improve the efficiency of this type of system.

FIGURE 20.
ROUND MOUNTED PV PANELS IN CRETE (Source: ReSEL, TUC)

PV arrays with trackers collect a higher amount of energy than those installed at a fixed tilt. The relationship between the annual solar radiation captured by a tracking system and a fixed tilt panel inclined at the angle of latitude is increased by more than 30% in locations with predominantly clear sky (Markvart & Castafier, 2003).

There are two types of tracking systems (DGS, 2008):

- Single-axis tracking: The array can be tilted automatically along a single axis from east to west. Output may be increased by approximately 20%, compared to a fixed array.
- Dual-axis tracking: The array can track the sun along the north-south and the east-west axes. Power output is higher in comparison to a fixed array: approximately 40% in Northern Europe, and 35% in Southern Europe. However, the tracker's moving parts require maintenance; potential failures, may decrease reliability and increase maintenance costs.

FIGURE 21.
TRACKING SYSTEM (Source: ReSEL, TUC)

2.1.6. BOS Locations

Balance-of-system (BOS) is the auxiliary equipment which is related to supporting and security structures, inverters, disconnects and overcurrent devices, charge controllers, batteries, and junction boxes (NABCEP, 2009).

Some of the components may need to be installed in weather resistant or rain-tight enclosures, if they are not rated for wet and outdoor exposure. The installer should estimate the dimensions of the required space to install all components during initial planning; the environmental conditions specified by the manufacturer should be also maintained.

Considering the BOS location, the installer should try to avoid sites exposed to direct sunlight, strong winds and to choose a place protected from rain and dampness. If the system includes batteries, it is essential that they are not exposed to extreme cold, which will reduce their effective capacity. Moreover, the ideal installation site for inverters is a cool, dry, dust free area, close to the PV array, the junction box and the batteries (if present), in order to minimize cable length and size (DGS, 2008).

2.1.7. Load Description

In case a stand-alone system has to be installed, the load has to be documented in detail. Autonomous systems can only be sized effectively for predictable loads; random load estimations may result in uncertain reliability of supply by the system.

The installer may also consult tables with indicative consumption values for different appliances, following identification of the customer's energy needs.

TABLE 4.
VALUES OF TYPICAL ENERGY CONSUMPTION (Source: Markvart & Castafier, 2003)

	Average rated power (W)	Average usage (h/day)	Annual energy consumption (kWh/year)
Lighting			
Bedroom	94	1.0	36
Dining room	165	2.3	136
Hall	78	1.7	49
Family room	106	2.0	77
Kitchen	95	3.2	109
Living room	124	2.4	109
Outdoor	110	2.9	116
Bathroom	138	1.9	96
Other Appliances			
Refrigerator			649
Freezer			46 5
Washing machine	0.375 kWh/load	4 loads per week	78
Dish washer	0.78 kWh/load	One load per day	283
Electric oven	2.300	0.25	209
Coffee machine			301
Microwave			120
Vacuum cleaner			14
Audio equipment			36
TV	100	5	182
PC			25

2.1.8. Performance ratio

During the on-site visit, the installer may be asked for an initial estimate of the system's annual yield and the size of area required.

An approximate estimate of the necessary surface is calculated as: $10m^2$ = 1 kWp; a rough estimate of the cost of a grid connected PV system is 2,800-3,600 €/kWp.

A rough estimate of production may be implemented using the Performance Ratio (PR). PR expresses the performance of the system in comparison with an ideal 'lossless' system of the same design and rating at the same location (reference yield), (Pearsall & Hill, 2001).

Typical PR values are 60-75% however higher values can be achieved. Rough array sizing can be done using estimates of the PR, as follows (SEAI 2010):

- Assumption of PR value: 0.7 (typical),
- Determination of the solar irradiation on the actual array.

For example: 1,000 kWh/m^2/y x 0.15 (module efficiency) x 0.95 correction factor for tilt and azimuth or 142.5 kWh/m^2/y.

- The output of the PV system, is estimated at 0.7 x 142.5 kWh/m^2/y = 99.8 kWh/m^2/y. (SEAI, 2010).

Based on this value, the installer may also estimate the annual income of the installation, taking into account the national electricity price/kWh.

2.2. System Sizing and Design

2.2.1. Basics

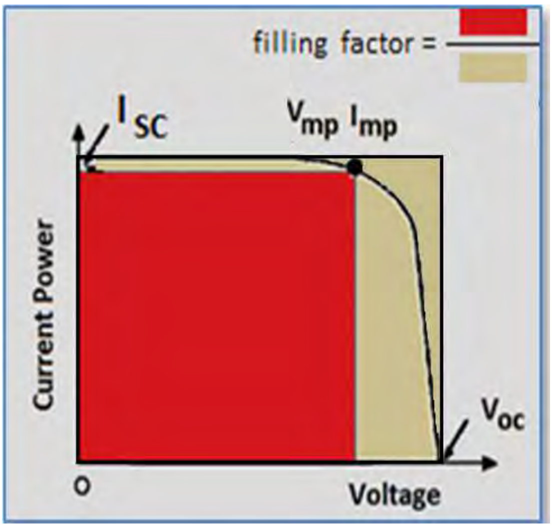
I-V curve

A current-voltage (I-V) curve presents the applicable combinations of current and voltage output of a PV (FIGURE 22).

The PV module produces its maximum current when there is no resistance in the circuit. This maximum current is known as the short circuit current (I_{sc}). When the module is shorted, the voltage in the circuit is zero (ANU, 2011).

The maximum voltage occurs when there is a break in the circuit. This is called open circuit voltage (V_{oc}). Under this condition the resistance is infinitely high and there is no current. The range between these extreme conditions, are presented on the I-V curve.

FIGURE 22.
I-V CURVE OF A SOLAR CELL (Source: ReSEL, TUC)



The available power (W) from the PV, at any point of the curve, is the product of current and voltage at that point.

The point on the curve's knee is where the maximum power output is achieved. This is called the Maximum Power Point (MPP) and the points describing this curve point are I_{MPP} (current at maximum power) and V_{MPP} (voltage at maximum power point).

The I-V characteristic curve is valid under standard conditions of sunlight and device temperature.

It is assumed that there is no shading on the device. Standard sunlight conditions on a clear day are assumed to be $1kW/m^2$, otherwise known as peak sun conditions.

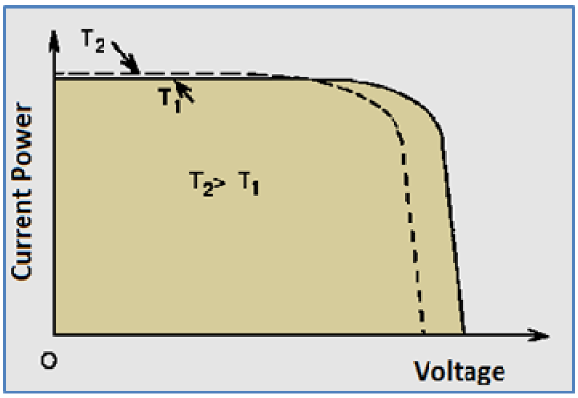
Filling factor

The Filling Factor FF informs us of the extent to which a module deviates from its ideal operation (FIGURE 22). It represents the ratio of the MPP to the product of V_{OC} and I_{SC}. The filling factor for a good module is around 0.75.

Effect of temperature

The operating temperature of PV cells is determined by the ambient air temperature, the characteristics of the encapsulation and the intensity of sunlight falling on the module, the wind and other variables. Temperature increase leads to a reduction in Voc, resulting in reduced cell output.

FIGURE 23.
EFFECT OF TEMPERATURE ON I-V CURVE (Source: ReSEL, TUC)



Interconnecting PV modules

PV modules can be interconnected in series, where the negative terminal of one module is connected to the positive terminal of the next module.

In series connections the voltage is cumulative:

$$V_{total} = V_1 + V_2 + \ldots + V_n$$

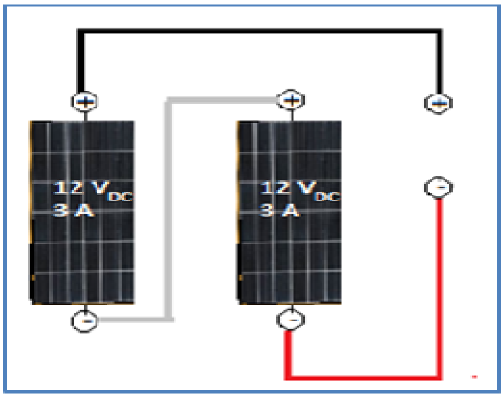
and the current remains constant:

$$I_{total} = I_1 = I_2 = \ldots = I_n$$

The modules in FIGURE 24 have an open-circuit voltage of 12V each, and 2 modules amounting to 24V.

$$V_{total} = 12V + 12V = 24V \text{ and } I_{total} = 3A$$

FIGURE 24.
SERIES CONNECTION (Source: ReSEL, TUC)



In parallel connections the current is cumulative:

$$I_{total} = I_1 + I_2 + \ldots + I_n$$

and the voltage remains constant:

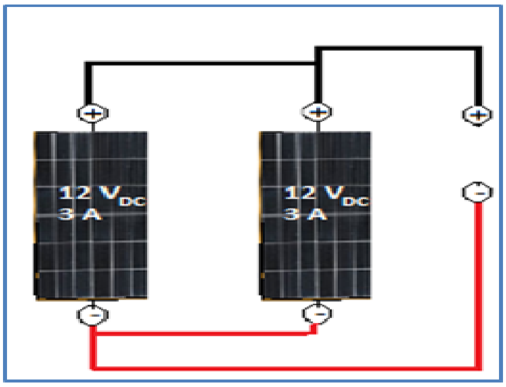
$$V_{total} = V_1 = V_2 = \ldots = V_n$$

In cases where a high current is demanded for specific applications, then the modules are generally connected in parallel.

For the modules connected in parallel (FIGURE 25)

$$V_{total} = 12V \quad \text{and} \quad I_{total} = 3A+3A = 6A$$

FIGURE 25.
PARALLEL CONNECTION (Source: ReSEL, TUC)

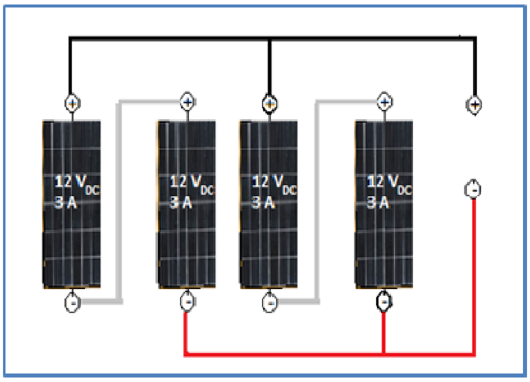


A series and parallel connection (mix connection) of different modules can also be implemented (FIGURE 26).

In this case

$$V_{total} = V_1 + V_2 = 24V \quad \text{and} \quad I_{total} = I_1 + I_2 = 6A$$

FIGURE 26.
SERIES AND PARALLEL CONNECTION (Source: ReSEL, TUC)



2.2.2. Inverters

An inverter converts the DC voltage of the modules to the two-phase or three-phase AC voltage of the grid. Inverters usually have a Maximum Power Point Tracking (MPPT) where the PV operates at its highest efficiency. However, the voltage and current generated by the PV modules must fit within the inverter range. If PV modules are connected in series, their voltage is added to give the total voltage, whereas if they are connected in parallel, the current is added to give the total current (Salas et al, 2009).

Three inverter families, related to specific PV system designs, can be defined (Myrzik & Calais, 2003): central inverters, module integrated inverters and string inverters.

a. Central inverters

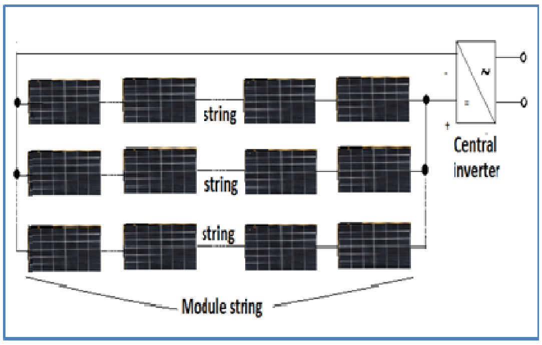
Central inverters were the most commonly used in the 1980s for PV grid connected systems. However, several drawbacks observed in the systems that used them (risk of electrical arc in DC wiring, poor adaptability to customer requirements) lead to the introduction of the modular system technology which was more reliable and cheaper.

In the low voltage concept (<120V), several modules are connected in series in a string. As only a few modules are in series the effect of shading will be less in comparison with longer strings. However, the reason that the concept is not commonly used is the high currents and the resulting high ohmic losses that can be limited with the use of high cable sections (DTI, 2008).

In the high voltage concept (>120V), smaller cable sections can be used as a result of the lower currents, however the high shading losses due to the long strings is an essential drawback.

In the master slave concept, one of the inverters is superior to the others and regulates the operation of the rest of the chain. With increasing irradiance, the power limit of the master device is reached and the next inverter (slave) is connected. When the radiation levels are low, higher system efficiencies are enabled compared to cases in which all inverters are permanently operating (Myrzik & Calais, 2003).

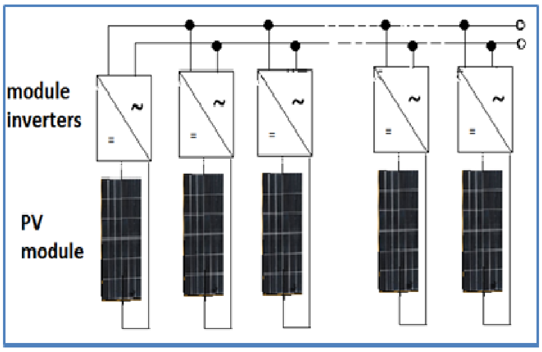
FIGURE 27.
PV MODULES CONNECTED TO A CENTRAL INVERTER (Source: ReSEL, TUC)



b. Module integrated inverters

The smallest possible grid connected PV system unit is a PV module with a module-integrated inverter, so that mismatching losses and DC wiring are minimized. However, this technology also has efficiency-related drawbacks, due to its low power ratings. Wattage costs are also high.

FIGURE 28.
PV MODULES CONNECTED TO MODULE INVERTERS (Source: ReSEL, TUC)

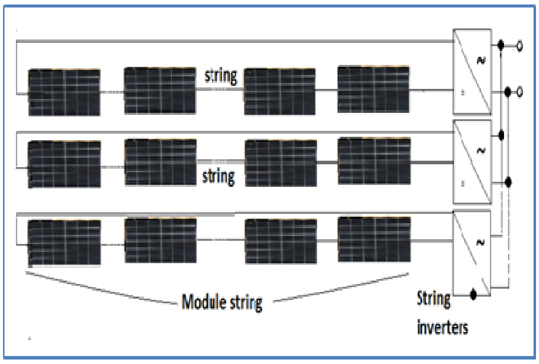


c. String inverters

A compromise between the concept of the module integrated inverter and the central inverter, the string inverter was placed on the market in the mid 90s and is the most popular inverter in use today.

The efficiency of a string inverter may range from 94-97%. Thus, researchers now focus on new PV system concepts, in order to increase efficiency and reduce the costs of the PV plant.

FIGURE 29.
PV MODULES CONNECTED TO STRING INVERTERS (Source: ReSEL, TUC)



Sizing the inverter

The nominal AC power of the inverter is the power that the inverter can supply continually at an ambient temperature of 25° ± 2°C.

The DC power rating of the inverter (P_{INV} DC) is approximately 5% higher than the inverter's nominal AC power (DTI, 2008).

The power range can be specified for the sizing range:

$$0.8\ P_{PV} < P_{INV\ DC} < 1.2\ P_{PV}$$

P_{PV} : the PV array power rating in Wp

The relationship between the installed power of the PV generator and the maximum inverter power is known as the inverter sizing factor C_{INV} and can be calculated by the following equation (Velasco et al, 2006):

$$C_{INV} = \frac{P_{PV}}{P_{INV\ AC}}$$

$P_{INV\ AC}$: the inverter's nominal AC power.

A typical value of C_{INV} would be in the range $0.83 < C_{INV} < 1.25$, but it seems to be cost effective for $C_{INV} > 1$.

Maximum number of modules

At low temperatures, the module voltage increases (FIGURE 23). The highest voltages are recorded for open-circuit voltages at low temperatures. If the inverter is switched off on a sunny winter day, it could lead to an excessively high open-circuit voltage when switched on again that might damage the inverter. In order to avoid damage, the highest voltage must be lower than the maximum DC input voltage of the inverter (DGS, 2008).

So the maximum number of series-connected modules is given by the following equation:

$$n_{max} = \frac{V_{MAX\ (INV)}}{V_{oc-Tmin}}$$

$V_{max(INV)}$: maximum input voltage of the inverter,

$V_{oc-Tmin}$: open-circuit voltage of the module at the minimum module temperature.

In most cases, the Voc-Tmin value is not provided by the manufacturer. However, it can be calculated, if the values of Voc at STC (25^{o}C) and the voltage temperature coefficient T_C are available. Thus, the Voc-Tmin is given by the following equation:

$$V_{oc-Tmin} = V_{oc\ -STC} + \Delta T \times Tc$$

ΔT: difference between the minimum ambient temperature and the temperature of 25^{o}C (STC).

Tc: voltage temperature coefficient in V/^{o}C, which means that for every ^{o}C that the temperature of the module drops below 25^{o}C, then the module voltage will increase by the same value.

Minimum number of modules

The maximum temperature reached on a PV panel is used to determine the minimum number of modules in a string.

On a sunny day in summer, the PV will have a lower voltage than 25 °C (STC) because of the increased temperatures. If the operating voltage of the system drops below the minimum MPP voltage of the inverter, it would not feed the maximum possible power, and it could even switch itself off.

Hence, the system should be sized in accordance with the minimum number of series-connected modules in a string, which is derived from the following equation:

$$n_{min} = \frac{V_{MPP\ (INV\ min)}}{V_{MPP-\ Tmax}}$$

$V_{MPP\ (INV\text{-}min)}$: minimum input voltage of the inverter at the MPP

$V_{MPP\text{-}\ Tmax}$: voltage of the module at the MPP at the highest temperature.

If $V_{MPP\text{-}STC}$ is given, the value of V_{MPP} at different temperatures can be calculated by the following equation:

$$V_{MPP\text{-}T} = V_{MPP\text{-}STC} + \Delta T \times Tc$$

2.2.3. Number of strings

The maximum PV array current must not exceed the maximum inverter input current. The maximum number of strings may therefore be estimated by the following equation (DGS, 2008):

$$n_{string} = \frac{I_{max\ INV}}{I_{n\ string}}$$

$I_{max\ INV}$: maximum permitted DC input current of the inverter

$I_{n\ string}$: maximum string current.

2.2.4. Sizing of cables

Three crucial parameters have to be taken into account when sizing the cables:

- cable voltage ratings,
- current rating of the cable,
- minimization of cable losses.

Voltage ratings

Voltage ratings of cables are in general greater than the PV system, however in large systems the voltage rating must be checked, taking into account the maximum open-circuit voltage at the lowest temperature of the PV array.

The cable cross-section is sized according the maximum current. The maximum current of the module or string cable is given by the following equation:

$$I_{max} = I_{SC\ PV} - I_{SC\ String}$$

$I_{SC\ PV}$: PV generator short-circuit current

$I_{SC\ String}$: the short-circuit current of one string

String fuses

String fuses can be used to protect cables from overloading and are usually used for systems with more than four strings.

The permitted current rating of the cable should be at least equal to or greater than the trigger current of the string fuse.

$$I_{z\ Cable} \geq I_{a\ String\ fuse}$$

The fuse has to be triggered at twice the string short-circuit current at STC:

$$2\ I_{SC\ String} > I_{n\ String\ fuse} > I_{SC\ String}$$

In order to avoid false trips,

$$I_{n\ String\ fuse} \geq 1.25\ I_{n\ String}$$

$I_{n\ String\ fuse}$: nominal current of the fuse, A

$I_{n\ String}$: nominal string current, A

Minimizing cable losses

The need for as little cable loss/voltage drop as possible represents one of the main objectives, when sizing the cable cross-sections.

It is recommended that the voltage drop in the direct voltage circuit should be less than 1% of the nominal voltage of the PV system at STC in order to limit the power loss through all DC cables to 1% at STC. Losses of 1% can be maintained with standard cable cross-sections, for PV systems with inverters operating with a higher DC input voltage (V_{MPP} > 120V). (DGS, 2008)

However, in PV systems with inverters, which are operating at an input voltage of below 20V, the voltage drop exceeds 1% with string or module cables, even when using a 6mm^2 cable. This mainly occurs when there is a long distance between the inverter and the PV generator. In these systems, a 1% voltage drop in the string cables and an additional 1% drop with the DC main cable are acceptable.

The recommended cross-section with 1% losses (at STC) can be selected by using the following equation:

$$A_M = \frac{2 \cdot L_M \cdot I_{St}}{1\% \cdot V_{MPP} \cdot \kappa}$$

L_M: simple wiring length for module and string cabling, m

I_{ST}: string current, A

V_{MPP}: string voltage, V

κ: electrical conductivity, m/Ω mm^2 (copper κ_{cu} = 56, aluminium $\hat{e}_{al}$ = 34)

The value then is rounded up to the next highest value for standard cable cross-sections.

The following equation is used to calculate the overall losses (W) in all modules and string cables for the selected cable cross-section.

$$P_M = \frac{2 \cdot n \cdot L_M \cdot I_{St}^2}{A_M \cdot \kappa}$$

n: number of strings of the PV generator

Where the PV systems lead to different string cable lengths, the following equation is used:

$$P_M = \frac{2 \cdot I_{St}^2}{\kappa} \cdot \left(\frac{L_1}{A_1} + \frac{L_2}{A_2} + \frac{L_3}{A_3} + \cdots\right)$$

The DC main cable and the DC bus cables from PV sub-arrays must be able to carry the maximum occurring current produced by the PV array. The DC main cable is in general sized to 1.25 times the PV array short-circuit current at STC

I_{max} = 1.25 $I_{SC\ PV}$

The cross-section of the cable must be selected according to the permitted current carrying capacity of the cable. It is again assumed that there will be a cable loss of 1 % in relation to the nominal power of the PV array.

The cross-section of the DC cable is given by:

$$A_{DC\ cable} = \frac{2 \cdot L_{DC\ Cable} \cdot I_n^2}{(v \cdot P_{PV} - P_M) \cdot \kappa}$$

$L_{DC\ cable}$: simple wiring length for module and string cabling, m

I_n: nominal current of the PV module, A

P_{PV}: nominal power of the PV module, W_p

P_M: line loss of the DC main cable, W

κ: electrical conductivity, m/Ω mm^2

v: loss factor v= 1 %, or v = 2 % with the low voltage concept.

The value is then rounded up to the next highest value for standard cable cross-sections.

The following equation is used to calculate the overall losses in all modules and string cables for the selected cable cross-section.

$$P_M = \frac{2 \cdot L_{DC\ Cable} \cdot I_n^2}{A_{DC\ cable} \cdot \kappa}$$

Calculation of the cross-section of the AC connection cable is done by assuming a voltage drop of 3% in relation to the nominal grid voltage. The cross-section $A_{AC\ cable}$ is then estimated by the following equation:

$$A_{AC\ cable} = \frac{2 \cdot L_{AC\ Cable} \cdot I_{n\ AC} \cdot \cos\varphi}{3\% \cdot V_n \cdot \kappa}$$

with a single-phase feed

$L_{AC\ cable}$: simple line length of the AC connect ion cable, m

$I_{n\ AC}$: AC nominal current of the inverter, A

cosϕ: power factor (between 0.8 and 1.0)

V_n: nominal grid voltage, single phase: 230V

In case of a three-phase feed:

$$A_{AC\ cable} = \frac{\sqrt{3} \cdot L_{AC\ Cable} \cdot I_{n\ AC} \cdot \cos\varphi}{3\% \cdot V_n \cdot \kappa}$$

V_n: nominal grid voltage, three phase: 400V

The cable loss $P_{AC\ cable}$ for the selected cable cross-section is then estimated:

$$P_{AC\ cable} = \frac{2 \cdot L_{AC\ Cable} \cdot I_{n\ AC}^2 \cdot \cos\varphi}{A_{AC\ cable} \cdot \kappa}$$

in a single-phase feed, and

$$P_{AC\ cable} = \frac{3 \cdot L_{AC\ Cable} \cdot I_{n\ AC}^2}{A_{AC\ cable} \cdot \kappa}$$

in a three-phase feed.

2.2.5. Blocking diodes

Blocking diodes are used in PV arrays to prevent reverse currents (Markvart & Castafier, 2003).

Blocking diodes when placed at the head of separate series-wired strings in high voltage systems can isolate shaded or damaged strings and prevent the other strings from loosing reverse current, if there is a short circuit in one of the modules.

Furthermore, in battery charging systems, the blocking diodes can block reverse flow of current from the battery through the module at night. As the module potential drops to zero during night, the battery could discharge all night backwards through the module. This could be harmful to the module and would result in the loss of the energy stored in the battery bank. When diodes are placed in the circuit between the module and the battery they block any leakage flow at night.

2.2.6. Earthing

Earthing or grounding is the procedure whereby one or more parts of an electrical system are connected to the ground, which is considered to have zero voltage (Markvart & Castafier, 2003).

Earthing procedures may vary depending on the different local codes. An equipment-grounding conductor is a conductor that does not normally carry current and is connected to the ground. This type is used to connect the exposed metal surfaces of electrical equipment together and then to the ground, in order to prevent electrical shocks and allow overcurrent devices to operate properly when ground faults occur.

PV systems should have equipment-grounding conductors that connect all of the exposed metal surfaces of the system to a grounding electrode (the metallic device used for earthing that makes actual contact with the ground).

However grounded conductors have to be used only for systems with a system voltage of over 50V. In this case, the voltage should be calculated for low temperatures as the open-circuit voltage will be higher than the open-circuit voltage marked on the back of the PV module at STC (Wiles, 1999).

A nominal 24V system has a rated open-circuit voltage of about 44V at 25°C. That means the voltage could exceed 50V at below-zero temperatures (see § Maximum number of modules) and current-carrying conductors should be connected to the grounding electrode.

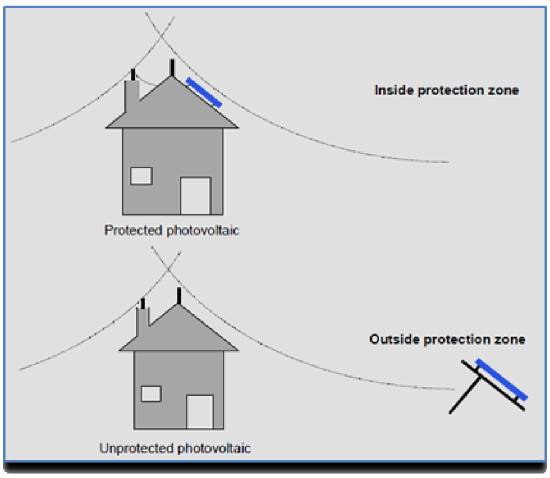
2.2.7. Lightning protection

Where the PV system is located outside the protection zone of a building, a protection device is needed to protect it against lightning strikes (FIGURE 30).

The system can be damaged even if the lightning does not strike it directly. Lightning protection may be achieved through several measures:

- use of a single ground electrode;
- connect all the metallic parts of the electric equipment to the ground;
- arrange the cables to avoid loops that can produce over-voltage generation;
- install lightning protectors connected to the protected equipment (IEA PVPS, 2003).

FIGURE 30.
EXAMPLES OF PROTECTION (Source: IEA PVPS, 2003)

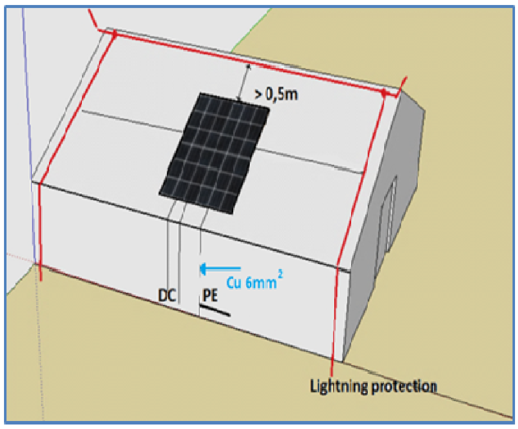


A Protective Earthing (PE) conductor can discharge the DC conductors in case of a direct strike; thereby limiting damage to the low voltage grid or to the inverters.

Wiring usually runs on the outside of a building from the roof to the power grid. In this case both the PE and the DC wires have to be exposed outside.

For small PV plants on buildings with lightning protection, the plant may be entirely protected by the existing lightning system. For this to be so, all parts of the PV generator have to be located in the mesh of the lightning protection system. The mesh consists of a ridge wire and two wires on each side (FIGURE 31).

FIGURE 31.
SMALL PV IN LIGHTNING SYSTEM MESH. (Source: Schletter Solar, 2005).



A safety distance, between the PV plant and all parts of the lightning protection system, has to be maintained. In practice, a distance of more than 0.5m has proven adequate (FIGURE 31).

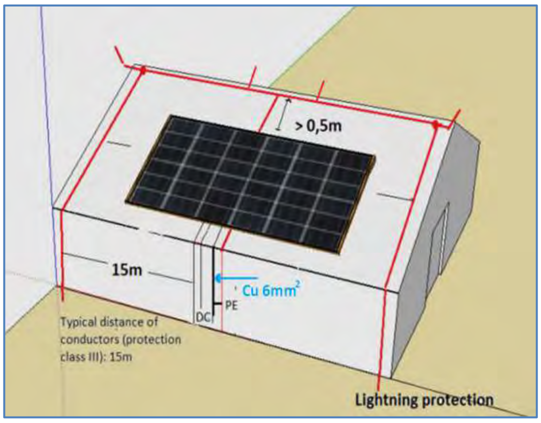
The minimum distances in large PV systems between plant and lightning protection can not always be followed. The plant may not cover existing lightning protection conductors, because surge currents could get into the building through the generator, in case of a lightning strike, and cause severe damage.

In this case:

- Lightning protection connections may be replaced by High Voltage Insulated (HVI) conductors, so that minimum distances are maintained.
- Additional connections and devices to protect building and plant (Schletter Solar, 2005).

If the minimum distance (>0.5m) cannot be maintained, the PV generator and the lightning protection system are connected, in order to limit the consequences of sparkovers. The connection (Cu) should have a cross-section of at least 16mm2.

FIGURE 32.
LARGE PV SYSTEM ON ROOF. (Source: Schletter Solar, 2005).



In this case, it would be better to have a connection between the mounting frame and the potential equalisation of the house. If such a connection is built, it should also have a cross-section of a least 16mm2 Cu. (Schletter Solar, 2005).

The rolling sphere (FIGURE 33) is a method of testing the protection areas against a direct lightning strike. A sphere is rolled over a model of the system and all the contact points represent possible points for direct lightning strikes (OBO-Betterman, 2010).

FIGURE 33.
ROLLING SPHERE METHOD. (Source: OBO-Betterman, 2010)

Rolling Sphere (R), penetration depth d, spacing of the interception rods

When several interception rods are used to protect the panels the penetration depth between them must also be taken into account (TABLE 5).

TABLE 5.
PENETRATION DEPTH BY LIGHTNING PROTECTION CLASS ACCORDING TO VDE 0185-305. (Source: OBO-Betterman, 2010)

Distance of interception system (d) in m	Penetration depth Lightning protection		
	class I	class II	class IIÉ
	Lightning protection sphere: R =		
	20 m	30 m	45 m
2	0.03	0.02	0.01
3	006	0.04	0.03
4	0.10	0.07	0.04
5	0.16	0.10	0.07
10	0.64	0.42	0.28
15	1.46	0.96	0.63
20	2.68	1.72	1.13

2.2.8. Stand-alone PV system sizing

Sizing Stand-alone PV arrays

The equation that may be used to size a stand-alone PV system (Antony et al, 2007) is:

$$W_{PV} = \frac{E}{G \cdot n_{SYS}}$$

W_{PV}: peak wattage of the array, W_p

E: daily energy requirement, Wh

G: average daily number of Peak Sun Hours (PSH) in the design month for the inclination and orientation of the PV array

n_{sys} : total system efficiency.

The total system efficiency can be calculated as follows:

$$n_{sys} = n_{PV} \times n_{PV\,BAT} \times n_{CC} \times n_{BAT} \times n_{DIST} \times n_{INV}$$

n_{PV} : module efficiency,

$n_{PV\ BAT}$: losses due to voltage drop in cables from PV array to battery,

n_{CC} : losses in a charge controller,

n_{BAT}: battery losses,

n_{DIST}: losses in distribution cables from PV battery to loads,

n_{INV} : losses in inverter.

The module's efficiency can be estimated by the following equation:

$$n_{PV} = n_{STC} \times f_a \times f_d \times f_t \times f_{dio}$$

n_{STC}: module's efficiency at STC,

f_a: de-rating aging factor,

f_d: de-rating factor for dirt/soiling,

f_t: temperature de-rating factor,

f_{dio}: de-rating diode factor.

Indicative values for the above-mentioned magnitudes are presented in TABLE 6.

TABLE 6.
INDICATIVE VALUES (Source: Antony, 2007)

Factors	Indicative values
$n_{PV\ BAT}$	0.98 due to 2% cabling losses from the PV to battery.
n_{CC}	0.98 due to 2% losses in a good quality charge controller.
n_{BAT}	0.90 due to 10% battery losses.
n_{DIST}	0.98 due to 2% cabling losses.
n_{INV}	0.90 due to 10% losses in a good quality inverter.
n_{STC}	0.12-0.14 for Poly-Si PV panels
f_a	Reduction in efficiency of about 1% per year: after 5 years f_a =0.95
f_d	0.95 for panels regularly cleaned 0.90 for panels lightly dusted 0.80 for horizontal dirty panels Indicative value 0.88
f_t	$f_t = 1- [(T_a + T_{PV})-25] \cdot 0.004$ T_a: mean monthly ambient temperature, ^{o}C T_{PV}: temperature on the PV panel , ^{o}C
f_{dio}	0.99 due to 1% losses from the blocking diodes.

The month used to size the system is the month with the lowest daily average solar radiation during the operational period of the system (December, if the system is used throughout the year).

The number of peak hours is for the inclination and orientation of the PV array. If the only available information is solar radiation on a horizontal plane, then a tilt and orientation correction factor should be applied.

Batteries

Stand-alone PV systems use battery backup. The most common types are lead-acid batteries, as these are cheap, reliable and have relatively good energy storage density. Lead battery cells consist of two lead plates immersed in dilute sulphuric acid which create a voltage of about 2V between the plates. The cells are then connected in series to produce 12V batteries.

The ideal charging cycle of a battery has the following stages:

- the battery is charged at constant current until the voltage reaches a predefined value,
- the voltage is held constant while the charging current diminishes,
- the charging voltage is reduced after a suitable period of time to avoid excessive gassing and loss of electrolyte.

However, ideal charging cannot be achieved in a PV system, if the available power is constantly changing.

In stand-alone systems, the battery cycle takes place over 24 hours, charging during the daytime and discharging at night. Typical daily discharge may range from 2-20 % of total battery capacity.

The design of the PV system should consider ways of preventing potential problems such as sulphation, stratification and freezing (Markvart & Castafier 2003).

- Sulphation occurs if the battery is discharged, if the voltage falls below the discharge cut-out voltage (deep discharge), and if there is a significant reduction in the acid concentration.
- Stratification occurs when acid forms layers of different densities throughout the battery cycles. Batteries that are regularly deep discharged and then fully recharged, concentrate lower density acid at the bottom; while batteries with regular shallow cycling which are not 100% recharged concentrate lower density acid at the top.
- Freezing in a lead-acid battery occurs as the battery is discharged; the acid becomes more 'watery' and the freezing point is raised, which can cause severe problems if the battery is operating under sub-zero temperatures.

Very good lead acid batteries may work for up to 4,500 cycles at 30% Depth Of Discharge (DOD), equivalent to a lifetime of 20 years (Kirchensteiner, 2011).

Batteries are generally installed in an insulated enclosure, separated from controls or other PV system components that may have cooling/heating mechanisms, in order to protect them from excessive variations in temperature. The enclosure should also be designed to limit direct exposure to sunlight. When temperature swings are reduced, the battery will perform better, have a longer life, and require less maintenance (Dunlop, 1997).

The nominal capacity of the battery is given by the following equation (Markvart & Castafier, 2003):

$$Q_n = I_n \cdot t_n$$

I_n: constant discharge current, A

t_n: discharge time, h

Battery sizing

The battery has to store energy for many days and must not exceed the DODmax while in use (Antony et al, 2007).

The following equation can be used:

$$Q = \frac{E \cdot A}{V \cdot T \cdot n_{INV} \cdot n_{cable}}$$

Q: minimum battery capacity required, Ah

E: daily energy requirement, Wh

A: number of days of storage required

V: system DC voltage, V

T: maximum allowed DOD of the battery usually on battery data sheet (indicatively 0.3 -0.9)

n_{inv}: inverter efficiency (1.0 if no inverter is used)

n_{cable}: efficiency of the cables delivering the power from battery to loads.

Diodes

Blocking diodes protect the battery from short circuiting and also prevent it from discharging through the modules when there is no light. Diode voltage droppers can also be used to ensure that the batteries will not supply voltages in excess of the load (Wenham et al, 2007).

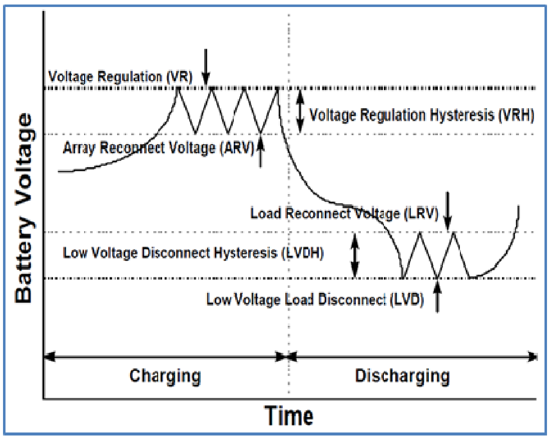
Charge controllers

Charge controllers, are required in stand-alone systems to protect batteries against limiting discharge and overcharge levels.

Main characteristics (FIGURE 34) of the control charger (Wenham et al, 2007) are:

- Regulation set point (VR): maximum allowable voltage. The control charger will either interrupt charging or regulate the current delivered to the battery the set point is reached (Dunlop, 1997).
- Regulation hysteresis (VRH): the difference between VR and the array reconnect voltage. If the hysteresis is set too high, interruptions to charging will be too long. If VRH is set too low, then the array will cycle on and off rapidly. The voltage level VR – VRH is called VRR.
- Low voltage load disconnect set point (LVD): defines the voltage at which the load will be disconnected to prevent over-discharging (DODmax). Over-discharging the battery can make it susceptible to freezing and shorten its operating life
- Load Reconnect Voltage (LRV) Set Point: The battery voltage at which a controller allows the load to be reconnected to the battery. Once the controller disconnects the load from the battery at the LVD set point, the battery voltage rises to the open-circuit voltage. When additional charge is provided by the array, the battery voltage is raised further and as soon as the battery voltage and state of charge are sufficiently high, it reconnects to the load.
- Low voltage disconnect hysteresis (LVDH)—the voltage span between the LVD and the load reconnect voltage. If the LVDH is set too low, the load cycles on and off rapidly at a low state of battery charge, implying possible damage to the load or controller, and extending the time it takes to charge the battery fully. If set too high, the load may remain off for an extended period until the array fully recharges the battery.

FIGURE 34.
CHARGE CONTROLLER SET POINTS (Source: Dunlop, 1997)



There are two main charging regulation methods (Wenham et al, 2007):

a) Interrupting (on/off) regulation. The controller leads all available PV current to the battery during charging. On reaching the maximum allowable voltage, the controller switches off the charging current. When the voltage falls to VR – VRH, the current is reconnected.

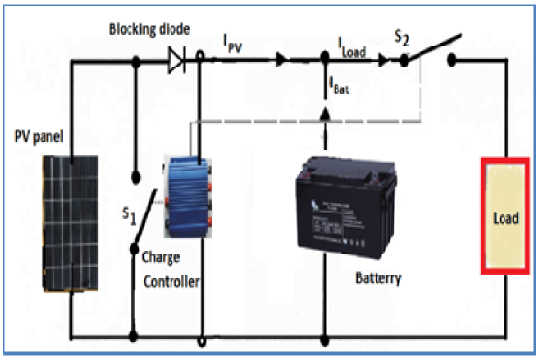
b) Constant voltage regulation. The controller can modify the VR set-point by sensing the battery condition or using a low VR in order to avoid excessive gassing, coupled with provision for an occasional gassing 'equalisation' charge.

The two charging regulation may be applied via shunt or series arrangements.

The shunt (parallel) regulator has a switch that is open when the battery is charging and closes when the battery is fully charged.

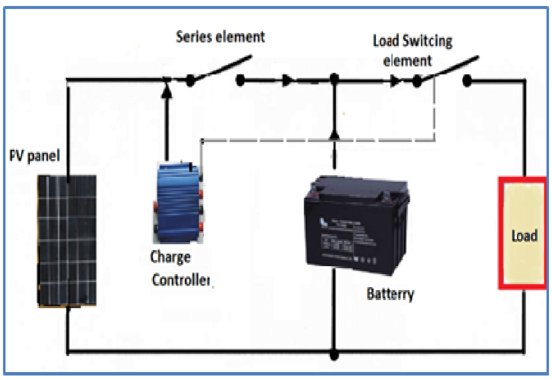
The series regulators are connected in series between module and battery. These regulators are usually simple and cheap.

FIGURE 35.
SHUNT CHARGE CONTROLLER (Source: DGS LV, 2008)



To limit the charging current, the regulator adjusts the transistor resistance according to the battery voltage. Series regulators are mainly used in small systems (Kirchensteiner, 2010).

FIGURE 36.
SERIES CHARGE CONTROLLER (Source: DGS LV, 2008)



Charge controllers should be sized according to the voltages and currents expected during operation of the PV system.

The controller should be able to handle typical voltages and currents, but also peak conditions from the PV array.

It is preferable, in view of the cost, to oversize the controller, as if it fails during operation, the costs of servicing and replacing several elements of the system will be significantly higher.

Under certain circumstances, the maximum power current measured at STC could be much higher and the peak array current could be 1.4 times the nominal peak rated value. Thus the peak array current ratings for charge controllers should be sized for about 140% or the nominal peak maximum power current ratings for the modules or array.

The total current from an array is calculated by the number of modules or strings in parallel, multiplied by the module current. It is better to use the short-circuit current (Isc) instead of the maximum power current (I_{MPP}), so that the shunt type controllers that operate the array under short-circuit current conditions are safe.

The followings should be taken into consideration during the inverter selection procedure:

- system voltage,
- PV array and load currents,
- battery type and size,
- environmental operating conditions,
- mechanical design and packaging,
- overcurrent, disconnects and surge protection devices,
- costs, warranty and availability (Wenham et al, 2007).

The Maximum Power Point Regulator

The MPP regulator searches for the best operating point of a module and ensures that the module delivers the maximum possible power under all conditions.

The MPP regulator samples the output of a cell and applies a resistance (load) to obtain maximum power for any environmental conditions. The procedure defines the current which the inverter should draw from the PV, in order to obtain the maximum possible power.

Stand-alone inverters

Battery storage is used in a PV stand-alone system along with the operation of several loads using DC. Stand-alone inverters enable the use of conventional loads of 230V AC, on a DC system.

Three inverter types are available: the rectangular, the trapeze and the sinus inverter (Kirchensteiner, 2010).

A stand-alone inverter is expected to comply with the following requirements (Daniel et al, 2009):

- very good conversion efficiency, even in a partial load range,
- high overload capability for switch-on and starting sequences,
- tolerance against battery voltage fluctuations,
- economical standby state with automatic load detection,
- protection against short-circuit damage on the output side,
- surge voltage protection,
- bi-directional operation so that batteries can be charged from AC generators, if necessary.

Cable selection and sizing

Cables for domestic use are always made of copper. The main requirements for wiring a module are temperature resistance, UV resistance, moisture resistance, flexibility, ease of handling and size for low voltage drops.

Every cable incorporates a voltage drop. This is a problem in stand-alone systems because the batteries may not be properly charged because of the resistance RC (ohms). As cable resistance increases, so too does the voltage drop according to the following formula:

$$\Delta V = I \times R_C$$

ΔV: voltage drop, V

I: current in the cable, A

R_C: resistance of the cable (Ù), which depends on the cable length and the cross-section.

Basic formula for calculating cross-section:

$$A_M = \frac{2 \cdot P \cdot L}{\kappa \cdot \Delta V \cdot V} = \frac{2 \cdot V \cdot I \cdot L}{\kappa \cdot I \cdot R_C \cdot V} = \frac{2 \cdot L}{\kappa \cdot R_C}$$

P: consumer power, W

A_M: cross-section, mm^2

L: cable length, m

κ: electrical conductivity, $m/\Omega\ mm^2$

Combiner Box

The conductors used to wire the PV array come into the combiner box, where they are connected via a power distribution block to larger ones that run to the charge controller and batteries. The purpose is to carry the electrical energy from the PVs to the batteries with a minimum voltage drop. A combiner box also permits a combination of multiple PV source circuits (sub-arrays, panels, or series strings) into a single DC source, and provides a method of removing a module or sub-array from the array without interrupting the rest of the system. It also allows for safe operation of the system in case of a problem with a source circuit that leads to a high current.

In summary, the basic steps that the technician should follow, in order to install a PV system, are presented in FIGURE 37 and FIGURE 38.

FIGURE 37.
DESIGN OF AN AUTONOMOUS SYSTEM (Source: ReSEL, TUC)

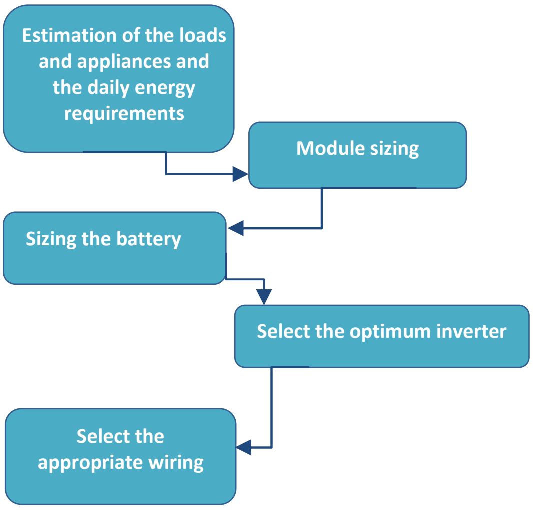
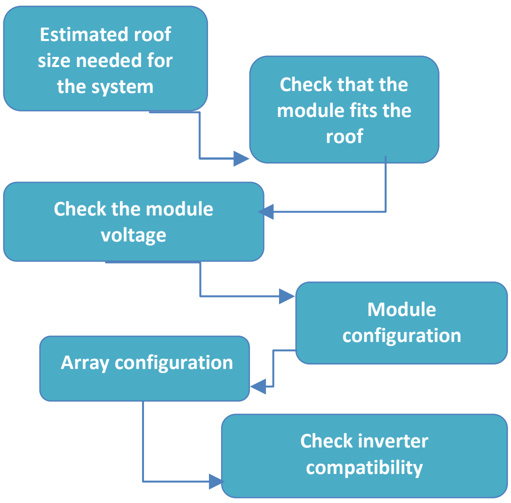


FIGURE 38.
DESIGN OF A GRID CONNECTED SYSTEM
(Source: ReSEL, TUC)



2.2.9. Legal Aspects

Administrative permits can represent a barrier to the implementation of a PV system. These procedures may involve obtaining building permits, environmental impact assessments, grid connection licenses, electricity production licenses etc.

The technician should be aware of the required procedure and the necessary permits, in order to comply fully with the conditions set by the relevant planning authorities or the Regulatory Energy Authorities.

For example, the installer should be aware if a building is listed, as in some cases PVs cannot be applied to buildings which are designated architectural, historical or cultural heritage; specific permission should therefore be issued by the competent authority. BIPVs are subject to complicated planning procedures in some EU Member States. Moreover, conditions for access to a low voltage grid have yet to be regulated and procedures for grid-connections have yet to be implemented in other Member States.

However, these barriers may easily be overcome if the installer is knowledgeable of permit procedures, rules on grid connections and technical standards, grid connection procedures and grid capacity issues. Regulations vary within the EU. Some information on this issue is presented in chapter 2.5.

2.3. Simulation software

There is a great variety of software tools for sizing and simulation of performance of grid-connected and stand-alone PV systems. Some of them are very complicated; others are user friendly, others may lack accuracy or reliability. The installer is advised to access the results to ensure consistency.

Indicative software solutions regarding PV analysis and planning and site analysis are briefly presented in this chapter (TABLE 7).

TABLE 7.
PV SIMULATION TOOLS

PV analysis and planning	
PV*SOL	http://valentin-software.com
PV F-CHART	www.fchart.com
PVSYST	www.pvsyst.com
PV-DesignPro	www.mauisolarsoftware.com
PVPlanner	http://solargis.info/doc/4)
Nsol!-GT	www.nsolpv.com
Solar Pro	www.lapsys.co.jp/english /products/pro.html
RETScreen	www.retscreen.net
PVGIS	http://re.jrc.ec.europa.eu/ pvgis/apps4/pvest.php
Solar Sizer	www.solarray.com
PVselect	www.pvselect.com
Performance Calculation	http://www.volker-quaschning.de/software/pvertrag/index_e.ph
Educational Sun applets	http://users.cecs.anu.edu.au/~Andres.Cuevas /Sun/Sun.html
Site Analysis	
ECOTECT	http://usa.autodesk.com/adsk/ servlet/pc/index?siteID=123112&id =12602821
Shadows	http://www.shadowspro.com/

2.3.1. PV analysis and planning software

PV*SOL (http://valentin-software.com)

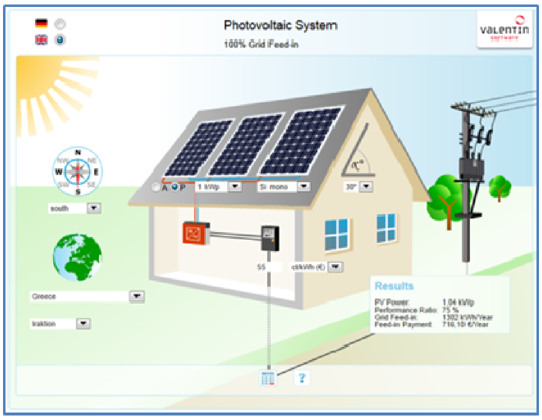
PV*SOL consists of a multi-product software suite appropriate for the design, simulation and financial analysis of PV systems, from small off-grid residential systems to large commercial grid-connected and utility-scale systems. The calculations are based on an hourly data balance and the results may be presented in graphic form, in a detailed project report or in summary form. PV*SOL products are among the most widely used.

PV*SOL programs include:

- PV*SOL basic,for the design of PVs<300kW,
- PV*SOL Pro, for the analysis of PVs<100MW,
- PV*SOL Expert, containing all the capabilities of PV*SOL Pro plus the added capability of 3D array design and detailed shade analysis.

A demo may be downloaded from the relevant website. An on line easy-to-use tool is also available for draft estimations.

FIGURE 39.
ON LINE PV*SOL TOOL



PV F-CHART (http://www.fchart.com)

The program provides monthly-average performance estimations for each hour of the day to calculate the long-term average performance of utility interface systems, battery storage systems, systems with no interface or battery storage. Each system is described using two sets of parameters (system and economics). The system set contains the parameters that describe the optical, thermal and electrical performance of the system. PV F-Chart contains weather data for over 300 locations, hourly load power demand profiles for each month, statistical load variation, buy/sell cost differences, time-of-day rates for buy/sell, and life-cycle economics.

FIGURE 40.
INPUT DATA EXAMPLE ON DEMO VERSION OF PV F-CHART

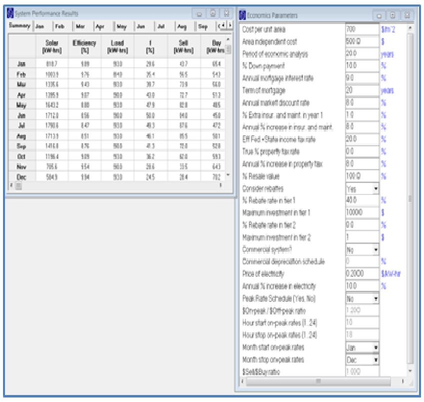
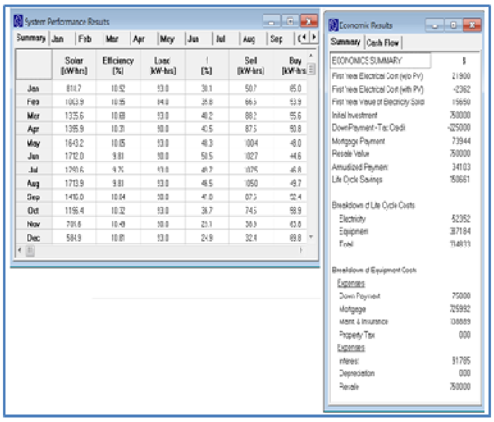


FIGURE 41.
OUTPUT OF EXAMPLE ON DEMO VERSION OF PV F-CHART (BASED ON FIGURE 40)



PVSYST (www.pvsyst.com)

This software is suitable for grid-connected, stand-alone and DC-grid systems, and offers extensive meteorological and PV-components database. It offers 3 levels of PV system study, corresponding to the different stages of the development of a real project:

i) Preliminary design: system yield evaluations are performed using only few parameters.

ii) Project Design: aiming to perform a thorough system design using detailed hourly simulations.

iii) Measured data analysis: importation of measured data is allowed to display tables of actual performances and perform close comparisons with the simulated variables.

An evaluation mode is available and may be downloaded for monthly trial use, free of charge.

PV-DesignPro (www.mauisolarsoftware.com)

The PV-DesignPro has been designed to simulate PV energy system operation on an hourly basis for a year, based on the user's selected climate and system design. There are three versions of the PV-DesignPro program: "PV-DesignPro-S" for standalone systems with battery storage, "PV-DesignPro-G" for grid-connected systems with no battery storage, and "PV-DesignPro-P" for water pumping systems.

PVPlanner (http://solargis.info/doc/4)

PVPlanner is used for planning and optimization of PV systems using climate and geographic data and new generation algorithms. The software can estimate PV electricity potential (in daily or monthly basis), PV conversion losses and performance ratio.

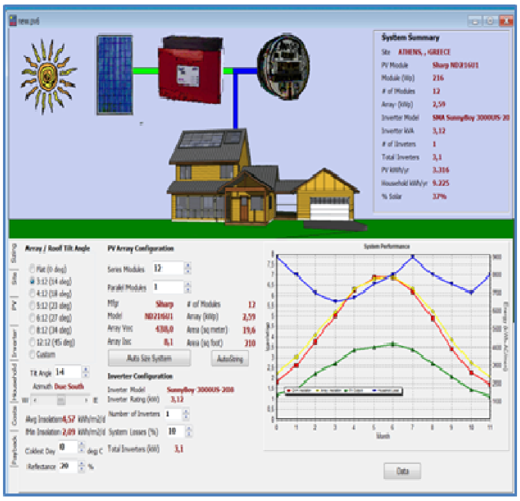
NsoI!-GT (www.nsolpv.com)

NsoI!-GT is a sizing software, specifically optimised for grid-tied PV systems. It includes databases for solar resource, PV modules, and grid-tied PV inverters. The software allows rapid and accurate system design and performance analysis. It also includes a basic economic payback analysis, including value for system rebates, tax credit and production credits.

NsoI! V.4.6 includes modules for standalone PVs, PV-generator hybrids and grid-tied PV. The standalone version includes the "Loss-Of-

Load-Probability" statistical analysis. A demo version is available for download.

FIGURE 42.
EXAMPLE FOR ATHENS ON DEMO VERSION NSOL.



Solar Pro

www.lapsys.co.jp/english/products/pro.html

Solar Pro develops and supports virtual simulations for PV systems, allowing the computation of solar power from module arrays. It also performs shade analysis and includes the influence of shading in the sizing process, in order to check optimal settings and module designs. The software calculates the amount of generated electricity based on the latitude, longitude and the weather conditions of the installation site. The calculated data are presented in graphical form so they can be used for reports and sales presentations of the PV system.

RETScreen (www.retscreen.net)

The RETScreen Software - Photovoltaic Power Model is used to evaluate energy production and savings, costs, emission reductions, financial viability and risk for central-grid, autonomous and grid connected PV systems.

RETScreen models a wide variety of projects, from large scale multi-array central power plants to distributed power systems located on commercial buildings and houses, or stand-alone battery storage systems for lighting. The software is available in multiple languages and includes project and climate databases for free downloads.

PVGIS

http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php

The PV Geographical Information System is an information service of the European Commission, Institute for Environment and Sustainability. This is a research, demonstration and policy-support instrument for geographical assessment of solar energy resources. It provides a map-based inventory of solar energy resource and assessment of the electricity generation from PV systems in Europe, Africa, and South-West Asia. It is a free, easy-to-use tool available online.

In addition to the above, there are numerous others online free tools, such as:

Solar Sizer (www.solarray.com) adds up the electrical requirements of predefined appliances and assists the selection of appropriate components, such as PV modules, inverters, controllers and batteries.

PVselect (www.pvselect.com), a tool for pairing and comparing PV Modules and inverters.

Performance Calculation for Grid-connected PV Systems (www.volker-quaschning.de/software/pvertrag/index_e.php), a tool estimating the output of a system installed on a building based on several characteristics of the location, the roof and the PR of the panel

Educational Sun applets

(http://users.cecs.anu.edu.au/~Andres.Cuevas/Sun/Sun.html), enables the draft design of a PV panel by providing as input the locations' latitude and monthly irradiation data, as well as PV panels' characteristics. The model displays monthly energy production.

FIGURE 43.
ONLINE TOOL FROM THE AUSTRALIAN NATIONAL UNIVERSITY

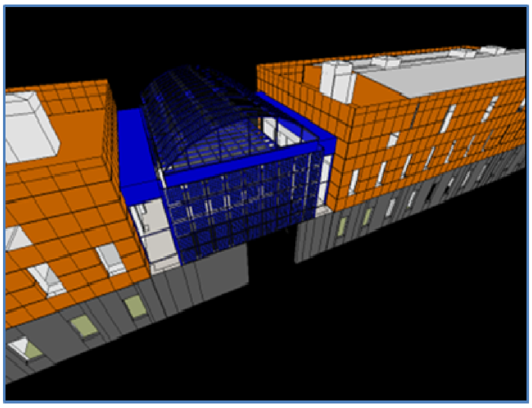
Several other energy simulation software packages such as TRNSYS and EnergyPlus have extensive modules for detailed PV systems simulations.

2.3.2. Software tools for site analysis

ECOTECT

Ecotec performs an entire building energy analysis in 3D. Furthermore, the position and path of the sun as well as solar radiation on windows and surfaces, over any period of the year, may be estimated and visualized.

FIGURE 44.
BIPV VISUALIZATION ON EXISTING BULDING IN CHANIA USING ECOTECT (Source: Papantoniou and Tsoutsos, 2008)



Shadows

Shadows is a useful program for solar energy engineering and assists in the design of sundials and astrolabes. It simulates, displays, and animates the shadows of different objects at different locations.

Shade Analysis,

A tool to estimate shading losses for panels at different locations and orientations with different tilts and slopes.

www.honeybeesolar.com/shade.html.

For further details on the above simulation software, the installer may visit the relevant website and/or contact the supplier or the software developer indicated in the software references.

2.4. Economics and Environmental Issues

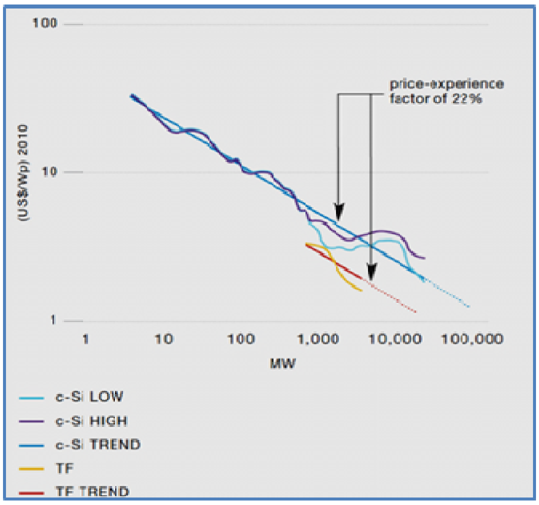
2.4.1. Economic Aspects

Market for PVs

The high cost of power from PV panels has been a major obstacle to market penetration. However, today, the constant reduction in costs each year is an encouraging sign (Lynn, 2010).

PV module prices are reduced by 22% each time the cumulative installed capacity (in MW) is doubled (FIGURE 45).

FIGURE 45.
PV MODULE PRICE EXPERIENCE CURVE (US$/Wp & MW) (Source: EPIA, 2011)



Owing to economies of scale, the manufacturing costs and retail prices of PV modules and systems has decreased significantly.

The price of inverters has also fallen over recent years, following the same trend as the PV modules. Several years ago the share of the panels in the total system cost was 60-75% and it is now estimated at 40-60%, depending on the technology.

Recently many governments have provided capital grants or FITs to encourage people to install domestic PVs.

TABLE 8.
SHARES IN THE TOTAL SYSTEM PRICE (Source: EPIA 2011)

PV modules	40-60%,
Inverter	8-10%
Engineering and procurement	7%

Germany and Spain, especially, have given a significant boost to the PV market, introducing FITs which provide an additional push to the "learning curve". As cumulative world production increases and prices fall, less developed "sunny" countries are more likely to install domestic PV systems.

The advantage of small domestic systems is that the power is generated on-site, and losses through transmission and distribution are limited. On-site generation can be an essential financial advantage that is often overlooked in cost analysis.

However, PV system costs need to be further reduced in order rival the cost of conventional sources of electricity. According to the European Photovoltaic Industry Association (EPIA, 2011) this may be achieved through: technological innovation, production optimisation, economies of scale, increased performance ratio of PV, extended lifetime of PV systems, development of standards and specifications.

Estimating the cost of PV Systems

When investing in a PV system, it is helpful to start by estimating the expected cash flows over the lifetime of the system (20-25 years).

The initial capital cost can be considered the largest share of the expenditure of a PV system's negative cash flow.

This value is affected by many factors (eg: cost of natural building, plant engineering, integration, bureaucratic, etc.); the system designer has to perform an analytic assessment, in order to provide a precise value.

At a rough estimate, the average value of a grid connected system is around 3,000 €/kWp. This value takes into consideration the cost of replacing the inverter which has an average lifetime of 12-15 years; its cost is approximately 8-10% of the plant's value.

The installer may estimate the cost of a PV system following the next steps (Infinite Power, 2009):

Step 1. Determination of the load, available sunlight, array size, battery size:

1.a. Determine the energy load required in Wh/d. Multiply the number of W the load will consume by the hrs/day the load will operate (see also TABLE 4 in Chapter 2.1.7). Multiply the result by 1.5.

Total Wh per day required: __ Wh

1.b. Determine the hr/day of available sunlight at the site.

Total available sunlight: ___hrs/day

1.c. Determine the PV array size. Divide the energy demand (1.a.) by the number of available sun hours per day (1.b.)

Total array size required: ___W

1.d. Determine the size of the battery storage (if battery is required). Multiply the load (1.a.) by 5 (result is Wh). Then divide by the battery voltage (eg, 12 volts) to get the Ah rating of the battery capacity.

Total battery capacity required: ___Ah

Step 2. Calculate the cost of the PV system needed for this application:

2.a. Multiply the size of the array (1.c.) by €3.0/W

Cost estimate for PV array: € ___

2.b. If a battery is used, multiply the size of the battery bank (1.d.) by €0.7/Ah.

Cost estimate for battery bank: € ___

2.c. If an inverter is used, multiply the size of the array (1.c.) by € 0.7/W.

Cost estimate for inverter: €____

Subtotal: € ___

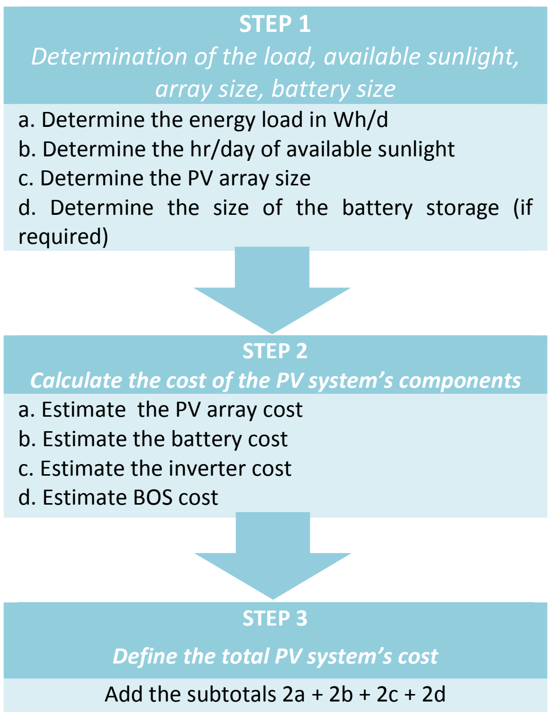
2.d. Multiply the subtotal above by 0.2 (20%) to cover BOS costs (wire, fuses, switches, etc.).

Cost Estimate for BOS: €____

Total estimated PV system cost: € _____ (2a+2b+2c+2d)

A number of free, on-line tools, such as "PV payback" (Sunearthtools.com, 2011): and "Solar Energy" from the Energy Bible.com (Energybible, 2011) facilitate estimates of the payback period in relation to the selling price (€/kWh). Most of the softwares presented in chapter 2.3, allows more precise estimations based on detailed input data.

FIGURE 46.
ESTIMATING THE COST OF PV SYSTEMS (Source: ReSEL,TUC)



Internal Rate of Return (IRR)

IRR is the actual annual rate of profits on an investment. It equates the value of cash returns with cash invested. The formula is:

Investment cost = $\sum_{t-1}^{n} \frac{periodic\ cash\ flow}{(1+i)^t}$ $\sum_{t-1}^{n} \frac{periodic\ cash\ flow}{(1+i)^t}$

i: internal rate of return

t: each time interval

n: total time intervals

This magnitude is essential in order to explain the concept of time value of money. Thus €1 today will worth more than €1 in the future. Eg. in the case of 5% interest rate, €1 today will worth €1.05 in 1 year ($\frac{1{,}05}{(1+5\%)^1} = 1$).

If a project costs €1,000 to set up and generates cash flows of €100, €500 and €1,500 in years 1-3, the hurdle rate which this project should earn in order to create value is calculated as :

$$-1000€ + \frac{10}{(1+i\%)^1} + \frac{500}{(1+i\%)^2} + \frac{1500}{(1+i\%)^3} = 0€$$

In this case, i = 32.8%

So the IRR may be defined as the hurdle rate for which the present value of a project's cash flows equals zero. Any project should have an expected return greater than the IRR, in order to be worthwhile (Hopkins, 2009).

2.4.2. Environmental Issues

Energy payback time (EPBT)

The EPBT is the time in which the energy input during the PV system life-cycle (production, installation, disassembling and recycling) is compensated by electricity generated by the PV system.

The EPBT is defined by the equation (Sunearthtools, 2011):

$$EPBT = E_{input}/E_{saved}$$

E_{input}: is the energy input during the module life cycle,

E_{saved}: annual energy savings due to electricity generated by the PV module.

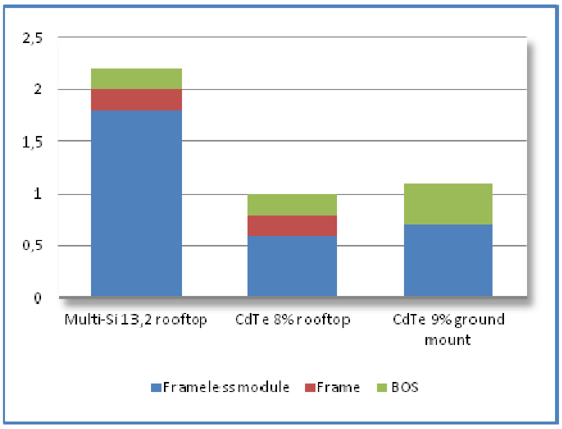
The EPBT depends on:

- cell technology, type of encapsulation, frame and array support,
- PV system application type (grid-connected or stand alone) and,
- PV system performance as determined by irradiation and the performance ratio.

¡Error! No se encuentra el origen de la referencia. illustrates the EPBT for different PV technologies. The calculations assume technologies for average southern European insolation (1700 kWh/m^2/yr), 75% performance ratio for roof-top installations, and 80% performance ratio for utility ground-mounted installations.

The EPBT values of future PV technology will be significantly improved. Recent developments in PV technology will result in decreased energy requirements in component production, leading to greater potential for fossil energy replacement.

FIGURE 47.
V ENERGY PAYBACK TIMES OF PV TECHNOLOGIES (Source: Sovacool, 2008)



Emissions

Emissions of greenhouse gases are expressed in carbon dioxide equivalents (CO_2 equiv).

TABLE 9.
LIFECYCLE GREENHOUSE GAS EMISSION ESTIMATES FOR ELECTRICITY GENERATORS. (Source: Sovacool, 2008).

Technology	Description	Emissions ($g\ CO_2/kWh_e$)
Wind	1.5 MW onshore	10
Biogas	Anaerobic digestion	11
Hydroelectric	300 kW run-of-river	13
Solar thermal	80 MW parabolic trough	13
Biomass	various	14-35
Solar PV	Polycrystaline silicon	32
Geothermal	80 MW hot dry rock	38
Nuclear	various reactor types	66
Natural gas	various combined cycle turbines	443
Diesel	various generator and turbine types	778
Coal	various generator types with scrubbing	960
Coal	various generator types without scrubbing	1050

A detailed Life Cycle Assessment (LCA) has to be performed, in order to estimate emissions during the lifetime of the PV system, which includes extraction and purification of raw materials, manufacturing processes, installation, and many years of operation; also recycling or disposal of waste products.

Values may differ (24gCO_2-equiv/kWh), (Moskowitz & Fthenakis, 1991) for PV systems as regards the PV modules type, methods and materials used for the manufacture of the BOS components etc.

Land use

Land use is often mentioned as an important issue for RES applications. One of the advantages of PVs in urban areas is that they are installed on the rooftops of buildings, avoiding field occupation all together.

In case of ground mounted PVs, land use may be quantified by the following metrics (Turney & Fthenakis, 2011):

- land area "transformation" per nameplate "peak" capacity (km^2 GWp−1), and
- land area "occupation" per unit of electrical energy generated (km^2yr TWh−1).

"Transformation" focuses on the one-time processions that change the physical nature of the land, (installation of the plant) whereas "occupation" measures the period that the land is being used (including time needed to recover). The restoration time is highly variable depending on the disrupted ecosystem.

PV plants are designed for 30+ years of operation. As the lifetime of a PV plant gets longer, the land transformation per capacity remains unchanged; however, the land occupation per generated energy unit decreases. PV installations have the lowest land occupation compared to other RES and compared to coal and nuclear fuel cycles; for example, the coal power life-cycle requires mining that increases land occupation. PV plants cover an average of 25 km^2/GWp. A 30-year old plant occupies 15% less land than a coal power plant of the same age. As the age of the power plant increases, the land use intensity of PV power becomes significantly smaller than it does for coal power (Turney & Fthenakis, 2011).

Raw Materials

Silicon, the material of which most PV panels are made, is one of the most common elements in Earth. It is a nontoxic element; however, several hazardous chemicals are used during the production process of the solar cells. The basic environmental and health issues arising from manufacturing are:

- the dispersion of kerf dust, from the sawing of silicon ingots into wafers,

- exposure to solvents, such as nitric acid, sodium hydroxide and hydrofluoric acid, used in wafer etching and cleaning.

Solar cells are welded by Cu wire and are Sn coated. Some PV manufacturers use solders containing lead and other metals, which if released into the environment may cause environmental and human health risks.

Other environmental risks include the release of hazardous gases from fires at the manufacturing facilities and deposition of lead into soil and, eventually the water table. Similar concerns arise when a fire breaks out at a PV plant.

Recycling

The PV cell counts for only a small fraction of the total materials required to produce a solar panel.

TABLE 10.
MASS BASIC FRACTIONS OF A PV MODULE (Source: Sander, 2007)

Components	Share
Outer glass cover	65%
Aluminum frame	~20%
Ethylene vinyl acetate encapsulant	~7.5%
Polyvinyl fluoride substrate	~2.5%
Junction box	1%
Solar cell	4%

Proper decommissioning and recycling of PV panels ensure that potentially harmful materials are not released into the environment; the need for virgin raw materials is also reduced. When batteries are used, they have to be decommissioned and recycled at the end of their life. The most appropriate use of "dead" batteries is to reuse the lead they contain or recycle them.

Recycling technologies exist for almost all types of PV products and most manufacturers are engaged in recycling activities.

Water consumption

PV systems do not require water during their operation; this fact makes them suitable in places where water is scarce. Some water is used during the production process; 85% for material extraction and refinement, and 15% for the module assembly (EPIA, 2011).

Small quantities of water may be also used for washing panels which is more necessary in sandy fields or in Southern European countries were sand storms are common.

The estimation for the water needed for washing the panels, in large scale PV plants, is 2-4m^3/MW/year (Turney & Fthenakis, 2011).

2.5. Standards and regulations

2.5.1. International Standards and Regulations

There are several standards that regulate PV system functioning and supervision or standards for advising, planning and implementation of such systems. See below for a list of the most important standards, including safety regulations, which have to be considered during PV system implementation.

FIGURE 48.
STANDARDS FOR PV SYSTEMS INSTALLATION (Source: PVResources, 2011)

Nr	Description
IEC 60364-7-712	Electrical installations of buildings – Part 7-712: Requirements for special installations or locations – Solar PV power supply systems.
IEC 61194	Characteristic parameters of stand-alone PV systems
IEC 61702	Rating of direct coupled PV pumping systems
IEC 61724	Photovoltaic system performance monitoring – Guidelines for measurement, data exchange and analysis
IEC 61727	PV systems – Characteristics of the utility interface
IEC 61683	Photovoltaic systems – Power conditioners – Procedure for measuring efficiency
IEC 62093	Balance-of-system components for PV systems – Design qualification natural environments
IEC 62116	Test procedure of islanding prevention measures for utility-interconnected PV inverters
IEC 62124	PV Stand-Alone Systems – Design Qualification and Type Approval
IEC/TS 62257,	Recommendations for small renewable energy and hybrid systems for rural electrification
IEC/TS 62257-7-1	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 7-1: Generators – PV arrays
IEC/TS 62257-8-1	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 8-1: Selection of batteries and battery management systems for stand-alone electrification systems
IEC/TS 62257-9-5	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-5: Integrated system – Selection of portable PV lanterns for rural electrification projects
IEC/TS 62257-9-6	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-6: Integrated system – Selection of PV Individual Electrification Systems (PV-IES)
IEC 62446	Grid connected PV systems – Minimum requirements for system documentation, commissioning tests and inspection
IEEE Std 1526	IEEE Recommended Practice for Testing the Performance of Stand-Alone PV Systems

Standards for batteries, over-voltage protection components and other system components are presented in TABLE 11.

TABLE 11.
STANDARDS FOR BOS (Source: PVResources, 2011)

Nr	Description
N 50524	Datasheet and nameplate information of PV inverters
EN 50521	Connectors for PV systems – Safety.
IEC 61173	Overvoltage protection for PV power generating systems – Guide
IEC 61683	PV systems – Power conditioners– Procedure for measuring efficiency
IEC 61427	Secondary cells & batteries for PV systems. General requirements and methods of test
IEEE Std. 937	Recommended practice for installation and maintenance of lead-acid batteries for PV systems
IEEE Std. 1013	Recommended Practice for Sizing Lead-Acid Batteries for PV Systems
IEEE Std. 1361	Recommended practice for determining performance characteristics and suitability of batteries in PV systems

2.5.2. National Standards and Regulations

Greece

There are no officially adopted requirements concerning PV system equipment in Greece. However, technical agents that want to registered to on the list organized by the Centre for Renewable Energy Sources (CRES) have to use panels and inverters to meet minimum standards acknowledged at EU level.

For PV panels

- IEC-EN 61215 η 61646,
- IEC 61730 – Class A (Class II insulation)

These certificates are provided by accredited laboratories.

For Inverters

- Confirmation of protection against islanding, according to VDE 0126-1-1 or equivalent method

- Protection against voltage and frequency limits (hypertension, hypotension, hyperfrequency)
- Total Harmonic Distortion (THD) current output less than 5%, manufacturer compliance certificate (optional).
- In case of electronic converters without iron, core transformer the maximum injected DC to the grid must be less than 0.5% of the nominal output current of converter, manufacturer compliance certificate (optional)

These requirements are necessary in order to fulfill the conditions of proper operation referred in the contract signed between the PPC and producer.

In Greece there are no statutory regulations for the installation of PV systems. PV technicians follow the basic guiding principles that appear in the ELOT 384 “Requirements for electrical Installations” (Hellenic Organization for Standardization, ELOT).

According to the Public Power Corporation (PPC), PV systems up to 100kW are connected to low voltage, via single phase power supply for up to 5kW and three-phase power supply for 5kW-100kW systems.

The default settings of the protection voltage limits and frequency should be as follows:

Interconnected System: Voltage: -20% to +15% of nominal frequency: +/- 0.5Hz

Non-Interconnected Islands: Voltage: -20% to +15% of nominal frequency: from 51 Hz to 47.5Hz.

The pricing of electric energy produced by photovoltaic stations as it applies, is carried out based on the data in the following table:

TABLE 12.
PRICES FOR ENERGY PRODUCED BY PV

Year-month	Interconnected System Euros/MWh		Non-Interconnected Islands
	>100kW	≤100kW	of any capacity
2010 February	400.00	450.00	450,00
2010 August	392.04	441.05	441,05
2011 February	372.83	419.43	419,43
2011 August	351.01	394.88	394,88
2012 February	333.81	375.53	375,53
2012 August	314.27	353.56	353,56
2013 February	298.87	336.23	336,23
2013 August	281.38	316.55	316,55
2014 February	268.94	302.56	302,56
2014 August	260.97	293.59	293,59
From 2015 and after, for each year (v)	1.3 *mts(v-1)1.4*mts(v-1)		1.4*mts(v-1)1.5*mts(v-1)
mts(v-1): marginal tariff system the previous year v-1			

For PV systems of up to 10kWp, in the domestic sector and in small businesses, the PPC (Public Power Corporation) will buy the energy produced for 0.55 €/kWh. This price is guaranteed for 25 years. The producer – consumer continues to buy power from the PPC (about 0.10-0.12 €/kWh). Revenues from energy sales are not taxed.

Moreover, following the approval of RES legislation (Law 3851/2010) and the subsequent Ministerial Decisions, some important changes have been applied in the normative framework overcoming certain administrative barriers.

More specifically:

- A production license is not required for systems <1 MWp.
- Rooftop systems of any size do not require environmental permits and procedures

have become easier for ground-mounted systems.

- Residential systems can be installed in all regions
- Applications previously excluded (such as façades, louvers, warehouses, carports, etc) are feasible in the residential sector.
- PV systems on historical buildings can now be deployed under a special authorisation procedure.
- Installation of PV systems on prime agricultural land is now allowed with certain limitations.
- A 150 €/kWp bank guarantee is needed for ground-mounted systems up to 1 MWp, before a grid connection contract may be signed.

The above data came into force in September 2011, and may be subject to change.

Installers are strongly advised to look for the latest legislative and normative framework before they start developing a PV project. Valid legislation, supporting mechanisms and applicable rules are published at the following links:

- Public Power Corporation: www.dei.gr
- Regulatory Authority for Energy: www.rae.gr
- Hellenic Transmission System Operator S.A: www.desmie.gr
- Ministry of Environment, Energy and Climate Change: http://www.ypeka.gr/
- Hellenic Association of Photovoltaic Companies: http://www.helapco.gr/
- Solar Energy Producers' Association: www.spef.gr

TABLE 14 and TABLE 15 present the current legislation, administrative issues and supporting mechanisms (valid on September 2011) for the countries participating in the PVTRIN Project (Bulgaria, Croatia, Cyprus, Greece, Romania, Spain).

Furthermore, the PV LEGAL project has developed a database comparing the administrative procedures for PV installations in the 12 EU Member States (Bulgaria, Czech Republic, France, Germany, Greece, Italy, Poland, Portugal, Slovenia, Spain, the Netherlands and UK). Three different types are examined:

- small-scale installations on residential buildings
- small to medium-scale installations on commercial buildings
- medium to large-scale ground-mounted installations on open lands.

The database identifies the administrative steps necessary to obtain permission for constructing, grid-connecting and operating of PV systems that could be a very helpful tool for both the installer and the customer. PV LEGAL is funded by the European Commission’s Intelligent Energy for Europe programme (PV LEGAL, 2011).

2.6. Databases

A number of databases have been developed that offer useful information on different aspects of a PV installations. Indicative links are listed to following table (TABLE 13).

TABLE 13.
PV DATABASES

Links	Description
www.pvresources.com/	Information on solar power and its applications. Large-scale PV power plants database on report simulation tools
www.pvdatabase.org/	Data on best practices, urban PV projects, BIPV products
www.iea-pvps.org/	National reports and statistics on PV market
www.pvlegal.eu	Detailed information on the administrative processes that need to be followed in order to install a PV system in each of the participating countries.
http://www.enf.cn/database /panels.html	Information on production equipment, solar components (eg. inverters, batteries), solar materials, solar panels, sellers, solar system installers
http://www.posharp.com /photovoltaic/database.aspx	Extensive database with characteristics of many PV panels
http://pvbin.com/	Database of all commercially available solar panels with functionality to search and sort by different data parameters
http://www.nrel.gov/pv/ performance_reliability/failure_database.html	Information about failures observed in PV installations.
http://www.semi.org/en/Store /Marketinformation/photovoltaics/CTR_028755	Database including over 750 PV facilities and covering the PVindustry value chain from Poly-Si to module manufactures. Resource for key business and technical contacts
www.meteonorm.com	Climatological database for solar energy applications: a meteorological database containing comprehensive climatological data for solar engineering applications at all points of the globe

TABLE 14. ADMINISTRATIVE ISSUES (Source: PVTRIN, 2011)

	Greece	Bulgaria	Croatia	Cyprus	Romania	Spain
Building regulations relevant to PV installation	Permission issued by the Planning and Architectural Commission is required in case of PV installation. a). in areas characterized as "areas of natural beauty" and b) in areas where listed buildings are found, as well as traditional settlements. PV installation is permitted on building roofs and façades, veranda covers and shelters. A PV array should not: -create a space of main or auxiliary usage or semi open areas -hinder the access in communal areas -exceed the frame -in penthouses (enclosed area on top of a building) -be installed at the end of the well hole -On sloped roofs, PV panels must be placed following the inclination of the housetop -In case PV panels are placed on the roof of the building, the distance from the parapet of the roof should be at least 0.50 m for safety reasons. For PV installation on buildings > 100kWp, approval of small scale construction work is required.	Permission based on an assessment of the impact on the environment is required. Installation of any RES systems in protected areas is very limited. For the installation of PV systems on arable land a special permit is required. (Law for Protected Territories, Regulation No 2 for construction works on arable lands) There are no specific architectural requirements for the installation of PV on buildings. The systems should be designed according to the rules for electrical installations that guarantee safe exploitation. The design should be approved from the relevant authorities. (Regulation No 1 from 27.05.2007 for designing, installation and maintenance of low voltage electrical installations in buildings).	PV systems on existing buildings are viewed as simple additions to existing buildings, such that no location permit is needed, thus PVs can be easily installed on the roofs, façades etc. However, during a procedure for eligible producer status, confirmation that there is no need for location/construction permits from local (municipality) office for construction permits is needed. Some protected areas could be excluded. The recommendation is that static calculations and electric design be made before installing PV modules on roofs. Only a limited number of municipalities/counties foresee the use of PV on buildings in their territorial plans. Use of alternative energy sources (including PV) must be prepared for every new building; however, none have to be incorporated in the final plan.	Directive 2/2006 issued to guide Planning Authorities in relation to the principles, criteria and procedures, for permitting RES installations and to apply building permit controls to applications that are related to their integration. Circular 3/2008 includes specific provisions that are related to the installation of small scale photovoltaic systems in buildings or on the ground and clearly states in which cases the application for planning permit is not required. The 2006 Law on Regulation of Energy Efficiency in Buildings (L.142(I)/2006) – PPR 446/2009 for new buildings foresees the provision of PVs for future installation. In agreement with the Electricity Authority, a bigger electricity panel board and cable from the panel board to the likely future location of an RES-e installation should be installed	Permission is required for all modifications to the building from the Urbanism department of each municipality – Law no.10/1995 on "Quality construction" The restrictions apply to historical areas and buildings. Law no.10/1995 on "Quality construction" amended by Governmental Decree no. 498 /2001, Law no. 587 /2002 and Law no. 123 /2007. Permission is required for all modifications to the building from the Urbanism department of each municipality. The restrictions apply to historical and religious buildings.	CTE-HE5: Technical Building Code" reproduces the contents of CPD (Construction Products Directive) and international technical standards with regard to target performances. It establishes the minimum solar photovoltaic electric capacity to be installed in certain types of buildings, regulates the size of the facilities and the layout of the modules, and gives maximum values for losses depending on the type of installation: general case, superposition and architectural integration Local urban legislation;
Planning permission required for PV installation	Planning permission is not required for the installation of photovoltaic systems on buildings (less than 100kW).	Yes, as for all electrical systems.	For smaller PV plants: not required. For large PV plants: Local Spatial Planning office has to change use of the land, and accept it in Spatial Plan (long and complicated procedure)	- only for PV parks 20-150kW& PVs on buildings over 100kW	Yes	Yes

Requirements for Grid connection	There is a limit for installations ≤ 100 kW. PV systems greater than this have to connect to the medium voltage network. PV systems >2MW have to be connected to the high voltage network.	The Bulgarian distribution grid has no specific requirements for the connection of a PV plant. Regulation №6 from 09.06.2004 "Connection of producers and users of electrical energy to the transmission and distribution grids"	- ≤4.6 kW – one phase connection - > 11.04 kW –3 phase connection - PV plants ≤ 100 kW Directly connected to a low-voltage line (0.4 kV) - PV plants ≤ 500 kW are connected at low voltages (0.4 kV) to connection points at the transforming station - PV plants ≤ 10 MW are connected at medium voltage (up to 35 kV) to the connection point at the transforming station - All power plants are required to have approval from DSO	Connecting RES to the electricity network follows the Regulation regarding the connection of users to public interest electricity networks and following the specifics of the Electricity Law no. 13/2007 with subsequent updates by GD 90/2008.	There are no regulations for private owners, only for producers that have a license for producing/distributing electricity All the necessary steps are described in the "Guidelines for the producer of electricity from renewable energy sources (e-res)" .	Compliance with the following regulations RD661/2007: it regulates the activities of transport, distribution and electricity commercialization. -RD 1578/2008: minimal requirements for the protection against electrical risk RD 1663/2000: Low Voltage Regulation - OM 5/9/1985: High Voltage Regulation. - RD 1110/2007, unified measurement points of the electrical system.
Links for current legislations	- Public Power Corporation: www.dei.gr - Regulatory Authority for Energy: www.rae.gr - Hellenic Transmission System Operator S.A: www.desmie.gr - Ministry of Environment, Energy and Climate Change: http://www.ypeka.gr/ - Hellenic Association of Photovoltaic Companies: http://www.helapco.gr/	- Ministry of Regional Development and Public Works www.mrrb.government.bg - State Energy and Water Regulatory Commission www.dker.bg - Ministry of Economy and Energy www.mi.government.bg - State Gazette http://dv.parliamnet.bg -	- Ministry of Economy and Ministry for Construction: - http://oie.mingorp.hr - Ministry of Environmental Protection, Physical Planning and Construction: www.mzopu.hr - Ministry of Economy, Labour and Entrepreneurship: - http://oie.mingorp.hr - Hrvatska Elektroprivreda (HEP Group): www.hep.hr	- Cyprus Energy Agency http://www.cea.org.cy	- Ministry of Regional Development and Tourism www.mdrt.ro - - Romanian Energy Regulatory Authority: http://anre.ro	- Ministry of Industry, Energy and Tourism http://www.ffii.nova.es/puntoinfomcyt/formulario-lseg01.asp - The National Energy Commission http://www.cne.es/cne/contenido.jsp?id_nodo=510&&&keyword=&auditoria=F - Technical Building Code: www.codigotecnico.org - Official State Gazette (BOE): www.boe.es

Note: TABLE 14 and TABLE 15 present the current legislation, administrative issues and supporting mechanisms (as of September 2011) for the countries participating in the PVTRIN Project. Use the above links to access current legislation.

TABLE 15. SUPPORTING MECHANISMS FOR PV INSTALLATION (Source: PVTRIN, 2011)

	Greece	**Bulgaria**	**Croatia**	**Cyprus**	**Romania**	**Spain**
Supporting mechanisms and incentives for the installation of PV	PV systems ≤100 kWp: 0.45€ / kWh PV systems ≤100kWp: 0. 40€ / kWh.	According to the new RES Law (2 /05/2011): Electricity PV installations will be supported by high tariffs for 15 years that will be defined every year by the State Energy and Water Regulatory Commission. Since 1/07/ 2011 the tariffs from PVs are: BIPV: <30 kWp on roofs or façades: 0.31 €/kWh BIPV: 30 -200 kWp on roofs or façades: 0.30 €/kWh BIPV >200 kWp on roofs/façades: 0.30 €/kWh For ground PVs <30 kWp: 0.29 €/kWh For ground PVs 30 -200 kWp: 0.29 €/kWh For ground PVs >200 kWp: 0.25 €/kWh The Kozlodui National Fund administrated by EBRD offer loans. Usually RES owners are granted a 20% discount from the principal sum of the loan after the completion of the project. USAID program guarantees 50% of the credit.	FIT from RES&PVs 0,32-0,52 €/kWh depending of the size of PV plant. Cap on total of 1 MW of PV plant. Level of FITs will changed, as well as cap with new Law on Renewables that is drafting, and is expected to be in power by the end of 2012. For updated information: Ministry of Economy: http://oie.mingorp.hr/	Natural persons & organizations, not involved in economic activities (residential): Grid connected <7kW : FiT 0.35€/kWh (15ys, no grant) Stand –alone <7kW: 55% grant < 20 kW (organizations): 55% grant (max €44,000) Natural persons & organizations, involved in economic activities: Grid connected 21-150kW : FiT 0.31€/kWh (20ys) Stand –alone< 20 kW: 40% grant (max €36,000) depending on the enterprise category. In the cases of stand-alone systems there is a maximum amount of grant i Comment: Likely to be changed in 2012.	Six green certificates for each 1MW produced and delivered by the producers of electricity from solar energy.	FIT 0.1385€ / kWh (2011) 50% of the IBI, reduction between 0-100% of the urban canon and reduction from 0-95% of the ICIO. Depending on the region: Soft loans, Tax incentives, Regional investments, VAT devolution
Supporting mechanisms and incentives for the installation of BIPV	PV systems < 10kWp in the domestic sector and in small businesses: 0.55 € / kWh.	The Kozlodui National Fund administrated by EBRD. The USAID program and some banks (credit lines). Programs for regional development	The above specific supporting mechanism will be implemented in new Law on Renewable as somewhat higher FIT. http://oie.mingorp.hr			< 20 kW : 0.2979€/kWh (2011) 20 kW–2 MW: 0.2095€/kWh (2011) All this under the consideration of not fulfilling the total quota of "allowed" installations.
Links for current legislation	- Ministry of Environment, Energy and Climate Change: www.ypeka.gr/ - Hellenic Association of PV Companies: www.helapco.gr/ - Solar Energy Producers' Association: www.spef.gr		- Ministry of Economy, Labour and Entrepreneurship: http://oie.mingorp.hr	-Ministry of Commerce, Industry and Tourism: www.mcit.gov.cy Cyprus Institute of Energy: www.cie.org.cy	- Ministry of Regional Development and Tourism www.mdrt.ro	

Note: TABLE 14 and TABLE 15 present the current legislation, administrative issues and supporting mechanisms (valid on September 2011) for the countries participating in the PVTRIN Project. Use the links above to see the current legislations.

2.7. Exercises

2.7.1. Case studies

Case Study 1

Sizing a 24VDC system voltage home

i. Loads, appliances and daily energy requirements

TABLE 16.
APPLIANCES AND DAILY ENERGY REQUIREMENTS

Loads and Appliances	Power rating of appliances (W)	Total power required (W)	hrs of use/day (h)	Daily energy require-ment (Wh)
Fluorescent lamps	12W	60W (5 lamps)	3	180Wh
TV	100W	100W	1.5	150Wh
Microwave	640W	640W	0.5	320Wh
Refrigerator	80W	80W	3	240Wh
Lighting outside	50W	50W	1	50Wh
TOTAL	**930W**		**940Wh**	

The house roof has an inclination of 50° and is orientated 60° southwest. The system is designed for January and a 3-day storage capacity is foreseen.

ii. Module sizing (see also chapter 2.2.8)

G = 5.0 PSH

n_{SYS} = 0.6

E =940Wh daily energy requirement.

$$W_{PV} = \frac{E}{G \cdot n_{SYS}} = \frac{940Wh}{5h \cdot 0.6} = 314W$$

Hence, the minimum system size is 314 Wp.

iii. Sizing the battery (see also chapter 2.2.8)

V = 24VDC system voltage.

A = 3 days

E = 940Wh

T = 0.5

n_{inv} = 0.9

n_{cable} = 0.97

The minimum required battery capacity, Ah

$$Q = \frac{E \cdot A}{V \cdot T \cdot n_{INV} \cdot n_{cable}}$$

$$Q = \frac{940Wh \cdot 3}{24V \cdot 0.5 \cdot 0.9 \cdot 0.97} = 269Ah$$

For a 24VDC home system, 2 batteries with 24V/150Ah connected in parallel will be chosen for a total of 24V/300Ah.

iv. Inverter

The system requires an inverter, as there are only AC appliances in the house. The total power required for AC appliances is 940W so a 1,500W inverter with 24VDC input will be recommended.

v. Wiring

In the case where the cable length is 8m, made of copper and the drop voltage is 10%:

$$A_M = \frac{2 \cdot P \cdot L}{\kappa \cdot \Delta V \cdot V}$$

$$A_M = \frac{2 \cdot 940W \cdot 8m}{56m/mm^2\,\Omega \cdot 2.4V \cdot 24V}$$

$$A_M = 4.66mm^2$$

This result will be rounded to the next standard value of 6 mm^2.

The standard cross-section sizes are 2.5mm^2; 4mm^2; 6mm^2; 8 mm^2; 10 mm^2; 12mm^2; 14 mm^2 ; 16 mm^2; 18 mm^2; 20 mm^2; 22 mm^2; 24; 26 mm^2; 28 mm^2; 30 mm^2; 32 mm^2.

An 80Wp mono-crystalline PV module of about 12VDC (a nominal voltage rate of 12V) with a nominal current of 4.5A is selected.

If we divide 314 by 80, we have 3.9, so 4 modules will be connected in series-parallel. This means that the 2 modules are connected in series and the 2 strings are connected in parallel. The total voltage is 2 x 12 V = 24VDC and the current is 4.5A x 2 =9.0A.

The current produced by the module determines the charge controller. In this case it is 9A. The charge controller has a minimum of 9A. We can choose a greater one (15A) in case of any foreseen expansion.

Case Study 2

Sizing a 5.5kW$_p$ PV system on a sloping roof (length 9.0 m, and width 5.0 m).

TABLE 17.
PV -MODULE CHARACTERISTICS

Parameter		Value
Maximum power	P_{max}	230
Voltage at Max. power	V_{MPp}	29.8V
Current at Max.power	I_{MP}	7.71A
Open Circuit Voltage	V_{OC}	35.8V
Sort Circuit Current	I_{SC}	8.34V
Max. System Voltage		1000V
Temperature coefficient	Voltage (V_{OC})	-0.35%/°C
	Current (I_{SC})	0.060%/°C
Length x Width x Depth	mm	1,550x962x40
Weight	kg	18.5

1.550m x 0.968m = 1.500m^2 for 230 Wp. This is equivalent to 6.5 m^2 /kW$_p$

i. Roof size

5.5kW$_p$ x 6.5 m^2/kW$_p$ =35.75m^2

Total modules: 5,500Wp/230W$_p$ = 23.9 thus 24 modules should be consider for total power output of 24 x 230 W= 5,520W$_p$

Modules should be checked, if laid out on portrait format or landscape format, which will depend on the length and the width of the roof.

ii. Check if the module fits the roof

- In portrait format

$$\frac{\text{Roof length}}{\text{Module width}} = \frac{9.0\text{m}}{0.962\text{m}} = 9.35 \text{ and}$$

$$\frac{\text{Roof width}}{\text{Module length}} = \frac{5.0\text{m}}{1.550\text{m}} = 3.23$$

The above calculation leads to a total of 9 x 3 = 27 modules; the maximum number of modules laid in portrait that could fit onto the roof is 27 (9 modules and 3 strings or opposite); more than enough space for the 24 modules.

- In landscape format

$$\frac{\text{Roof length}}{\text{Module length}} = \frac{9.0\text{m}}{1.550\text{m}} = 5.8 \text{ and}$$

$$\frac{\text{Roof width}}{\text{Module length}} = \frac{5\text{m}}{0.962\text{m}} = 5.19$$

5 x 5 is approximately 25, so maximum 25 (5 modules and 5 strings) modules can also fit in landscape format.

The modules can be laid in both formats, but it is better to choose the format in which most modules may be laid out, so that the system can be extended in the future. The portrait format is therefore selected.

iii. Checking the module voltage

Voltage temperature coefficient: - 0.35% x Voc/°C= -0.0035 x 35.8 = - 0.125V/°C

$V_{MPP-25°C}$ = 29.8V

$V_{MPP-10°C}$ = 29.8 + 15x 0.125 = 31.67V

$V_{MPP-70°C}$ = 29.8 – 45 x 0

$V_{oc-10°C}$ = 35.8 + 15 x 0.125 = 37.67 V *iv. Inverter selection*

Inverter nominal power is between 90% and 100% of (array) this is between 90% x 5,520= 4,968W and 5,520W (this range is chosen because in case of good sunny days with radiation at the STC or over the STC, the inverter should not be undersized), so 4 inverters (TABLE 18) can be chosen for a string-inverter concept.

TABLE 18.
INVERTER CHARACTERISTICS

Parameter	Units	Value
Max DC power	W	1,400
Max DC voltage	V	400
V-voltage range, MPPT	V	96-320V
Max Input Current	A	12.6

v. Module configuration

Maximum number of modules on a string:

$$n_{max} = \frac{V_{DCmax(inverter)}}{V_{OC-10^oC}} = \frac{320V}{37.67V} = 8.49$$

Minimum number of modules on a string:

$$n_{nim} = \frac{V_{MPP\ min\ (inverter)}}{V_{MPP-70^oC}} = \frac{96}{24.18} = 3.97$$

Therefore the maximum number of modules is 8 on a string and the minimum is 4.

vi. Array configuration and inverter compatibility

4 strings of 6 modules with 1 inverter on each string, will be implemented. The voltage compatibility has to be checked.

$V_{MPP\ -70°C}$ = 6 x 24.18V = 145V, this is acceptable as it is above the lower voltage of the MPP-range (96V) V_{MPP}

$V_{MPP\ -\ 10°C}$ = 6 x 31.67V = 190 V, this is also acceptable as it is below the upper limit of the MPP voltage range (320V) V_{MPP}

$V_{oc\ -10°C}$ = 6 x 37.67= 226V, this is below the maximum inverter input voltage (400V) also acceptable Voc

The current at the MPP of the module is 7.71A, which is acceptable and below the maximal input current of the inverter (12.6 A).

This is a string-inverter concept. The array has a total wattage of 5,520kWp which consists of 24 modules, each with 230 Wp. The array is configured in 4 strings of 6 modules.

2.7.2. Multiple Choice Questions

1. What is meant by the Standard Test Condition (STC)
   a) Radiation: 1,000W/m^2, temperature: 25°C, and Air Mass: 1.5
   b) Radiation: 1,000W/m^2, temperature: 20°C, and Air Mass: 1.5
   c) Radiation: 1,024W/m^2, temperature: 25°C, and Air Mass: 1.5
   d) Radiation: 1,000W/m^2, temperature: 18°C, and Air Mass: 1.0

2. If a PV cell produces 0.5 V, then four PV cells connected in series will produce:
   a) 2.0 V
   b) 0.5 V
   c) 2.5 V
   d) 1.0 V

3. The total power across four PV cells of 0.5V connected in series when Acell = 1A is:
   a) 2.0 W
   b) 0.5 W
   c) 2.5 W
   d) 1.0 W

4. If a PV cell delivers a current of 0.6A and there are three PV cells in parallel then the current flowing through the load is:
   a) 2.0 A
   b) 0.6 A
   c) 1.8 A
   d) 1.0 A

5. The total power across three PV cells of 0.5V connected in parallel when Icell = 0.6 A is:
   a) 2.0 W
   b) 0.9 W
   c) 0.3 W
   d) 1.0 W

6. If 24 PV cells (0.5V) are connected in series and parallel (6 cells and 4 rows), the total voltage across the load is:
   a) 2.0 V
   b) 2.4 V
   c) 12.0 V
   d) 3.0 V

7. If the height of an obstacle is 3m the minimum distance (Lmin) so that the PV will not be shaded is:
   a) 4.0 m
   b) 6.0 m
   c) 3.0 m
   d) 1.0 m

8. "Increase in temperature leads to an increase of n V_{OC} resulting to increased cell output".
   a) The statement is right
   b) The statement is wrong
   c) V_{OC} does not depend on temperature

9. The efficiency of a PV cell may be improved by:
   a) adjusting the light facing angle all day
   b) placing colored acetates on the cell
   c) cooling the cell
   d) changing its direction to north

10. Solar PV systems can be:
    a) connected to the power grid
    b) used to sell power to the grid
    c) a stand-alone source of electricity
    d) all answers a, b, c

11. In a series connection:
    a) the positive terminal is connected to the positive terminal
    b) the negative terminal is connected to the negative terminal
    c) the positive terminal is connected to the negative terminal
    d) all of the above

12. A stand-alone PV system can provide electricity when no sunlight is present with:
    a) batteries
    b) inverter
    c) a battery charge controller
    d) a and c

13. An inverter is required on a PV system if:
    a) batteries are used
    b) DC power is needed
    c) AC power is needed
    d) if the load is very large

14. If a PV system is tied into the electric utility grid:
    a) it does not have to use batteries
    b) it needs batteries
    c) no inverter is required
    d) it cannot provide AC

15. The available surface area of a building is 108m^2 (length=12.0m and width =9.0m), and the area required by a panel is length=1.64m and width =0.98m. If 55 PVs are to be installed the optimum layout will be:

a) landscape format
b) portrait format
c) there is no difference
d) neither format is appropriate

16. Wh-efficiency is always less than Ah-efficiency in a battery.
    a) True
    b) False
    c) We cannot know

17. A 100 W refrigerator can operate using a 150 W inverter without any problems.
    a) True
    b) False
    c) We cannot know

18. A 24V back-up power system is supplied via a single, 4mm2 solar cable, 15m long, from a 200 W module. Is the cross-section sufficient?
    a) Yes
    b) No
    c) We cannot know

19. To improve the efficiency of the whole system as of the planning procedure, the designer should?
    a) Install the modules in a way that they will be well ventilated
    b) Keep the cables as long as possible
    c) Keep the tilt of the panels less than 15°
    d) None of the above

20. A string concept with 8 inverters is planned for the PV system with 12kWp. What DC output should each inverter have? Between…
    a) 1.35 and 1.5 kW
    b) 0.67 and 1.42 kW
    c) 1.35 and 1.42 kW
    d) None of the above

2.7.3. True–False questions

1. A Tracking system which follows the sun's daily migration can boost production by up to 8%.
   a) True
   b) False

2. If half of a cell is shaded, the reduction in output is the same as when even half a row is shaded.
   a) True
   b) False

3. The maximum voltage occurs when there is a break in the circuit.
   a) True
   b) False

4. Deep discharge improves the life expectancy of a Pb-acid battery.
   a) True
   b) False

5. Temporal overcharge of a battery improves the homogeneous of the catalyst.
   a) True
   b) False

6. When sizing the cables, the permitted current rating of the cable should be at least equal or greater than the trigger current of the string fuse.
   a) True
   b) False

7. The efficiency of string inverters range from 50-60%.
   a) True
   b) False

8. The cost of the panels in about 70-80% of the cost of the total system.
   a) True
   b) False

9. A safety distance of 0.10m between the PV plant and all parts of the lightning protection system has to be maintained.
   a) True
   b) False

10. The lifetime of the system is 10-15 years.
    a) True
    b) False

11. The material of which the PV cells are made is toxic and hard to be found on Earth.
    a) True, in most of the cases
    b) False, in most of the cases

12. All available online software applications for PV system dimensioning provide accurate calculations and reliable data.
    a) True
    b) False

13. The most expensive components of an autonomous PV system are the batteries.
    a) True
    b) False

14. A rough estimation of the average value of a PV system is approximately 8,000 €/kWp.
    a) True
    b) False

15. An approximate required surface can be estimated, bearing in mind that: $10m^2$ = 1kWp
    a) True
    b) False

2.7.4. More Practice

1. A PV system uses 720 silicon PV cells connected in an array which supplies up to 120 V.

   1i.How many PV cells are connected in series if 120 V are needed and one cell delivers 0.5 V?
   a) 240
   b) 120
   c) 360
   d) 60

   1ii. What is the number of the rows connected in parallel?
   a) 2
   b) 6
   c) 4
   d) 3

   1.iii When the light intensity is 1,000 W/m^2, the total power output from the PV array is 360W. What is the energy efficiency of the PV cells? Each PV cell is a square measuring 118mm by 118mm.
   a) The energy efficiency of the cells is 3.0%
   b) The energy efficiency of the cells is 2.8%
   c) The energy efficiency of the cells is 3.6%
   d) The energy efficiency of the cells is 4.8%

   1iv. What type of silicon PV material are the PV cells made from?
   a) a-Si
   b) poly-Si
   c) mono-Si

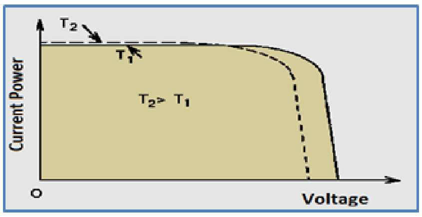
2. Which type of charge controller is the most appropriate for a PV system with 30 modules and a total power of 47Wp connected to a 24V battery? The modules are connected via 15 branches of 2 panels per series and the maximum voltage of

each module is 17V. Take into account that 6 lamps each of 60W and a CD player of 160W will be in operation at the same time.

a) A 24V – 65A charge controller
b) A 12V – 65A charge controller
c) A 24V – 45A charge controller
d) A 1V – 45Acharge controller

3. 130 kWh of energy are required to manufacture 1 m² Poly-Si module. How long will it take for this module to generate an equivalent amount of energy, given that solar irradiation in Greece is 1,350 kWh / (m² x yr)?
   a) the energy payback of the PV system is approximately 8 years.
   b) the energy payback of the PV system is approximately 6 years.
   c) the energy payback of the PV system is approximately 1.5 years.
   d) the energy payback of the PV system is approximately 4.5 years.

4. Briefly explain how PV panel efficiency is influenced by temperature variations.



5. What is the optimum panel inclination for a panel sited in Crete (ϕ=35.16°)?
   a) ϕ= 35,16°
   b) ϕ= 55,16°
   c) ϕ= 15,16o
   d) ϕ= 60,00o

6. How does an inverter work?
   a) it converts AC voltage of the modules to a higher value of AC voltage
   b) it converts DC voltage of the modules to AC voltage of the grid
   c) it converts DC voltage of the modules to a higher value of DC voltage
   d) it converts AC voltage of the modules to DC voltage of the grid
   e) it converts AC voltage of the modules to a higher value of AC voltage

7. Name 3 of the most common failures where a PV system may lose energy. Explain the reason for these losses
   a) Shading (reduced irradiance on the panel)
   b) temperature decrease (reduced I_{mpp})
   c) temperature increase (reduced V_{oc})
   a) fault orientation (reduced irradiance on the panel)
   d) short wiring (increased resistance)

8. What is the role of a blocking diode?
   b) Blocking diodes protect the battery when there is no light
   c) Blocking diodes break the electrical circuit if too much current is present
   d) Blocking diodes search for the best operating point of a module
   e) Blocking diodes connect the frame of an electrical device to the ground

9. What are the main requirements of a stand-alone inverter?
   e) low overload capability for switch-on and starting sequences,
   a) intolerance against battery voltage fluctuations,
   b) very good conversion efficiency, even in partial load range,
   c) one-directional operation
   d) all the above

10. Which is the part of the PV system that ensures max output power from the PV module?
    a) MPP Tracker
    b) Blocking diode
    c) Bypass Diode
    d) Fuse

11. Under which circumstances a PV system could cause environmental damage?
    a) PV system are in general harmful for the environment
    b) There is no way that a PV system can cause damage to the environment
    c) Release of hazardous gasses in case of a fire breaking out in a system
    d) In case it is sited over an aquifer

12. Why should the PV systems be recycled? Which is the main reason?
    a) gain some money from selling raw materials
    b) potentially harmful materials are not released into the environment
    c) to avoid unnecessary aesthetical impacts of useless systems

13. Name 3 parameters on which a PV system's energy payback time is depending on.
    a) cell technology
    b) the colour of the wiring
    c) type of encapsulation
    d) line with the current fashion
    e) frame and array support

BAPV and BIPV 3

3. BAPV and BIPV

3.1. Mounting and building integration options

3.1.1. BAPV and BIPV

Building-applied photovoltaics and building-integrated photovoltaics are PV modules installed in buildings to serve as a principal or additional energy source. The installation of a PV system in a building is a very sustainable solution, as roofs and façades are used instead of additional land.

Building-applied photovoltaics (**BAPV**) are photovoltaic installations fixed over the existing elements of a building envelope such as roofs, skylights, façades, balconies and shelters.

FIGURE 49.
BAPV ON FALT ROOF. (Source: SEC)

FIGURE 50.
BAPV ON PITCHED ROOF. (Source:SEC)

Building-integrated photovoltaics (**BIPV**) are photovoltaic products (sheets, tiles, glasses, etc.) that are used instead of conventional building materials in parts of the building envelope such as roofs, skylights, or façades. They are usually installed in new buildings, but they could also be installed in existing buildings during their renovation. The advantage of BIPV is that the costs of construction are reduced, as these modules replace traditional building materials. On the other hand, solutions with BIPV modules are usually more aesthetic.

FIGURE 51. BIPV ON ROOF. (Source: SEC)

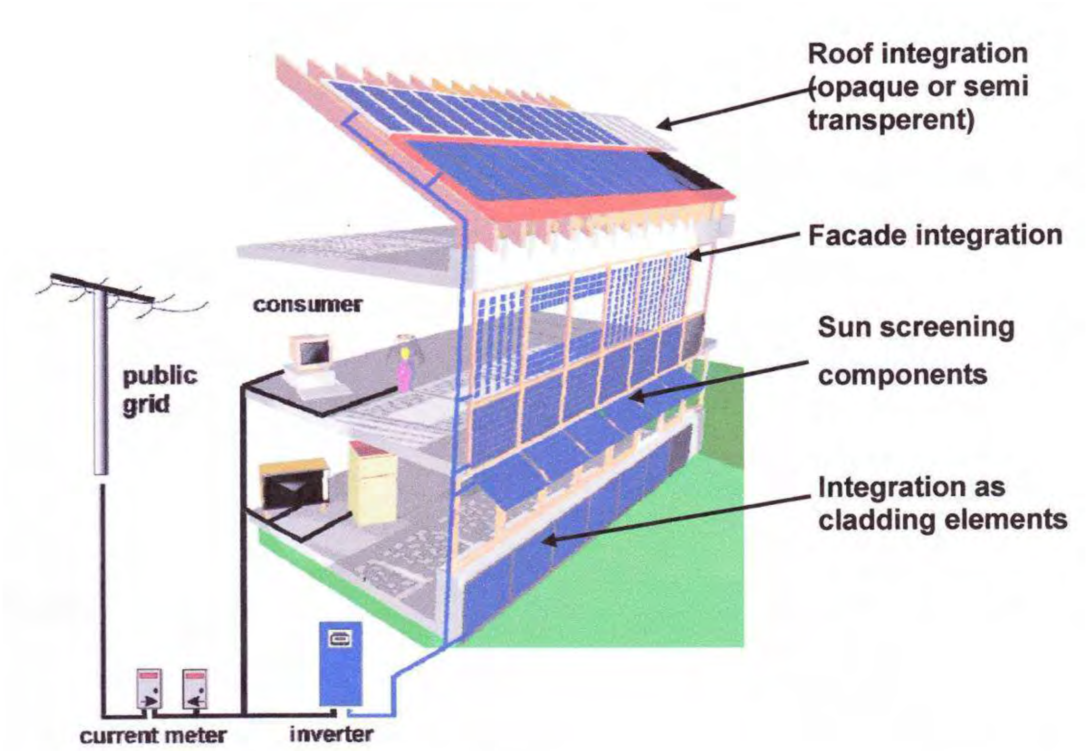
3.1.2. Building integration options

BAPV and BIPV can be installed in all type of buildings: dwellings, houses, schools, all types of public buildings and industrial buildings as well in urban structures such as bus/parking shelters.

The key components of a grid-connected system are:

- The PV modules,
- The inverter,
- The current meter.

FIGURE 52. ALTERNATIVES FOR INTEGRATING PVs IN BUILDINGS (Source: PURE project. Roman et al,2008)



The criteria for reliable integration of PV modules in buildings are:

- Natural integration,
- Architectural solutions,
- Pleasant composition of materials and colours,
- In line with the context of the building,
- Innovative design.

Several issues should be taken into consideration at the urban planning stage for seamless integration of PV systems in buildings:

- For PV on sloped roofs, the streets should be oriented east-west, such that they have south oriented slopes.
- For PV integrated in façades, the optimal orientation should be chosen, depending on the open spaces.
- Shading from other buildings or trees should be taken into account and minimised.

3.2. BIPV and BAPV on roofs

PV elements can be installed on all types of roofs – flat, pitched, and domed roofs.

3.2.1. PV modules on flat roofs

The installation of PV modules on flat roofs is an excellent choice, as the modules can be oriented and inclined in the best position.

When installing PV modules on a flat roof, several aspects should be taken into account:

- The structure of the roof,
- The elements of the roof such as chimneys, exits, skylights, etc.,
- The orientation of the building.
- The material covering the roof.

FIGURE 53 illustrates different options for the integration of PV systems on flat roofs (ECN).

When PV modules are installed in new buildings, the structure of the roof is calculated according to the load of the installation, but when they are installed on existing buildings, the load bearing capacity of the structure should be checked. In some case, the roof structure should be reinforced in accordance with building regulations.

PV modules on flat roofs are fixed on metal or adapted concrete or plastic structures.

The water-proofing covering of the roof should be preserved, when the structures (metal or plastic) are installed. The structural fixtures on the roof should be insulated with water-proof materials.

FIGURE 53.
OPTIONS FOR INTEGRATION OF PV SYSTEMS ON FLAT ROOFS (Source: ECN)

FIGURE 54.
PV INSTALLATION ON FLAT ROOF – EXTERNAL VIEW AND STRUCTURE. (Source: SEC)

When planning the installation of the structure, the elements of the roof should be taken into account. PV modules should not be installed close to chimneys, exits or paths.

Flat roofs are very convenient for PV systems, as they can be oriented in the best position, but distances of at least ½ of the height of the structure should be left between the rows of PV modules in order to avoid mutual shading. Shading from chimneys and walls should also be examined.

3.2.2. PV modules on pitched roofs

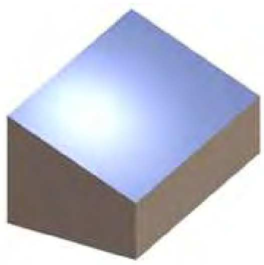
There are several integration options for installing PV modules on pitched roofs. They can be mounted over roof (BAPV) or integrated in the roof (BIPV).

FIGURE 55.
OPTIONS FOR INTEGRATION OF PV SYSTEMS ON PITCHED ROOFS (Source: ECN)

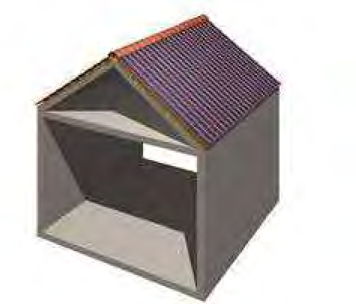
a) Mounted over tiles (BAPV)

b) Integrated in the roof (BIPV)

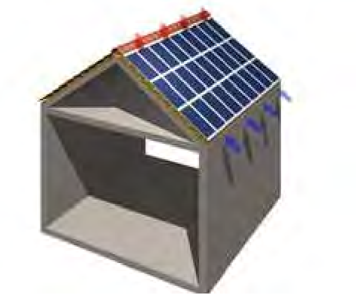
c) The whole roof can be covered with PV modules (BIPV).



d) Solar tiles



e) PV modules installed with an air gap on the rear to ensure the necessary ventilation and avoid problems with over-heating,



BAPV on pitched roofs

BAPV have an independent support structure and are easier for installation.

They are more suitable than BIPV for retrofits of existing buildings and can be easily replaced.

Because of their independent structure they are cooled from the rear and there is no problem with over-heating.

BIPV on pitched roofs

BIPV offer better possibilities for a good integration.

Mutual shading is avoided.

Be careful to ensure good water tightness and ventilation.

TABLE 19.
PROBLEMS AND SOLUTIONS FOR THE INSTALLATION OF PV MODULES ON PITCHED ROOFS. (Source: SEC)

	Problems to be solved	**Solution**
BAPV	Good fixation of PV modules without damaging the roof's covering	Stainless steel fixtures stuck under the tiles to secure the structure
	Ensure good air circulation on the rear	The distance between the PV elements and the roof's covering should be 5-10 cm.
BIPV	Water tightness between the panels and between the panels and the roof covering	Use special products such as: PV roof tiles/ sheets and observe the manufacturer's recommendations at all times.

FIGURE 56.
BIPV ON RESIDENTIAL BUILDING (Source: SEC)

3.3. PV on façades

The Energy Performance of Buildings Directive (EPBD) requires all EU countries to update their building regulations and take steps to foresee sufficient sources of renewable energy.

Although roofs are the best place for installing PV modules, space for PV elements should also be foreseen on the façades to ensure the required amount of energy production.

When examining the installation of PV modules on façades, it should be taken into account that the efficiency of the system will be at least 30% lower than a roof system with the best tilt and orientation.

3.3.1. Options for integration

There are several options for integration of PV modules on façades.

a) fully integrated

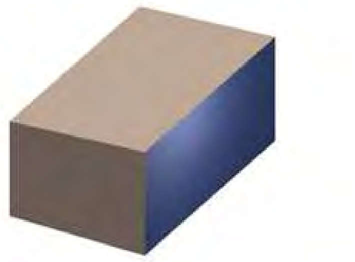
b) partly integrated

c) additional glass façade

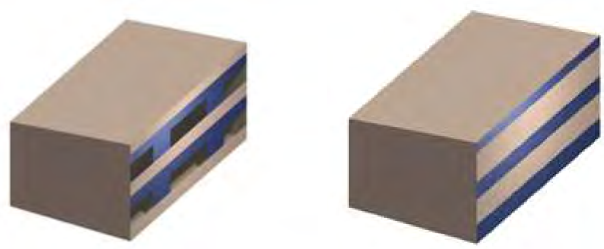
d) fixed on the balcony

FIGURE 57.
OPTIONS FOR INTEGRATION OF PV SYSTEMS ON FAÇADES (Source: Education and training material for architects (ECN)

a) fully integrated.



b) partly integrated.



c) additional glass façade.

d) fixed on the balcony.

3.3.2. BAPV on façades

BAPV is a good choice for installing PV systems on the façades of existing buildings.

BAPV can be cheaper than BIPV because:

- One of the advantages of BAPV systems is that it is easier to ensure cooling of the system through the air gap between the PV panels and the wall.
- There is no need for cladding or decorative plastering on the walls behind the PV panels.
- There is no need to ensure air tightness between the joints.
- BAPV are easier for maintenance and replacement.
- The PV panels can act as additional thermal insulation.

FIGURE 58.
BAPV ON REFURBISHED RESIDENTILA BUILDING (Source:SEC)

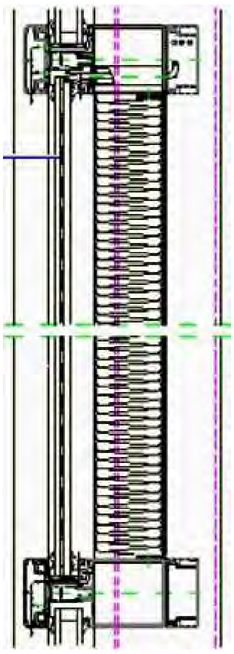
3.3.3. BIPV on façades

BIPV are suitable for new buildings. They give better opportunities for good architectural solutions.

BIPV installations can be integrated in buildings as warm façades. In this case they are integrated in the structure of the façade as a part of the wall. The PV modules are fixed between two panes of glass and are incorporated in the structure of the façade. The façade panels may be composed of either a glass package with PV modules and a sandwich panel with thermal insulation, as shown in figure 57, or of a glass-glass package where the sandwich panel is replaced by an argon filled space and thermal-coated float glass, as shown in figure 58.

FIGURE 59.
BIPV IN WARM FAÇADE (Source:SST)

F

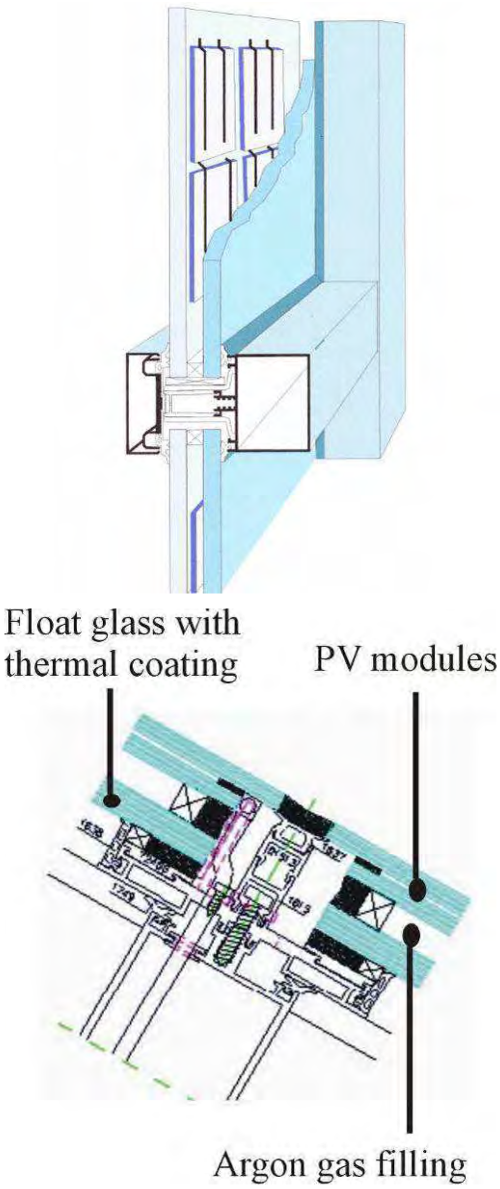


Different architectural solutions may be applied through the integration of the modules in the structure of the façade:

- A fully glazed façade,
- Alternation of PV modules and glass.

The following figures show different examples of the integration of modules in façade construction. (Roman et al, 2008))

FIGURE 60.
BIPV IN WARM FAÇADE (Source: Roman et al, 2008)



BIPV installations can be integrated in buildings as cold façades. In this case they act as a second "skin" of the façade, or double façade. PV modules are fixed on an additional structure with an air space between the modules and the wall. Depending on the distance between the modules and the wall, we can categorize facades as:

- Ventilated facades when the space between the wall and the modules is up to 10cm, as the fixing of the PV modules is not air tightened, the air can circulate between the wall and the modules and secure the necessary ventilation. In these facades the PV modules also act as finishing cladding.
- Curtain wall – the distance between the wall and the PV modules is more than 20 cm. and can even ressemble a glazed balcony.

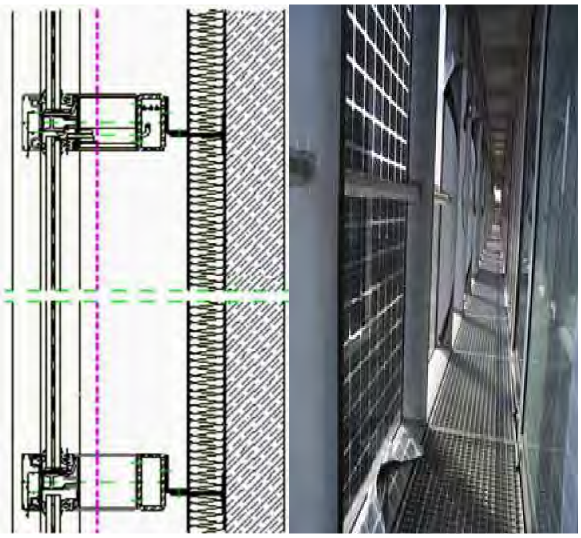
Cold façades are more expensive as the modules are additional elements of the construction, but they have other benefits.

The solution with cold façade avoids the problem with cooling of the modules.

This second "skin" acts as a very efficient additional thermal insulation and can ensure a better indoor climate.

With a good planning of the cold façade it is not necessary to foresee additional shading.

FIGURE 61.
BIPV IN COLD FAÇADE (Source: SST)



3.3.4. Mounting requirements

BAPV and BIPV integrated in façades should follow the following safety requirements and recommendations for troublefree functioning: :

- When mounting PV modules on existing buildings, the load bearing capacity of the structural elements of the façade should be checked.
- The fixtures carrying the modules should be strong enough to resist severe weather such as wind, hailstorms and snow.
- The joints of warm façades should ensure good air and water tightness. There are special modules that ensure good insulation, but closely follow the manufacturer's recommendations at all times!
- Limit the installation of modules on the ground floor, close to paths and other areas accessible to the public, in order to avoid damage.

3.4. Glass roofs, shading systems and other applications

3.4.1. Glass roofs

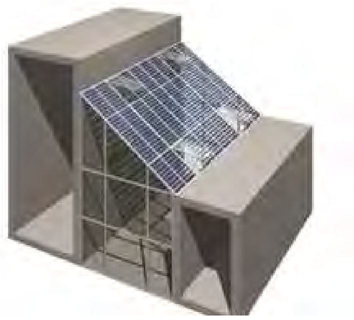
Glass roofs from PV modules are an excellent choice. They can be integrated on flat roofs, sloped roofs or individual construction.

The following figures show possibilities for the integration of glass roofs from PV modules (ECN)

FIGURE 62.
OPTIONS FOR INTEGRATION OF PV SYSTEMS ON GLASS ROOFS (Source: ECN).

a) flat roof.

b) sloped roof.



c) individual construction, roof membrane

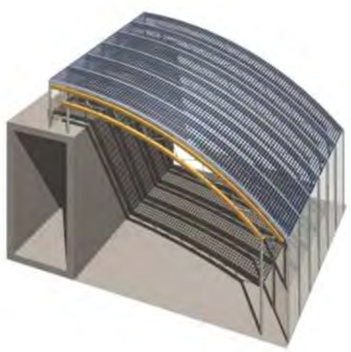
For example, a PV parasol makes good use of a glass roof. A roof construction in the form of a parasol covered with PV modules reduces the heat load, making the conditions within the building more comfortable.

The PV parasol can be with or without a water-retaining function, depending on the needs of the building. (ECN)

The following figure shows examples of a PV parasol with and without a water-retaining function.

FIGURE 63.
OPTIONS FOR THE INTEGRATION OF PV PARASOL SYSTEMS (Source: ECN).

a) PV parasol with water-retaining function.



b) PV parasol without water-retaining function.

FIGURE 64.
EXAMPLE OF GLASS ROOF WITH PV MODULES (Source:SEC)

3.4.2. Shading devices

Shading devices are ideal for PV modules integration in buildings.

This solution is suitable both for new and existing buildings.

These shading devices composed of PV modules offer the following advantages:

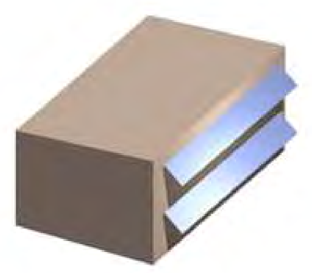
- Passive cooling,
- Daylight control, as the best inclination for PV modules is the same as for providing most shadow,
- Electricity production.

There are several options for building integration of shading devices from PV modules.

They can be independent from the building envelope, incorporated in the building envelope as a curtain wall, or as an additional element of the building, such as a canopy.

FIGURE 65.
OPTIONS FOR THE INTEGRATION OF PV SYSTEMS IN SHADING DEVICES (Source: ECN).

a) PV shading devices independent from the building envelope.



b) PV shading devices incorporated in the building envelope as a curtain wall.

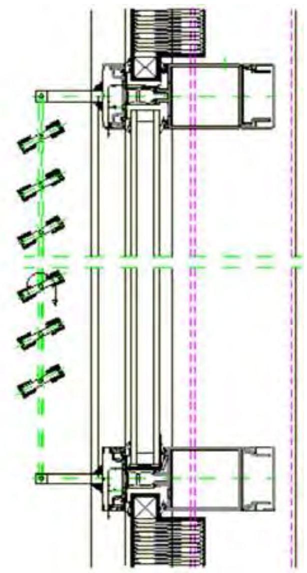
c) PV shading devices additional as a canopy.

They can be fixed or movable.

FIGURE 66.
PV SHADING (Source:ECN)

The following figure shows an example of the installation of a PV shading curtain on the façade.

FIGURE 67.
INSTALLATION OF PV MOVABLE SHADING ELEMENT (Source:SST)



3.4.3. Other applications

PV modules can be used for other applications such as ensuring natural lighting.

PV on skylights should be installed on the southern side of the element. They will ensure a good light with the necessary sun protection for the premises in the building.

Laminated double glazed opaque cells with a space of 1-3 cm. between the cells should be used for sky lights.

PV modules on sky lights ensure diffuse or tempered light with interesting shadow patterns.

The integration of PV modules in buildings is widely used for passive solar design.

Elements from PV modules such as awnings, double façades and glass roofs prevent the building from overheating.

Transparent PV modules integrated in the building envelope improve the indoor climate and ensure access to daylight.

An innovative solution is the combined function PV-solar thermal. (ECN)

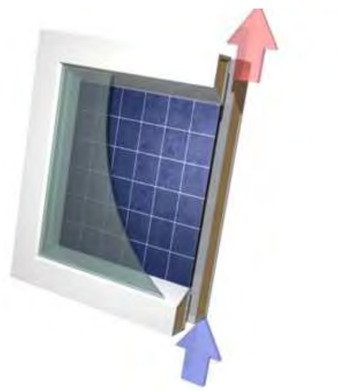
The benefits of hybrid collectors with medium air or water are:

- Cooling the PV element improves its efficiency.
- Heat from thermal element can be used for hot water and heating.

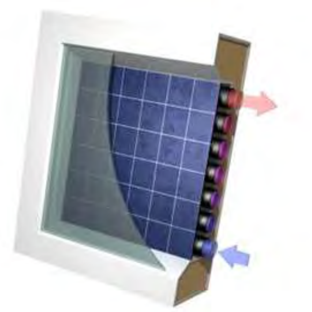
This solution is attractive when the roof space is limited.

FIGURE 68.
COMBINED PV-SOLAR TERMAL FUNCTION (Source: ECN)

a) Air medium



b) Water medium



PV modules can be integrated in many urban constructions:

- Bus stops,
- Car parks,
- Roofs of railway or bus stations,
- Sound barriers,
- Information boards,
- Street lights, etc.

FIGURE 69.
ROOF OF BUS STOP AND CYCLE PARK WITH PV MODULES (Source: SEC)

3.5. Design Parameters and Performance Factors

3.5.1. Location and urban planning

The efficiency of a PV system depends on the following factors:

- The amount of solar radiance on the site,
- The orientation and tilt of the modules,
- The quality of the modules and inverter.
- The PV system design

Appropriate urban planning is the first step for successful implementation of PV installations in buildings and other urban constructions. If the site does not have the appropriate orientation, the south oriented slope of the roof and the façade might not have enough space for a larger PV installation.

Even the surrounding vegetation should be planned correctly. Trees situated close to the southern façade of a building will overshadow the building.

The following pictures show several planning solutions for one site.

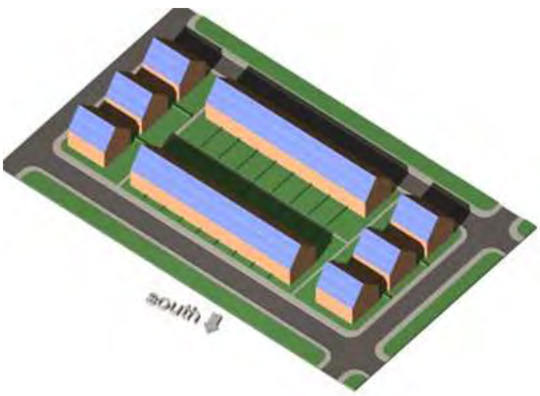
The first picture illustrates the best solution, as all PV modules are foreseen to be installed on the south roof slope.

The second picture shows also a good solution with two long buildings oriented to the south and two small ones oriented to the east

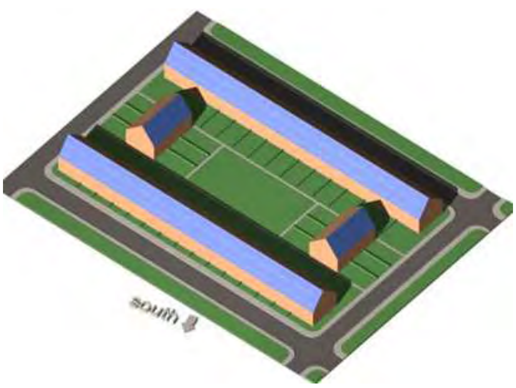
The last two pictures illustrate alternative solutions, but not the best.

FIGURE 70.
PLANNING SOLUTION FOR ONE SITE. (Source: ECN)

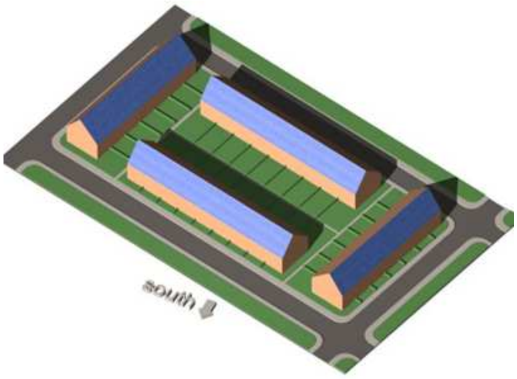
a) best solution, as all PV modules will be installed on the south-facing roof slope.

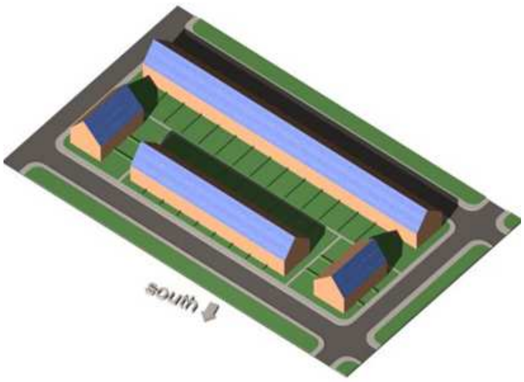


b) a good solution with two long buildings oriented to the south and two small ones oriented to the east.



c) alternative solutions, but not the best.





3.5.2. Orientation and tilt

The benefits of a PV system depend to a great extent on the orientation and tilt of the PV modules.

PV production depends on inclination and orientation of several façades or roofs:

Optimum Orientation = South

Optimum Inclination angle = Latitude (º) – 10º (over 30º in Europe)

PV modules on façades are 30% less efficient than PV modules on roofs.

The following table gives the factors for calculation losses from PV efficiency depending on the orientation and tilt of the modules.

TABLE 20.

ORIENTATION AND TILT FACTORS (Source: SEC)

Factor for calculation losses at a given orientation and tilt				
Tilt / Orientation	0º	30º	60º	90º
East	0,93	0,90	0,78	0,55
South-east	0,93	0,96	0,88	0,66
South	0,93	1,00	0,91	0,68
South-west	0,93	0,96	0,88	0,66
West	0,93	0,90	0,78	0,55

Best orientation	Very good orientation
Good orientation	To be avoided

3.5.3. Shading

Even having foreseen the best orientation and tilt for the PV modules, the system can be very inefficient if shading is not taken into account.

We should examine two types of shading issues:

- Shading from surrounding buildings, trees and topography and
- Self-shading.

Shading by surrounding landscape and buildings should be taken into consideration for:

- winter and morning and evening sun,
- growth of the trees,
- planning further erections of new buildings.

To avoid this problem dummy PV modules or by-passes should be foreseen for shaded areas.

Care must be taken as shaded diffuse light can strongly affect the efficiency of the PV installation!

FIGURE 71.
SHADING FROM TREES (Source: ECN)

To avoid self-shading, examine the building geometry and such details as:

- Satellite receivers on roofs,
- Chimneys and shafts,
- Skylights and other higher parts,
- Hanging elements.

FIGURE 72.
SELF-SHADING (Source: ECN)

To avoid self-shading the solution is the same as for shading from surrounding elements: install dummy PV modules or by-passes.

3.5.4. Construction requirements

The planning stage

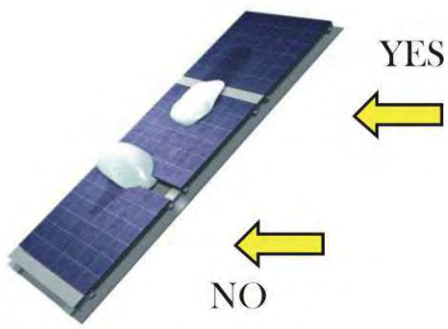
The structure of the elements of the building envelope where will be mounted PV modules should be calculated according to the expected additional load of the installation. This should be done for new buildings at the planning stage. For existing buildings it is advisable to check the condition of the structural elements of the roofs and façades and to follow the building regulations closely.

When planning construction works, accessibility to roofs and façades for mounting the elements of the PV installation and for maintenance should be examined.

The fixation of the PV modules should be calculated to be strong enough to meet the load from snow, ice and hail.

In countries with heavy snowfall, the tilt angle of PV modules should be at least 45º. The modules should have a smooth surface to allow snow slippage (ECN)

FIGURE 73.
SNOW SLIPPAGE OVER A MODULE(Source: ECN)



The construction of the system will also be exposed to strong wind that can lead to twisting, vibrations and additional dynamic and static load. The system should be calculated to meet building legislation on wind loads in the country.

3.5.5. Temperature effect and ventilation

Temperature has a negligible effect on module current, but a huge impact on the MPP voltage. Depending on the temperature coefficient, the voltage of a PV module can increase or decrease by more than 10V, when compared to the STC value during winter or summer, respectively. This must be considered during the PV system design phase to avoid a risk of failure or fire.

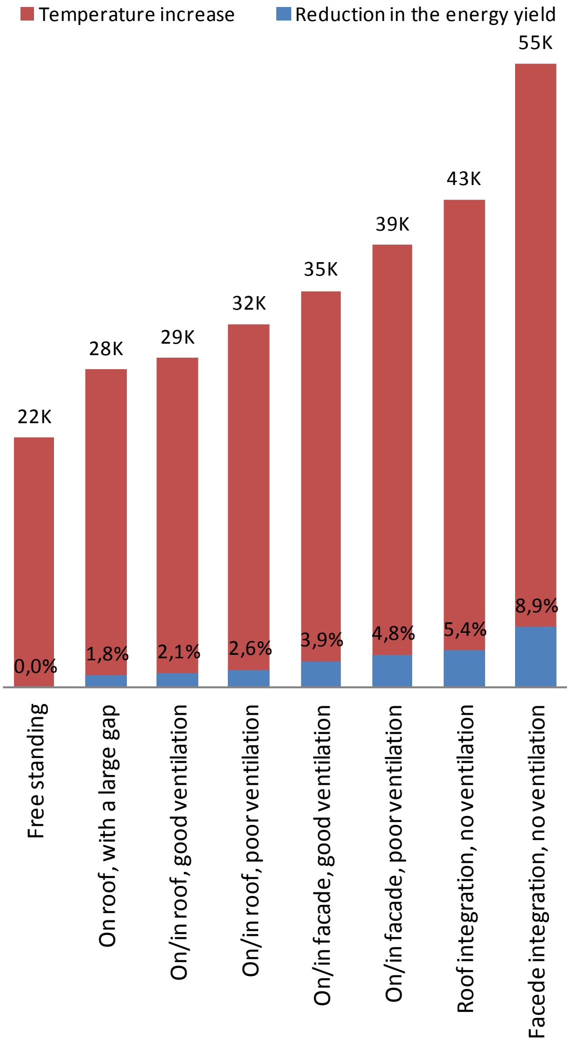
The temperature dependence of the voltage will of course affect the PV module power output and the energy yield of the PV system.

In consequence, it is important to understand the parameters that impact on the operating temperature of a PV module among which the most important are the type of mounting and installation.

As an example, a free-standing PV module has an operating temperature of 42°C in central Europe on a typical summer day (1000 W/m² and an ambient temperature of 20°C). With a roof integrated PV system, the operating temperature of the same PV module can reach 63°C without ventilation.

In order to ensure proper ventilation, the technical requirements provided by the PV module manufacturer should be followed during the PV system design phase. FIGURE 74 shows the temperature increase and the energy yield reduction of a PV system in Germany for the typical installation types (with an irradiation of 1000 W/m² and an ambient temperature of 20°C).

FIGURE 74.
IMPACT OF THE TYPE OF INSTALLATION ON TNE TEMPERATURE AND ENERGY YIELD (Source: Fraunhofer ISE, 1997)



3.6. Examples from the residential sector

PV modules can be integrated in roofs and façades when retrofitting a building.

The most typical example of PV application in buildings is BAPV on roof of existing buildings. They are usually installed on roofs covered with tiles as additional elements (i.e. not integrated in the structure).

FIGURE 75.
PV ON ROOF (Source:ECN)

The following picture illustrates the integration of PV on façades of an historical building in Aarhus, Denmark. Solar thermal collectors are also mounted on the façades for domestic hot water and heating. The PV modules and solar collectors are installed on the façade facing the inner courtyard of the building, while the main façade and its historical aspect are unaffected.

FIGURE 76.
INTEGRATION OF PV MODULES IN AN EXISTING BUILDING (Source: SEC)

When PV modules are installed on roofs and on the façades of new dwellings, they are usually fully integrated (BIPV).

The PV modules are elements of the design concept of the building.

The following pictures illustrate examples from the Netherlands.
The **Waterkwartier Nieuwland** (Water district New Land) is known as a 1 MW (megawatt) project, as many homes have been fitted with solar panels for electricity production.

FIGURE 77.
WATER DISTRICT NEW LAND BIPV ON ROOFS OF SINGLE FAMILY HOUSES (Source: SEC)

FIGURE 78.
WATER DISTRICT NEW LAND, BAPV ON FAÇADE OF MULTI-FAMILY DWELLING BUILDING (Source: SEC)

FIGURE 79.
WATER DISTRICT NEW LAND, BAPV ON FAÇADE OF SINGLE-FAMILY HOUSES (Source: SEC)

The residential area in **Amersfoort** is a unique European project regarding not only grid-connected solar panels, but various architectural solar panels also and natural illumination applications, in daylight, with a southerly orientation.

FIGURE 80.
RESIDENTIAL AREA AMERSFOORT. BIPV ON ROOFS OF SINGLE FAMILY HOUSES (Source: SEC)

FIGURE 81.
RESIDENTIAL AREA AMERSFOORT, BIPV ON ROOFS OF KINDERGARTEN (Source: SEC)

FIGURE 82.
RESIDENTIAL AREA AMERSFOORT, BIPV ON ROOFS OF CAR AND CYCLE PARKS (Source: SEC)

The above examples show that PV modules will very soon form an integral part of the urban landscape. They may be found on roofs, façades, shadings devices, shelters on bus stops and car parks, etc.

PV systems are also very important for remote areas and locations where it is not possible to ensure a grid connection.

Interesting examples are the floating islands on the Lake Titicaca, Peru. The PV modules are the only possible source of electricity. They can secure enough energy for computers (even in the school), TV and some other small consumer devices.

FIGURE 83.
PV MODULES ON THE FLOATING ISLANDS OF LAKE TITICACA (Source: SEC)

3.7. Exercises

3.7.1. Mounting and building integration options

1. BAPV and BIPV are PV modules installed in buildings exclusively as the principal energy source.
   a) True
   b) False

2. Which is the main difference between BAPV and BIPV?
   a) BAPV can be installed only on roofs, while BIPV can be installed on roofs, façades, shelters and others
   b) BAPV are used only as additional energy source, while BIPV are used both as additional and principal energy source
   c) BAPV are fixed over the existing elements of building's envelope, while BIPV are photovoltaic materials used instead of conventional building materials

3. Where can BIPV and BAPV be installed?
   a) Only in dwellings
   b) In all type of buildings and in urban structures as bus shelters
   c) Only in industrial and dwelling buildings

4. Building integration (BIPV) means that:
   a) The modules serve an energy and architectural purpose and also substitute certain elements of the building construction
   b) The modules serve an aesthetic and architectural purpose and also substitute certain elements of the building construction
   c) The modules serve an energy and architectural purpose, but do not substitute any of the elements of the building construction.

5. There are three key components of a grid-connected system. Choose the right ones.
   a) The façade of the building
   b) The PV modules
   c) The inverter
   d) The roof
   e) The current meter
   f) The public grid
   g) The Windows

3.7.2. BIPV and BAPV on roofs

1. Which parameters should be taken into account when installing PV modules on flat roofs? Choose the three correct aspects from the list below.
   a) The structure of the roof
   b) The thickness of the thermal insulation
   c) The orientation of the building
   d) The type of modules
   e) Roof elements such as chimneys, skylights, etc.

2. What should be checked, according to the building regulations, when PV modules are installed on existing buildings?
   a) The covering material of the roof
   b) The load bearing capacity of the structure
   c) The insulation materials

3. We should take care of the water-proofing membrane of the roof when installing PV modules.
   a) True
   b) False

4. BAPV are more suitable for:
   a) Installation on existing buildings
   b) Installation on new buildings
   c) Installation on flat roofs

5. Explain how the over-heating of PV modules on pitched roofs could be avoided?
   a) Covering the whole roof
   b) Using PV tiles
   c) Ensuring 5-10cm between the PV element and the roof covering

3.7.3. BIPV and BAPV on façades

1. PV modules can be fully integrated and cover the entire façade?
   a) True
   b) False

2. PV modules can be fixed to balconies.
   a) True
   b) False

3. PV modules can be fixed as an additional glass façade.
   a) True
   b) False

4. We should ensure air tightness between the joints of BAPV on façades.
   a) True
   b) False

5. BAPV on façades are easier for maintenance.
   a) True
   b) False

6. BAPV may act as an additional thermal insulation of façades.
   a) True
   b) False

7. It is easier to ensure cooling of BAPV than of BIPV.
   a) True
   b) False

8. BIPV provide better opportunities for aesthetic architectural solutions.
   a) True
   b) False

9. What is the difference between a cold and warm façade?
   a) Warm façades face the south while cold façades face the north.
   b) Warm façades have additional thermal insulation, which is thicker than on the cold façades
   c) Warm façades are façades where the PV modules are integrated in the structure of the façade, while cold façades are façades where PV modules are an additional element, like a second “skin” of the building

10. We should take the weather into account such as wind and hailstorms when fixing the modules on the façades.
   a) True
   b) False

11. We should ensure air and water tightness of joints between the modules of BIPV.
   a) True
   b) False

12. The installation of modules on a ground-floor façade is highly recommendable.
   a) True
   b) False

3.7.4. Glass roofs, shading systems and other applications

1. A glass roof of PV modules reduces the heat load and creates more comfortable conditions within the building.
   a) True
   b) False

2. Is the installation of PV modules possible on shading devices
    a) Yes, but it is not recommended
    b) Yes, they are very appropriate
    c) No

3. We can combine PV and solar thermal functions.
    a) True
    b) False

4. PV modules can be integrated in sound barriers, street lights, information displays.
    a) True
    b) False

3.7.5. Design parameters and performance factors

1. Name 3 factors which may affect the efficiency of a PV system?
    a) The amount of solar radiance on the site
    b) The type of building
    c) The orientation and tilt of the modules
    d) The grid connection
    e) The behaviour of the occupants of the building
    f) The quality of the modules and inverter

2. In the following table, rate the tilt and orientation of PV modules from 1 to 4 (1 – the best orientation and tilt, 4- the worst).

Tilt / Orientation	0^o	30^o	60^o	90^o
East	1	2	3	4
South-east	2	1	3	4
South	2	1	3	4
South-west	2	1	3	4
West	1	2	3	4

3. We should take into account future erection of new buildings around a building where PV are to be installed.
    a) True
    b) False

4. When planning to install a BIPV/BAPV, we should take into account satellite receivers and sky lights on the roof.
   a) True
   b) False

5. We could avoid problems with shading through dummy modules and by-passes.
   a) True
   b) False

6. Name 4 parameters which should be taken into account during the planning stage:
   a) The accessibility of the roof
   b) The accessibility of the façade
   c) The load-bearing capacity of the structure of the building
   d) The number of open spaces of the building (windows etc.)
   e) The traffic
   f) The load from snow, wind, ice and hail

7. Which is the appropriate tilt angle for PV modules in regions with heavy snowfall?
   a) At least 30^o
   b) At least 45^o
   c) At least 60^o

8. The installer should avoid stepping on the module.
   a) True
   b) False

9. The installation of a PV installation cabling should be waterproof.
   a) True
   b) False

INSTALLATION – SITEWORK 4

4. INSTALLATION – SITEWORK

4.1. Working safely with PV

The installer of a PV system is not only responsible for the health and safety of on-site workers, but also for the health and safety of customers and anyone else who might be affected by the work. The installer is also responsible for the long-term safety of the PV systems that are installed. Hence, it is the responsibility of the installer to identify all risks associated with the PV installation and to take appropriate steps to monitor and minimise these risks and to keep them as low as possible.

Every installation is different, so this handbook will never be able to provide a fully comprehensive and definitive list of safe working practices and system design processes that the installer should apply to all installations. However, this section does provide information on potential hazards associated with the installation and operation of PV systems that may be considered when preparing method statements and risk assessments for the installation of PV systems. (OSHA, 2011)

4.1.1. Safe Working Practices

The European Council Framework Directive 89/391/EEC of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work and legislation to implement it in the Member States contains a hierarchy of control measures to be followed:

1. Are risks preventable or avoidable? Is it possible to get rid of the risk? This can be done, for instance, by:
   - Considering whether the task or job is necessary.
   - Remove the hazard, using different substances or work processes.
2. If risks are not avoidable or preventable, how can risks be reduced to a level at which the health and safety of those exposed is not compromised. The following additional general principles for prevention should be followed:
   - Combating the risk at source.
   - Adapting to technical progress.
   - Substituting the dangerous by the non-dangerous or the less dangerous (replacing the machine or material or other feature that introduce the hazard with an alternative).
   - Developing a coherent overall prevention policy which covers technology, organization of work, working conditions, social relationships and the influence of factors related to the working environment.
   - Giving collective protective measures priority over individual protective measures (e.g. controlling exposure to fumes through local exhaust ventilation rather than personal respirators).
   - Giving appropriate instruction to workers (OSHA, 2011)

4.1.2. Potential hazards

The installation of PV systems presents a combination of hazards which the installer is unlikely to have encountered during previous building work. These include manual handling, working at height and the risk of electric shock.

European and national requirements for safe working practices in the workplace are widely available. (e.g. http://osha.europa.eu and www.hse.gov.uk), so not all of them are included here. However, there are many PV specific hazards that should be considered when preparing a method statement and risk assessment for the installation of a PV system; examples of which are presented below.

Please note that due to the continuously changing nature of PV installations the following information is not a definitive list, it has no legal standing and no liability is accepted for its use.

When preparing method statements and risk assessments consideration should be given to the equipment required to ensure the safety of the installer (i.e. personal protection equipment) and the safe operation of the installed system (i.e. measurement and testing equipment).

The importance of risk assessment

Prior to the implementation of good practice information in the workplace, it is highly important that a suitable and acceptable assessment of hazards and risks in the workplace should be conducted. This assessment should consider all the risks and hazards in the workplace to ensure that there is a real reduction in the exposure of workers and others to harm rather than merely replacing one risk with another.

The following is a simple description of a risk assessment. "A risk assessment is nothing more than a careful examination of what, in your work, could cause harm to people, so that consideration is given to whether sufficient precautions are in place or whether more should be done to prevent harm. The aim is to make sure that no one gets hurt or becomes ill. A risk assessment involves identifying the hazards present in any undertaking (whether arising from work activities or from other factors, e.g. the layout of the premises) and then evaluating the extent of the risks involved, taking into account existing precautions. The results of a suitable and sufficient risk assessment should help users choose which good practice measures are the most appropriate."

A risk assessment should always be carried out before good practice is applied in the workplace. It has to be adapted to individual circumstances and needs. More information on risk assessment can be found at OSHA riskassessment, 2011

4.1.3. Safety with electrical installations

4.1.3.1. Working with electrical circuits

Preventing electrocution and electric shock by working on de-energized circuits is an essential safety measure.

The following are some items to consider when working on electric circuits.

- Always de-energize circuits before beginning work on them.
- A de-energized circuit will not give an electric shock. Unfortunately, many electric accidents have been caused by assumed 'dead' circuits. Working safely on circuits includes testing them for hazardous energy prior to working on them.
- Use a meter or circuit test device such as a current clamp to ensure the circuit is dead prior to working on it.
- Implement circuit lock and tag out rules
- Lock out the power on systems that are capable of being locked out. Remember that the lock out tag is not for the person that the installer is aware of and that knows the installer is working on the electrical circuit – it is for the person the installer does not know and who does not know that the installer is working on the circuit. All affected persons should be notified.

- Tag out all circuits that require work at points where that equipment or circuit can be energized (OSEIA,2011).

4.1.3.2. Working with solar electric systems

Electricians are familiar with electricity coming from the utility side of the meter. With solar electric systems there are two sources of electricity: the utility and the solar electric system.

Turning off the main breaker does not stop a solar electric system from having the capacity to produce power. Electricians are used to isolating the 'load' from the power source (usually with a breaker or other disconnect switch) and they then proceed to work on that 'safe zero energy load'. With a solar electric system, work is done on the power source itself (the PV panels or associated wiring) – this is fundamentally different from working on a 'safe load' and should be borne in mind. Even low light conditions can create a voltage potential that can lead to a shock or arc-flash. A surprise shock delivered at the wrong time could cause a fall from a roof or ladder.

The following are some issuess to consider when working with solar electric circuits:

1. Follow the procedures listed in the previous section on working with electrical systems.
   - Note that PV inverters may have significant capacitors that could hold a charge after the power source is removed – always follow manufacturer's instructions and check the equipment for specific information on its operation and safety.

2. The only method of 'turning off' a solar array is removing the 'fuel' source – the sun. If needed, cover the array with an opaque cover that blocks sunlight to prevent a solar panel from generating electricity.

3. Small amounts of sunlight can produce a voltage potential and shock or arc-flash hazard
   - Voltages can be present even in very low light conditions. While these voltages may not be enough to operate the inverter, the potential voltages are enough to produce an electric shock that might harm an unsuspecting installer. Surprise shocks may cause direct injuries or cause a fall from a roof or ladder.
   - Prior to working on a string of solar PV panels, which would involve connecting or disconnecting circuits, disrupt the current path by disconnecting the DC disconnect switch. Tag and lock out the circuit using standard procedures discussed in the previous section.

4. Grid tied solar systems have two energy sources to consider
   - Shutting off the main circuit. Breaker does not affect the potential output of a solar PV array – even if the inverter shuts off. It's important to remember that opening (turning off) the main breaker does not shut off the power source from the solar array. Wires from the PV side of the circuit can still have a voltage potential that can deliver significant current even in low light conditions.
   - Disconnect switches can isolate the solar PV array but they do not shut the power off. Remember that if the DC disconnect switch is turned on, the line from the solar PV array may still have voltage potential on it. This is similar to the voltage potential present on the utility side of the line after the main breaker is opened. Treat the wiring coming from the solar PV array with the same caution

as the utility power line. A residential PV array can have up to 600 VDC potential.

5. An electric arc-flash hazard exists while adding or removing a series of solar PV panels

FIGURE 84.
ARC FLASH HAZARD (Source: OSEIA,2011)

- NEVER disconnect PV module connectors or other associated PV wiring under load!
- While adding or removing a series of solar PV panels, if a path for current is completed or if the string is under load, an electrical arc can occur across the wire junction. The bright arc-flash has sufficient energy to cause severe burns. Another hazard is the surprise arc blast that may cause loss of balance and falls from a roof or ladder.

- Always open the DC Disconnect Switch prior to working on a solar PV system.

Use a current clamp to check for hazardous energy prior to working on a PV array (OSHA, 2011).

FIGURE 85.
CURRENT CLAMP (Source: OSEIA,2011)

4.1.3.3. Working with batteries

Working with battery back-up systems can be the most dangerous part of solar electric installations and maintenance. Batteries can be dangerous!

Make sure all employees working with batteries understand the dangers and safety codes relevant to battery systems.

- Refer to manufacturing guidelines for issues pertaining to proper handling, installation, and disposal of batteries.
- Typical batteries are lead acid. Both lead and acid are harmful chemicals. Lead is known to cause reproductive harm and acid can cause severe burns.
- Care should always be taken to prevent arcing at or near battery terminals. Always open the Main DC disconnect switch between the batteries and the inverter prior to servicing or working on the battery bank.
- Battery banks can store voltages with very high current potentials. These higher potentials can create electrical arc hazards. Metal tools and personal jewellry can create arcing on batteries that lead to severe burns and battery explosions. Remove personal jewelry and use only

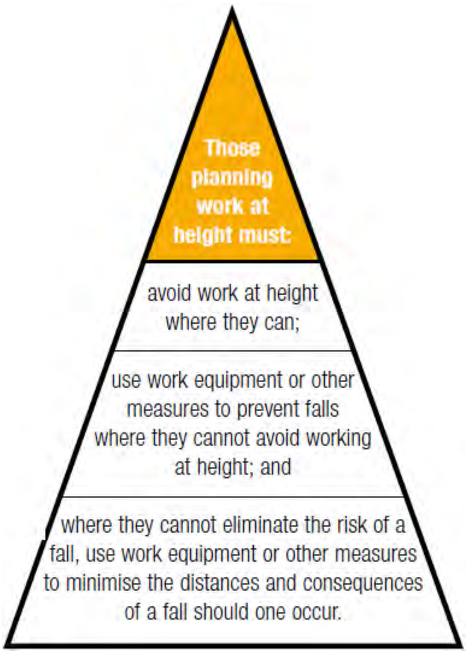
appropriate tools when working on batteries.

- When working on batteries it is recommended that eye protection be worn.
- Dead batteries are considered hazardous and must be properly recycled. (OHSA, 2011)

4.1.4. Security measures for working at height.

A 'risk assessment' has to be prepared when planning work at height. This should supplement the overall health and safety risk assessment.

FIGURE 86.
PLANNING WORK AT HEIGHT (Source: OSHA, 2011)



Do not overcomplicate the process. The risks of working at height are usually well known and most necessary control measures are easy to apply.

The law does not expect the elimination of all risks, but the installer is required to protect people by minimising risk as far as 'reasonably practicable'.

If work at height is inevitable:

- **Use an existing safe place of work to access work at height** – do not cut corners, if a safe means of access already exists, such as a permanent stair and guard-railed platform use it.
- **Provide or use work equipment to prevent falls**, such as scaffolding, mobile access towers or mobile elevating work platforms (MEWPs) which have guardrails around the working platform.
- **Minimize distance and consequences of a fall,** for example by using a properly set up stepladder or ladder within its limitations for low level, short duration work only.

FIGURE 87.
WORK AT HEIGTH in Cristal Tower (Source: Martifer Solar SA.)

4.1.4.1. Mobile Accesses

Mobile tower

The installer must be competent at erecting and dismantling mobile scaffolds, must always read and closely follow the manufacturer's instructions and on no account attempt to use the equipment beyond its limitations.

Commonly referred to as mobile access towers or mobile scaffold towers, these structures are manufactured from prefabricated components where the principal structural materials are aluminium alloys or fibreglass.

Wheels or feet of the tower must be in contact with a firm surface. Outriggers should be deployed as specified by the manufacturer.

FIGURE 88.
OBILE TOWER (Source: OSHA, 2011)

Mobile Elevating Work Platforms (MEWPs)

MEWPS can provide a safe way of working at height, because they:

- Allow the worker to access the task quickly and easily.
- Have guard rails and toe boards which prevent a person falling.
- Can be used in-doors and outside.
- Include cherry pickers, scissor lifts and vehicle-mounted booms.

FIGURE 89.
MOBILE ELEVATING WORK PLATFORM (Source: OSHA, 2011)

Leaning ladder

Ladders should be used for low risk, short duration work.

Ladders can be classified for type of use: for trade and light industrial use; for heavy duty and industrial use; or for domestic use.

Manufacturers must always supply information about the specification of their ladders and provide information such as maximum working load.

People should only use a ladder, step ladder or stability device if they are competent. Users should be trained and instructed to use the equipment safely. (OSHA, 2011)

FIGURE 90.
LEANING LADDER (Source: OHSA, 2011)

4.1.5. Safety equipment

The purpose of Personal Protective Equipment is to protect employees from the risk of injury by creating a barrier against workplace hazards. Personal protective equipment is not a substitute for good engineering or administrative controls or good work practices, but should be used in conjunction with these controls to ensure the safety and health of employees.

Employers should provide and pay for the Personal Protective Equipment (PPE) that is required for the worker to complete the job safely. The employer must also ensure that employees use and maintain PPE in a sanitary and reliable condition. When employees choose not to comply with PPE rules, it usually indicates a failure of the safety management system.

PPE can include the following:

- Eye and face protection (e.g., safety goggles, glasses, face shield, visor).
- Head protection (e.g., hard hats, helmets, hats). Hard hats are required if there is a risk of objects falling onto a person or a risk of hitting your head on an object. For example, if someone is working on the roof at a higher level, a hardhat must be worn at all times.
- Protection of extremities (e.g., steel-toed shoes, other protective footwear, safety gloves, latex gloves, kneepads).
- Respiratory devices (e.g., respirator, dust mask). These are especially important if working around lead paint or asbestos. Masks may be warranted in attic spaces around insulation.
- Hearing protection (e.g., ear plugs, canal caps, ear muffs).
- Protective clothing.

4.1.6. Fire protection

The installation of a PV system on a building may affect fire safety.

- For roof applications, the PV system should be mounted over a fire resistant roof covering that is rated for the application.
- Do not install or use PV modules near hazardous locations with flammable gases.

In case of fire in a building, PV modules on the roof are likely to produce dangerous DC voltage, even in cases of:

- Low light intensity, when modules are disconnected from the inverter.
- Modules being partly or entirely destroyed.
- Wiring being compromised or destroyed.

During and after a fire, stay away from all elements of the PV system, inform the fire brigade about the particular hazards from the PV system. (YINGLI, 2011)

4.1.7. Other risks

- Unlike glazing units for roofing or vertical cladding, PV modules are often manufactured using laminated toughened glass. This means that the glass component will not shatter if damaged and could fall as a single piece.
- The edges of PV modules, particularly where glass edges are exposed, may be sharp.
- Although not sufficient to cause harm during installation or maintenance, some PV products contain cadmium which may present a toxic dust hazard should the product be crushed during disposal.
- PV modules produce electricity when exposed to daylight and cannot be switched off. This means that the installation of PV systems often requires working on live electrical circuits.
- When wiring the system bear in mind safety. PV modules produce d.c. electricity which behaves differently from a.c. electricity. For example a d.c. arc can propagate over an air gap of several mm (depending on voltage) and continue until the voltage is removed or the air gap increased. Such arcing may cause fires and/or significant damage.
- The fault current in PV module wiring is little more that the normal operating current. This often means that fuses and circuit breakers cannot be used to provide protection.
- A PV installation can develop lethal d.c. voltages if inadequately earthed
- PV systems may be described as ‘low voltage’ even if they generate up to 1500V between conductors. 20V d.c. touch voltage is normally considered sufficient to give a risk of shock.
- The risk of shock is greatly increased if a PV module or installation is damaged.
- To maximise efficiency PV modules are generally installed in unsheltered places. Thus cold, wind and rain may present a hazard during installation and maintenance.
- Parts of PV modules may reach high temperatures (ca. 80C) during normal operation.
- The surfaces of PV modules can reflect a significant proportion of incident sunlight which could cause eye damage.

For further information and guidance see Further reading.

4.2. Installation plan

The installation and commissioning phases of the project provide the means to implement good design practices that are discussed in section 2.

However, the use of both high quality components and installation procedures is not just a matter of adherence to regulations. The quality of the system installation has a strong influence on the ongoing performance of the system and in meeting expected system lifetimes and output levels.

Having selected appropriate components for the PV system, it is important that they are installed in accordance with the manufacturer's recommendations, especially in terms of required fixtures, ventilation, operating temperature range and safety aspects. Failure to adhere to the correct operating conditions can lead to poor performance levels, shorter component lifetimes and even failure of the system in some cases.

Attention should be paid to minimising cable lengths and, particularly, to ensuring that all connections are correctly made and protected. Whilst it may not affect the initial performance of the system, a poor connection can become more influential with time and lead to poor performance in the long-term.

Performance losses due to poor connections can be significant but are generally time-consuming to identify and rectify, especially if they are within the array. It is much better to ensure the quality of the connections at the time of installation than to have to address this issue later during system operation. Excess cable should be avoided wherever possible. Where a small excess is necessary (such as when allowing for a system component to be moved for inspection without disconnection), the excess should not be coiled as this will reduce the cable's ability to dissipate heat, and could also lead to inductive voltage spikes being transmitted to the inverter on disconnection of the array or a string.

Whilst perhaps not impacting directly on the initial performance of the system, the quality of the physical installation of the system, particularly the PV array, can influence the long-term performance of the system and its costs. Poor fixing of array components can result in damage to the array during adverse weather conditions, resulting in loss of output and the need to repair or replace part of the array. It can also lead to damage to other parts of the roof, in some cases affecting the weatherproofing.

The commissioning procedure allows a check of system performance at the time of installation. Certain aspects of the commissioning will be discussed in terms of their relation to system performance issues. (DTI, 2006)

During the planning stages of a photovoltaic installation, the provisions, transportation and inventory need to be taken into account. In general, the following questions should be addressed before the installation of a photovoltaic park:

What, How and When (to do the) assigned tasks --> Doing

These questions need to be resolved during the planning stages of assembly, regardless of the size of the installation. In this way, we eliminate unexpected factors, setbacks, improvisations and dangerous situations.

All of the components of an installation come with assembly instructions, risk assesments, etc. from the corresponding manufacturer. Follow these best practices to ensure proper execution of a reliable and secure assembly.

All basic operations included in the assembly process should be clearly defined, with estimated duration and time constraints required for each operation; that is, deadlines for each stage from the exact moment of execution. These tasks should figure inside an established timeline. (Gantt diagram or similar) (ASIF, 2002)

4.2.1. Work Sequences

The sequence of work the installer should follow begins by planning all of the personal and material resources necessary to accomplish the installation properly.

The on-site mounting process consists of the following steps (TKNIKA, 2004):

a) Mounting structures

b) Mounting the photovoltaic field

c) Connecting the photovoltaic modules.

d) Mounting the corresponding distribution board.

e) Layout of tubes and conduit.

f) Connecting components.

g) Running and testing the system

4.2.2. Technical documentation

An authentic project should always include the applicable legislation regarding the installation, taking into consideration all technical as well as environmental aspects. In this sense, there is a great distinction between photovoltaic systems and those which are connected to the power grid, especially since the latter involves a much more extensive legal procedure.

The following action plan should be implemented, when embarking on a project after receiving the appropriate information from the customer and a description of their needs: feasibility study, annual report, blueprints, list of conditions, budget, safety plan, etc. In this way, and with the pertinent information available, the installer will be able to perform the installation in the allotted time for the project and meet the applicable quality standards.

Feasibility Study

Before undertaking the project itself, the designer compiles a Feasibility Study, a document that takes customer needs and the installation type into consideration, which has to:

- Evaluate the energy needs and interests of the user, in order to determine the most appropriate type of installation and its features.
- Determine the potential level of solar power generation of the region where the installation is to take place, in order to quantify the feasibility of the application of solar power. To this end, different means should be used: charts or available statistics, on-site measurements, use of computer systems, etc.
- Formalize and make solar installation proposals official in accordance with the energy needs and interests of the customer.

The finished product will be an economic and technical study of the proposed installation for the customer's consideration. (TKNIKA, 2004)

Report

The objective of the report is to explain the purpose of the project (what will be done) as well as the decision-making process followed and the justification of each choice made, providing details – if possible – of the entire procedure. At the same time, the report indicates how each part of the technical system designed works, etc. In essence, it is a description of every step taken during the design phase of the project.

Depending on the type of project, the outline of the report may vary substantially, but in general, the following phases of a grid-connected photovoltaic solar energy project may serve as a useful guideline:

- Determining the project
- Features of the PV installation
- Calculation of the components of the installation
- Estimation of total electric energy generated annually
- Calculation of approximate annual revenue
- Conclusion of the project
- Addendums

Budget

The budget indicates the economic cost of the execution of the project. This section should include: the detailed cost of the different items of the materials, handwork, transport, leasing of tools or machinery, as well as any other component used to accomplish the project.

It is advisable to make a table indicating at least the following items: Concept, quantity, unit price, and total amount.

List of Conditions

This section will include all of the standards to be met by the materials selected to execute the proposed project, the rules or guidelines the installer must follow for proper execution and completion of the project, and all other administrative conditions that govern the relationship between the foreman or installer and the management or owner of the property: provisional reconsideration, property assessment, liens, form of payment, guarantees, etc.

4.2.3. Technical drawings

This section should include all of the drafts or blueprints necessary for the installer to carry out proper mounting procedures which leave no room for doubt and are clear and precise. Standard formats and symbology should be implemented when elaborating these drafts, to avoid any possible margin of error in their interpretation:

As a guide, some of the basic drafts to include are:

- Site Map
- Views of on-site location
- Floor plans of the project
- One-line Diagram of Electrical Schematic
- Layout of component distribution
- Floor plan of electric power line distribution
- Etc.

As previously mentioned, the number and type of drafts may vary substantially, depending on the project. In any and all cases, such plans or blueprints must be sufficient to assure proper execution of the project and leave no room for doubt. (TKNIKA, 2004)

4.2.4. Tools and Equipment

The tools and equipment at the disposal of the installer are not substantially different from those that any certified electrician should have at their disposal. In any case, all relevant regulations contained in the corresponding legislation of each country should be strictly followed.

All of the necessary components to assemble installations on roofs or building façades as well as the necessary safety equipment must be at available to the installer, who will have received the necessary training in their use.

It is advisable to have access to the tools and machinery necessary for the transfer and lifting of photovoltaic modules and other materials to rooftops, so that these do not constitute an excessive physical load for the installer.

Lastly, the installer should have a compass and inclinometer available for correct positioning of the photovoltaic field. (Tknika, 2004)

4.2.5. Safety Plan

Depending on the scope of the project, the safety plan may be more or less extensive, but it should at the least include:

- List and description of the works to be performed
- List of existing risks and detailed precautions to be taken
- Description of safety rules to follow and list of any safety measures to be taken
- Applicable regulations

This section is very important to ensure the safe execution of the project with sufficient safety guarantees to avoid potential accidents. Therefore, when preparing the plan, its content must be clear and concise so that the installer can easily understand and apply the proper guidelines.

4.3. Electrical components installation

4.3.1. Mitigate electrical hazards

When compiling a method statement and risk assessment for the installation of a PV system, there are a number of PV specific hazards that need to be addressed.

These will be in addition to standard considerations such as PPE (Personal Protective Equipment), working at height, manual handling, handling glass, other applications and construction regulations.

PV modules produce electricity when exposed to daylight and individual modules cannot be switched off. Hence, unlike most other electrical installation work, the electrical installation of a PV system typically involves working on a live system.

PV module string circuits cannot rely on fuse protection as a current limiting device for automatic disconnection of supply under fault conditions, as the short-circuit current is little more than the operating current. Once established, a fault may remain a hazard, perhaps going undetected, for a considerable time.

Good wiring design and installation practice will serve to protect both the system installers and any persons subsequently coming into contact with the system from an electric shock hazard (operator, owner, cleaner, service engineers, etc).

Undetected, fault currents can also develop into a fire hazard. Without fuse protection to clear such faults, protection from this fire hazard can be achieved only by both a good d.c. system design and careful installation.

PV presents a unique combination of hazard –due to risk of shock, falling, and simultaneous manual handling difficulties. All of these hazards are encountered as a matter of course on a building site, but rarely at the same time.

While roofers may be accustomed to minimising risks of falling or injury due to manual handling problems, they may not be used to dealing with the risk of electric shock. Similarly, electricians would be familiar with electric shock hazards but will not be used to handling large objects at heights. (OSHA, 2011)

4.3.2. Install grounding system

Connection of parts of a PV system to earth affects:

- The electric shock risk to people in the vicinity of the installation
- The risk of fire under fault conditions
- Transmission of lightning induced surges
- Electromagnetic interference

Effective earthing is an important safety element of a properly installed PV system. Grounding for PV systems is covered in NEC 690(V). If the maximum system voltage of a PV system is greater than 50V, then one conductor must normally be grounded. A recent provision, Article 690.35 that was introduced in the 2005 NEC, provides details on how to install a compliant ungrounded PV system of any voltage. This new provision is likely to cause some changes in the design of PV systems which are likely also to bring changes in installation methods for these systems. The key issue addressed in the 2008 NEC relating to Article 690.35 is the provision to use “PV Cable” or “PV Wire” to meet the conductor requirements for ungrounded array wiring. Several manufacturers offer module leads with these types of conductors.

Two types of connections to earth need consideration:

1. Earthing of exposed conductive parts (eg. the array frame)
2. System earths – where an array output cable is connected to earth

1) Earthing of exposed conductive parts

The majority of installations will utilise class II modules, class II d.c. cables & connectors and will be connected to the mains via an inverter with an isolation transformer. This approach is recommended and permits the array frame to be left floating.

Notes to terms used in the following diagram:

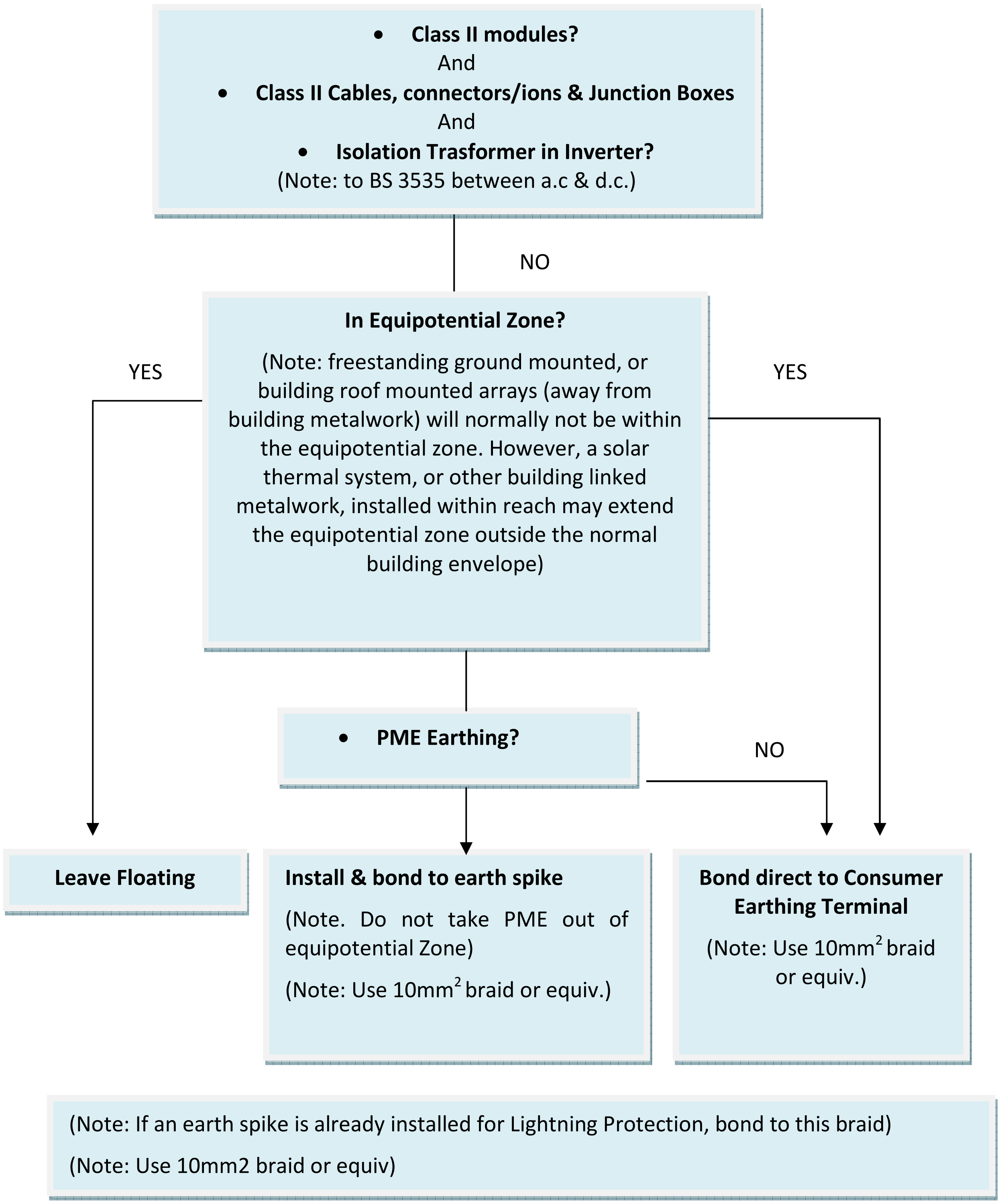
a) Isolating transformer: An isolating transformer is one in which the input and output windings are electrically separated by double or reinforced insulation.

While the hazards presented by an array frame reaching the system d.c. potential may be significant, the potential fault/shock current is typically much less than that from a mains fault. Hence it is the electrical separation of the mains from the d.c. using an isolating transformer that is the key determining factor when assessing the requirement for array frame earthing.

b) ‘Equipotential Zone’: defined as a zone in which exposed-conductive parts and extraneous-conductive parts are maintained at substantially the same potential by bonding. Thus, under fault conditions, the differences in potential between simultaneously accessible exposed and extraneous-conductive parts will not cause electric shock. ‘Extraneous-conductive parts’ are conductive parts liable to introduce a potential, generally earth potential, and not forming part of the electrical installation, such as a water pipe, outside tap, a metal downpipe – anything conductive that is connected to ‘Earth’ but not electrically part of the system.

c) PME: Protective Multiple Earthing – an earthing arrangement whereby the supply neutral and earth are combined into a single conductor. Where the incoming supply is PME, (the majority of domestic supply arrangements) the PME earth cannot be taken outside the equipotential zone. This is to prevent the potential shock hazard should the supply neutral ever be lost.

FIGURE 91.
ARRAY FRAME EARTHING DECISION TREE (Source: BRE et al, 2006).



2) System earthing (D.C. Conductor earthing)

Bonding of any of the current carrying D.C. conductors to earth is not recommended. However as in the note below, earthing of one of the live conductors of the D.C. side is permitted, if there is at least a simple separation between the a.c. side and the D.C. side, including in the inverter.

Note: In some countries it has been the practice to bond one part of the D.C. conductors to earth (eg earth connection at midpoint of PV string or earthed D.C. negative), or for performance reasons on certain types of modules to earth the d.c. positive. Due to the increased possible earth fault paths and possible problems with commonly available European inverter types and internal earth fault detection circuitry, such practice should only be made when unavoidable (any connections with earth on the d.c. side should be electrically connected so as to avoid corrosion) (DTI, 2006).

4.3.3. Conduit

The tubes and conduit used in PV installations must meet the official standards required by the corresponding country depending on the type of installation to be executed: underground or in the open air, in a busy public place or remote locations, exposed to the elements or covered. It should be taken into account that these cable ducts are often exposed to the elements and subjected to extremely high temperatures. (DTI, 2006)

4.3.4. Protections

The protections to be installed in a PV solar energy installation will be different according to the type of installation – stand-alone or grid-connected,. In general, the different types of protection to be installed are:

Class II Protections

The modules used will be certified for use as CLASS II protected equipment with an operating voltage up to 1000V.

All of the wiring used in the DC portion of the installation will be done in keeping with this degree of protection, that is, double insulation.

Protection against indirect contact

In the AC portion of the installation, a differential switch will be installed.

In stand-alone installations with AC consumption, a high-sensitivity differential switch will be installed, with a characteristic discharge of 30mA or 300mA, depending on the type of circuit that is protected and with a response time of 0.2 seconds.

In grid-connected installations, along the electric power line connected to the low-voltage grid, a differential switch with a 300mA discharge will be installed, with a response time of 0.2 seconds. The differential switch to be installed will be automatically resettable, in case of discharge – the device resets itself under suitable conditions.

Protection against overcurrent

In the DC portion of the installation, suitable gG type fuses of the appropriate current will be installed allowing the two poles to connect and to disconnect, positively or negatively. Instead of these fuses, resettable, drawout, and protected fuses of the appropriate current and C curve, which allow for the connection and disconnection of the two poles, may also be used. These components must be prepared for DC use.

In the AC portion

In stand-alone installations thermomagnetic switches will be put in place to protect the different circuits of the installation, as indicated in the Low Voltage Electric Equipment Regulations (LVEER).

In grid-connected installations, at the outlet of the inverter, a thermomagnetic switch of suitable current-voltage and C curve will be installed to allow for its isolation from the rest of the installation as a kind of protection against overcurrent and short-circuits.

At the connecting point, where the photovoltaic installation and the electric power grid are connected, a thermomagnetic switch of suitable current-voltage and C curve will also be installed to allow for proper isolation of the photovoltaic installation from the grid and protection against overcurrent and short circuits.

Class I Protection

Grounding, of the metallic masses through a specific conductor, called landline or PE.

4.3.5. Circuit Conductors

Conductors used in photovoltaic installations, as in any other electrical installation, should be sufficiently spaced to avoid overheating and excessive drops in voltage in different powerlines, as indicated by statutory regulations.

Conductors used in the DC part, will be classified as Class II (double insulation). The installer should use type RZ1 conductors (polyethylene reticulated insulation – XLPE - with a polyolefin covering), running temperatures above or equal to 90°C and strain-voltages of 750/1000V.

In the AC portion, the instructions indicated in the Low Voltage Electric Equipment Regulations (LVEER) should be followed for these types of regulations.

4.4. Equipment Installation

4.4.1. Photovoltaic module

4.4.1.1. Considerations

When choosing a photovoltaic module, that will be used to configure a photovoltaic field, keep the following in mind:

- Type of photoelectric cell.
- Electrical features.
- Physical characteristics.
- Assembly.

Type of Cell (Photoelectric Cell):

Nowadays, different types of cells are available (monocrystalline silicon, poli crystalline silicon, amorphous crystalline, etc.) and various technologies to apply when selecting the module to configure the photovoltaic generator.

Monocrystalline silicon cells have a good performance thanks to their structural precision. The manufacturing process is the same as they use in the electronic industry with a very high degree of purification, which makes their production that much more costly.

Poly crystalline silicon cells are similar to monocrystalline cells, but they contain a higher concentration of impurities, reducing their output, although their cost-output proportion is better than monocrystalline silicon cells.

Nowadays monocrystalline panels may be found that are very cost competitive with polycrystalline silicon cells and polycrystalline modules and that have similar levels of performance. Therefore, the choice of one or the other depends on market conditions.

Electrical Features:

TABLE 21.
ELECTRICAL FEATURES (Source: Tknika, 2004)

Parameters	Description	Units
Isc	Short Circuit Intensity	Amperes
Voc	Open circuit voltage	Volts
Ip– Imax	Peak Intensity of primary input current	Amperes
Vp – Vmax	Maximum of primary output voltage	Volts
Wp – Wmax	Peak Power – Maximum power	Watts

The strain-voltage of stand-alone installations is from 12, 24 or 48 volts. So it is essential to connect these modules in series or parallel in order to obtain optimal voltage and intensity.

In grid-connected installations, the strain-voltage is much greater and depends on the inverter used. In this case, it is important to test the maximum number of modules that may be connected in series, without causing any damage.

Physical Characteristics:

The most important physical characteristics are the dimensions and weight of the solar module that have to be taken into account when calculating the amount of space the photovoltaic field will occupy and when planning transport and assembly (heavy-tonnage vehicles, heavy duty cranes, number of necessary personnel).

4.4.1.2. Assembly:

When assembling the installation, begin with the photovoltaic field, bearing in mind that they cannot be disconnected and when they receive solar radiation they generate emf (electromotive force). So, the necessary precautions for work with high voltage need to be taken. Furthermore, the necessary means of transportation and assembly of the photovoltaic field need to be considered, since this very often includes assembly on rooftops or façades, and due to their weight and dimensions, this can be very complicated.

The two key aspects to take into consideration when mounting the panels are:

- The positioning of the panels.
- Location.
- Joining the panels.

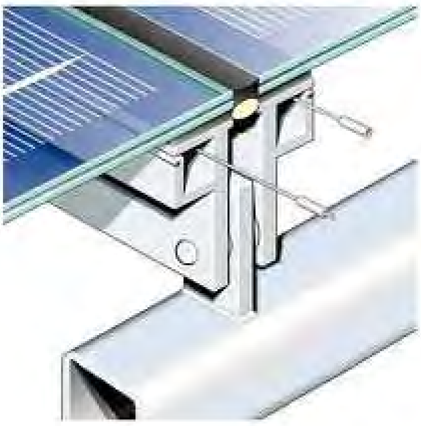
Location

The weather conditions of any given locale are normally quite variable, and the proper functioning of the PV module will vary accordingly. Steps must therefore be taken to ensure that the maximum amount of irradiance falls upon the module, and that the temperature, at each and every moment, is kept to a minimum. This is made possible by the optimal choice of angle, direction and assembly of the photovoltaic modules, ensuring that they are exposed to the maximum amount of sunlight throughout most of the day.

Positioning the PV Modules

Under normal conditions, the anchoring of the modules to the structure takes place in two stages: connecting them in series and in parallel, and the actual mounting of the structure. The modules are normally connected in angular metallic cross-sections, in U-shape or squares, which are screwed together, forming an integral panel structure.

FIGURE 92.
UNION OF PHOTOVOLTAIC MODULES (Source: Flickr, 2011)



Joining panels involves contact between two different metals (aluminum in the module and steel in the cross-section), entailing a real risk of appearance of galvanic corrosion. Insulation such as nylon or non-stick washers must be therefore used, which prevents contact between the two metals.

Only the modular holes of the panel that is specifically designed by the manufacturer should be used. This helps ensure proper dismantlement of the frame surface and avoid irreparable damages to the panel (such as glass breakage).

Placing the panels together in formation should be done in such a way as to prevent any deterioration, such as leaning modules against the package wrapping and placing them on a work bench or similar structure.

Once the panels are in proper formation, they are now ready to be positioned inside the structure. This operation must be carried out by a number of operators and using the appropriate mechanical apparatus such as cranes, pulleys, etc., especially when the structure is located at a considerable height from the ground.

The cross-sections used to place the panels in proper formation are also used to anchor them to the structure.

FIGURE 93.
ATTACHING PV MODULES TO THE STRUCTURE. (Source: EKILOR)

Connecting PV Modules

Once the panels have been properly placed in formation, we are ready to join them appropriately.

The main objective is to prepare the electrical components of the PV Park; that is, to prepare the main terminals, positive and negative, which define the main circuit of the PV generator. These terminals are characterised by specific voltage and intensity parameters during the design stage.

To prevent potential mistakes in joining panels, especially when dealing with PV layers in series or in parallel configuration or regulation, the use of technical drawings or outlines that take into account the position and wiring of modules, are highly recommended.

The wiring between modules should be done through the existing connections of each module fuse box. The most common wiring is non-metallic, hose-like flexible tubing. These must be perfectly adjusted to the fuse boxes.

Normally for PV parks with a considerable number of modules, modular junction boxes are used for in-series connections between panels. (ASIF, 2002)

Parallel Circuits

Several (one or more) modules must connected in parallel circuits, to obtain more intensity than a single module. (See section 2.2.1)

All of these circuits must have equivalent characteristics. For this reason, each one is selected, one by one, according to their tolerance.

The intensity of the sum of the panels in parallel circuits is equal to the sum of every panel. So the circuit conductors will increase their capacity in proportion to the number of panels that are connected.

Series Circuits

Several (two or more) modules need to be connected in series to obtain the maximum voltages for each module. It is extremely important that every module possesses the same voltage - current characteristics. For this purpose, each one is selected, one by one, according to their tolerance. The intensity of all panels in series, as a whole, will be the same as each individual panel. Each one will therefore have the same cross-section. (Tknika, 2004) (See section 2.2.1)

Mixed Connections

In this case, the desired voltage is achieved by **associating several modules in series (ms)**. This structure forms a **branch connector** of the generator. (See section 2.2.1)

The desired intensity is obtained by associating a specific number of **branch connectors in parallel (Bn).**

In installations of defined power levels, the maximum number of modules should be positioned in series to avoid sections of large wiring; as long as the operating voltage of the connected modules permits this type of wiring.

When having to connect many branch connectors in parallel, the wires for each of them should be run to a central fuse box, and all of them connected in parallel. In this way, the section containing the conductors will always be the same for every installation. This fuse box normally contains the circuit breakers, voltage loaders, the fuses and other specific components of the design.

The use of this central control fuse box greatly facilitates maintenance and measurements, making it easy to access and locate the terminals of the different circuit generators (rows of modules connected in parallel).

4.4.2. Inverter

4.4.2.1. Considerations

There are different classifications for inverters. Some depend on the location in the Photovoltaic system (see section 2.2.2) and others depend on the type of installation: stand-alone inverters and grid-connected inverters. Each one has different parameters.

<u>Stand Alone Inverter</u>

Type of Output Wave:

The form of output wave of a stand-alone inverter may be: squared, modified sine or pure sine. Either one may be used, depending on the type of receiver that is connected. In any case, today we can find pure sine wave inverters (which have the best features) and almost at the same price than others in its class, which is why they are highly recommended.

Strain-Voltage:

Input voltage is usually 12, 24 or 48 DCV, which will be determined by the voltage of the installation, while the output voltage will be 230ACV.

Power:

This value indicates the power of the receivers that we are able to connect to the inverter.

Physical Characteristics:

It is a good idea to know the dimensions and weight of the inverter, in order to size up the cabinet where it will be installed.

Grid-connected inverters

Type of output wave:

These devices that are connected to the public grid should send a signal to the network that is identical in voltage, frequency and interval to the tolerances allowed under local regulations.

Strain-Voltage:

This indicates the input and output voltage of the inverter. In this case, it is important to know the maximum admissible DC input voltage, since this data will determine the number of modules that may be connected in series to the port of the inverter. The output voltage will be a sine wave of the same frequency of the grid and a voltage of 230 ACV in single-phased systems and 400 ACV in tri-phased systems.

Physical characteristics:

It is advisable to know the dimensions and weight of the inverter in order to carefuly plan out its positioning and needs for transport and assembly ahead of time. Neither should we forget the fact that high power inverters weigh a considerable amount.

Insulation / Protection:

These types of inverters should incorporate a series of protections against:

- Electric grid power failure.
- Grid voltage out of range.
- Grid frequency above strain limits.
- Overheating of the inverter.
- Low voltage of photovoltaic generator.
- Insufficient intensity of photovoltaic generator.

Besides, the most modern inverters come with the monitoring function of the Maximum (peak) Power Point Traking (MPPT) incorporated, so they adapt to the levels of voltage and intensity of the PV generator to obtain the maximum power supply possible for any level of radiation.

4.4.2.2. Assembly:

When assembling inverters, we should remember that on many occasions these devices are left exposed to the elements, so they should have the corresponding IP.

Location

The inverter should be positioned in an enclosed space, sheltered from the outside weather. In any case, they can always be placed inside a watertight box for outdoor use.

Besides stand alone inverters should be installed in places that are as close as possible to the storage batteries, especially since this section suffers the most considerable loss of voltage. In any case, at all times maintain the minimum separation prescribed in safety regulations, so they are unaffected by fumes from the storage batteries.

FIGURE 94.
SOLAR INVERTER. (Source: Saecsa energia solar, 2011)

Placement

Normally all necessary elements to position the inverter on a vertical surface are included (screws, pliers, etc.).

The inverter usually comes with the appropriate holes and anchors. The installation should never be modified or altered, always respecting the indications and recommendations provided by the manufacturer (i.e. regarding the necessary ventilation of the inverter).

Connection

This is a simple operation since the manufacturer supplies all of the relevant instructions to complete the connection operation without any problems.

An inverter usually has two entry terminals to connect the battery, the current / voltage regulator or the PV park (according to the type of inverter), and two or three alternate current exit terminals (phase, neutral and ground) for the closed circuit in alternating current or external grid (according to the type of inverter).

The type of available terminals in low power inverters is quite diverse (type of outlet, for example.) Nevertheless, inverters of medium to high power are normally equipped with screwed terminals. The instructions of the inverter clearly indicate each terminal with easy to understand symbols.

The connection terminals of the inverter are not normally accesible, but rather duly protected since the voltages are out of personal safety range, at entry as well as exit position. (ASIF, 2002)

4.4.3. Storage Battery System

4.4.3.1. Considerations

The most important features when selecting a battery are:

- Applied technology
- Type.
- Capacity.
- Physical characteristics.

Applied technology:

The batteries employed in photovoltaic solar energy installations are considered stationary, three different types of technology may be used within this category: lead-acid, gel or nickel-cadmium.

Lead acid batteries are the ones that are most commonly used for their value for money, although they have the disadvantage of requiring maintenance to avoid electrolyte evaporation, provoking the deterioration of the battery.

Gel batteries have similar characteristics to lead acid ones, but due to the type of electrolyte employed, they require no maintenance. For this reason, their use is becoming more and more popular.

Nickel-cadmium batteries present the best characteristics and performance and need no maintenance. The only disadvantage is that they are much more expensive than the gel batteries mentioned previously, so their use is restricted to highly vulnerable services where full-service is key (telephone installations, security systems, etc.) (Tknika, 2004)

Type

There are two types of lead–acid batteries: mono block and 2-volt cell batteries.

Mono block batteries have 12-volt strain voltages and are quite compact. They are used when the required storage capacity is not very high.

When the storage capacity is much higher (more than 1000 Ah), two-volt cell batteries should be used either in series or in parallel to accomodate the necessary storage. There are a number of different storage batteries on the market with different storage capacity. (Tknika, 2004)

Capacity:

The battery capacity (C) is the amount of electricity that can be obtained during a complete discharge or battery. The capacity of a battery is measured in Amp-hour (Ah) for a given discharge time. The capacity of the storage battery is defined by the energy needs of the installation, which will have already been calculated during the design phase of the project. When the exact capacity of battery can not be found, a battery must be selected the storage capacity of which exceeds the required level. As mentioned in the previous section, 2V storage batteries should always be selected for long-term storage capacity. Pay close attention at all times to the C rate of the chosen battery; i.e. C10, C20, C100, etc. As is known, this parameter indicates the discharge rate for the particular capacity that is required. This parameter is also used to compare batteries.

The use of C20 or C100 batteries is recommended for photovoltaic solar energy installations, as they have the most accurate discharge times for proper functioning of the battery. (Tknika, 2004)

Physical Characteristics

The most important physical characteristics to keep in mind are: the dimensions and the weight.

Weight is an important variable, because it determines the necessary means of transportation and assembly. Remember that battery cells with a large storage capacity can weigh a considerable amount.

4.4.3.2. Assembly:

Certain accessories are also needed for installation of the batteries. Batteries are often mounted on an insulating work surface, in case of electrolyte ground spillage and to prevent exposure of the batteries to ground humidity.

Moreover, terminals must be placed in such a way as to isolate contact and avoid potential corrosion and connecting hoses must be placed in the appropriate section for appropriate battery connections. These connecting hoses are usually provided with the batteries. In any case, they can easily done by installers, using the appropriate section.

The transfer of the batteries to the assembly site should be done by first transporting the empty batteries and then proceeding to fill them up in the actual place of assembly. When assembling, connecting and handling the batteries, use the necessary Proper Individual Protection (EIP) elements, especially because of the presence of toxic and corrosive substances.

When connecting a number of batteries in parallel to increase storage capacity, a maximum number of two branches in parallel will be placed in a cross-section.

The necessary accumulation of electricity produced by panels - if they are not grid-connected, can be elevated, requiring an inordinate number of storage batteries. This means the process of mounting panels may be laborious and last for longer than just one extra workday.

The three main points to consider when mounting the storage batteries are their location, positioning and connection.

Location

The batteries should always be located in an enclosed area, protected from the elements and not exposed to any direct radiation from the sun.

When the liquid electrolyte is not sealed in the storage batteries, the storage battery room must be properly ventilated (by artificial or natural means) because the gases emitted during the charging phase are extremely dangerous. Besides, the room should also be free of any potential elements that might cause flames or sparks.

Depending on the number of storage batteries necessary, the installation of a shed specifically for this purpose may be required, complete with a series of work surfaces that allow for proper stability. This also protects against any possible humidity, corrosion or acid which they may absorb in case of electrolyte spillage.

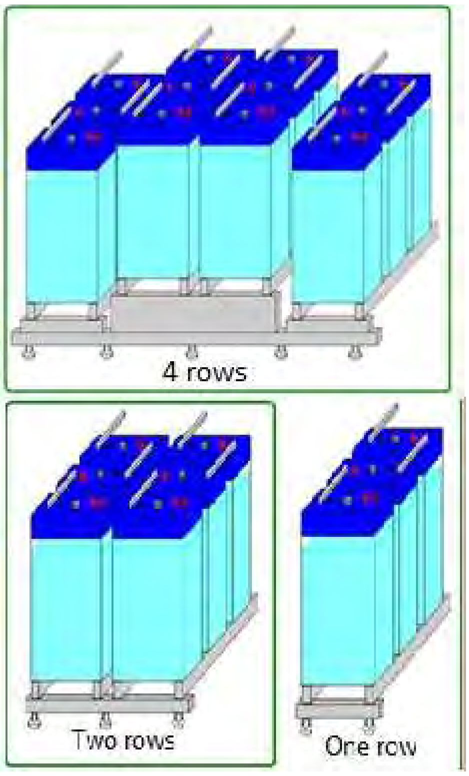
Placement

The following general guidelines should be strictly followed:

- Batteries should be emptied before any type of transport.
- When filling batteries with electrolytes, the proper safety protection should be used, such as masks, gloves, appropriate attire, etc. especially since the electrolytes contain toxic and corrosive acid.
- The worksurface must be completely level.
- Ensure that the disposition of storage batteries is equal to the specifications included in the original design.
- When handling storage batteries, proper mechanical means, suitable in weight, must be used because the batteries themselves may surpass 100 kg. in weight.
- Terminals should never serve for anchoring purchases.

  In case an inordinate number of batteries are required, they should be grouped in batches, leaving enough space between them to allow for proper maintenance and handling.

FIGURE 95.
DIFFERENT AVAILABILITY OPTIONS. (Source: Tknika, 2004)



Connections

It is essential that each batterie have the same exact electrical features. For this the same manufacturer and model must be selected. With the exception of substituting a defective battery, new batteries should never be mixed with other older batteries.

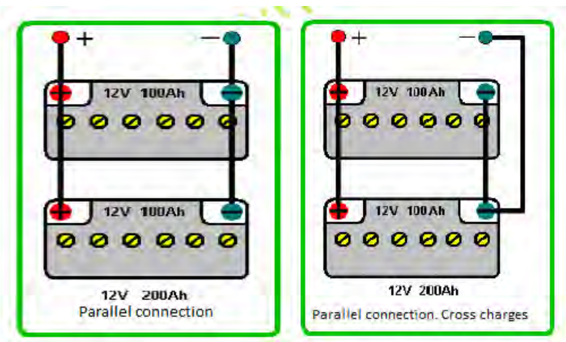
There are two major groups of batteries regarding to terminals:

1. Those that are equipped with terminals compatible with standard connections; much more connection’s flexibility,
2. Those that incorporate their own connections, especially designed for these types of batteries. It’ more rigid, as connection elements are predefined and unique (irreplaceable). However, they offer more reliability and are easier to assemble as manufacturer itself provides a practical solution for connections. (ASIF, 2002)

Parallel Connections

Use the cross parallel mode to connect several (at least two) batteries in parallel. This type of connection facilitates homogeneous discharge for both. It is recommended not to connect more than two parallel accumulators as if one of the batteries suffers a short circuit, the other(s) are also in short circuit and they will completely discharge , even provoking an irreversible deterioration in each one of the batteries.

FIGURE 96.
PARALLEL AND CROSSED PARALLEL CONNECTIONS. (Source:Tknika)



Serial Connections

A PV installation that has to function at 24 volts needs 2 storage batteries connected in series, connecting 12 two-volt cells, in series.

A PV installation that has to operate at 48 volts needs 4 storage batteries connected in series, connecting 24 2-volt cells in series. (Tknika, 2004)

FIGURE 97.
48 V. 100 Ah. SERIES CONNECTION. 4 BATTERIES. (Source: Tknika, 2004)

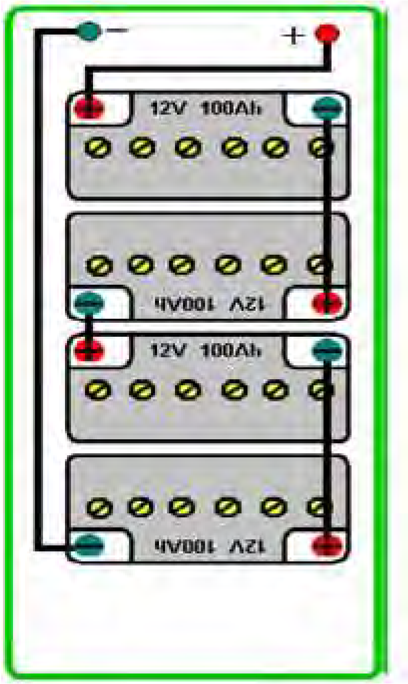
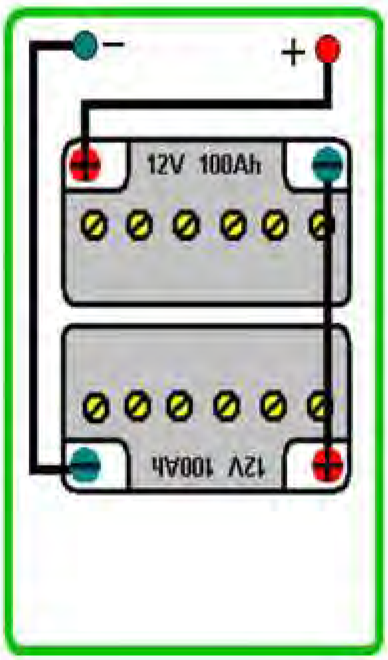


FIGURE 98.
24 V. 100 Ah. SERIAL CONNECTION. 2 BATTERIES. (Source:Tknika)



<u>Serial and Parallel Connections</u>

In this case the desired voltage is obtained by associating several storage batteries in series.

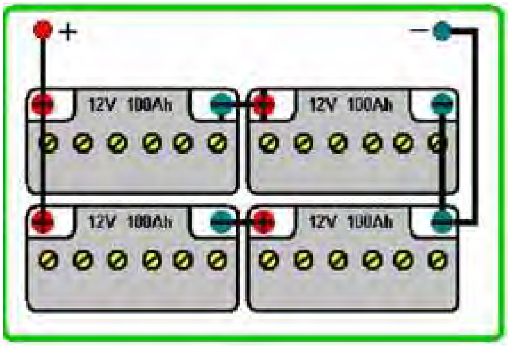
This structure forms a branch storage battery system. The desired capacity will be obtained by associating a specific number of branch connectors composed of storage batteries in series, in parallel.

Crossed-connections should always be used.

A PV installation that should function at 24 volts needs 2 storage batteries connected in series, connecting 12 two-volt cells in series.

A PV installatioin that should operate at 48 volts, needs 4 storage batteries connected in series, or joins 24 2-volt cells in series.

FIGURE 99.
4V. 200Ah. MIXED CONNECTION. 2 GROUPS OF 2 SERIAL BATTERIES PARALLEL CONNECTED. (Source: Tknika)



<u>Serial connection with 2 volt cells</u>

As the storage battery connection in series is less problematic than the connection in parallel, 2 V cells should be used when significant capacity is needed. These should cover the total capacity that is needed, connected in series, until the desired voltage is obtained.

For example: In a PV installation which functions at 12 volts and requires a capacity of 2,000 Ah, we need to connect 6 two-volt cells in series, each with an individual capacity of 2Ah.

4.4.4. Current/Voltage Regulator

4.4.4.1. Considerations

The most important features of a regulator are:

- Type of Regulation.
- Electrical features.
- Physical characteristics.

Type of Regulation

Regulators may be connected in series or parallel, may function in two or three stages and may or may not have maximum power detection.

Today, thanks to new advances in electronic systems, we can find a number of regulators with a great number of features at competitive prices.

Regulators in parallel are recommended for low-consumption installations, while regulators in series may be used in low or high consumption installations due to the type of regulation employed.

Electrical Features

The following electrical features should be taken into consideration:

- Strain-voltage: usually 12, 24 or 48V. There are also bi-voltage models.
- Maximum intensity: The maximum current to be regulated.
- Consumption: The actual consumption of the regulator itself.
- Maximum Short Circuit Intensity: The maximum current supported in case of short circuit.

Physical Characteristics

The most important physical characteristics are: dimensions, weight, and insulation index.

Dimensions and weight of the regulator should be taken into account when measuring up the cabinet where the regulator will be installed.

The insulation index will indicate whether the regulator may be left exposed to the elements. Generally speaking, regulators are installed in a cabinet that will be as close as possible to the batteries to avoid sudden drops in voltage, but in such way that it is not affected by battery vapours.

4.4.4.2. Assembly

Regulator assembly does not require any special attention, but as with any piece of electronic equipment, all necessary precautions should be taken. In many cases, it is advisable to use the necessary protection against electric overload. Furthermore, special care is needed while grounding or earthing the equipment and assembling it in the absence of any voltage or tension.

Location

Suitable siting of the installation should comply with the following requirements:

- Maximum atmospheric temperature must be less than 45ºC and in a well-ventilated area;
- without any leakage or similar drawbacks; and protected from the elements.
- The ideal location will be close to the storage batteries (especially since this is where the voltage drop is greater), but without any gas emissions.

FIGURE 100.
LOCATION OF THE CURRENT / VOLTAGE REGULATOR IN A PHOTOVOLTAIC INSTALLATION. (Source: Tknika,2004)

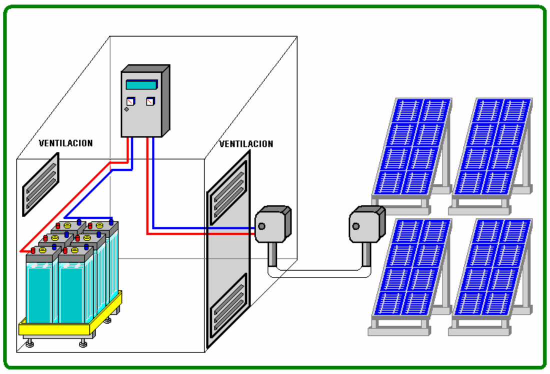
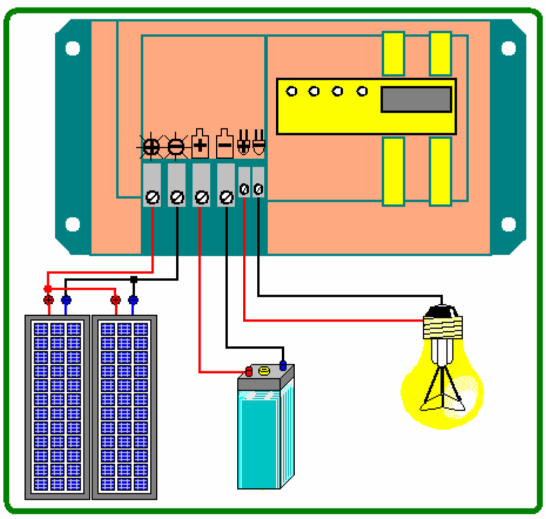


FIGURE 101.
SOLAR REGULATOR. (Source: Solostocks, 2011)

FIGURE 102.
ETAILS OF PV REGULATOR CONNECTIONS. (Source:Tknika)



Positioning

The manufacturer will have already considered the question of positioning. Fastening takes place directly over a vertical face. The most common method of anchoring consists in fixing the structure with a series of screws and hooks. The current / voltage regulator normally comes equipped with the necessary holes for anchoring. Therefore, there is no need for the installer to make any physical alterations (holes, etc.)

Proper ventilation of the apparatus is an extremely important point. (ASIF, 2002)

Connections

The current / voltage regulator is equipped with a terminal strip, located at the bottom which is duly indicated with symbols for each line. The three different lines for the Panel, Battery and Metre may be identified, respectively, together with the polarity indicated in each case.

Before proceeding to make any connections, it is important to verify the polarity and correct positioning of each line, otherwise there will always be the danger of making an erroneous connection that may result in short circuits.

<u>Connection Procedure for Current / Voltage Regulator</u>

When connecting the regulator, the following sequence must be strictly followed:

1. Connect the storage battery to the terminals of the regulator, designated with the battery symbol. This way, the regulator already receives the preferred voltage to feed into its circuit.
2. Connect the PV generator field to the terminals of the regulator labelled module.
3. Connect the load to the terminals of the regulator as indicated, respecting the polarity.

All of the equipment may suffer irreparable damage, if this order is not strictly followed with certain regulator models, especially those that function in series.

In order to disconnect the regulator inside an installation in operation, follow the inverse procedure. That is:

1. Disconnect the terminals from the loads.
2. Disconnect the terminals from the PV generator field.
3. Disconnect the terminals from the battery, thus eliminating electric feed.

Wire Gauges to Employ

The wire gauge is important to avoid possible the voltage drops that may result in a system malfunction.

As a guideline, a voltage drop above 3% of the nominal voltage under conditions of maximum intensity should not be permitted, except in the wiring from the regulator to the batteries, which will be in the order of 1 %.

$$\text{Wire Gauge} = 2 \times L \times I_{max}/56 \times C$$

L is the longitude of the wiring used (metres)

I_{max} Maximum Intensity (A).

C maximum allowable voltage (V).

NOTE:

"Some regulators have negatively charged components inside the electronic circuit, which means they should not be used in installations in which the negatively charged conductor of the installation may be grounded."

4.5. Mechanical Components Installation

4.5.1. Adapting the Mechanical Design

Once the PV system components have been selected, the installer must decide how best to install the parts, so that the system will be safe, will perform as intended, and will look aesthetically pleasing.

If the chosen design calls for installation on a sloped roof, the mounts need to be fastened solidly to the roof trusses or rafters—not to the roof decking. Depending upon the type of roof, the mounts need to be attached in a manner that will ensure that the roof will not leak at the roof penetrations. Other methods may be allowed with engineered systems that have been certified by an accredited organization.

Manufacturers of commercially available roof mounting systems provide instructions for attachment to many types of roofs. Ensure that the module edges are not chipped or cracked, when handling and mounting the modules. Small chips or nicks in the glass result in high stress points where cracks can begin with the expansion/contraction associated with temperature. Torque values given for compression-types of PV mounts must be followed.

PV Module layout is important for aesthetics and to assist in cooling the modules. A landscape (horizontal) layout may have a slight benefit over a portrait (vertical) layout when considering the passive cooling of the modules. Landscape is when the dimension parallel to the eaves is longer than the dimension perpendicular to the eaves. In the landscape layout, air spends less time under the module before escaping and provides more uniform cooling. Modules operate cooler when they are mounted at least 3 inches above the roof.

A number of pre-engineered standoff mounts are available commercially. When installed properly, engineers or test laboratories certify these mounts to be capable of withstanding specified wind loads. If commercial mounts are not used, verification is necessary.

4.5.2. Structure Support

There are different types of structures in the market which vary according to type of installation: on ground, façades or rooftops.

These structures should be rust-proof and maintenance-free, such as anodized aluminum or treated steel.

Besides, all of the hardware used should be stainless steel and should comply with current regulations.

In any case, there are a number of solutions in the market that adjust to virtually any type of installation.

The materials employed in the construction of structures may vary as a function of the type, the environment they are subject to, resistance, etc.

The main materials in use are:

- aluminum
- iron
- stainless steel
- fibreglass

Regarding assembly, the two main aspects to take into consideration are:

- Location
- Positioning

FIGURE 103.
PHOTOVOLTAIC FIGURE. (Source: TKNIKA)

Location

Apart from specific considerations, such as architectural integration, the structure should be placed in an open location, free of shade during daylight hours, in such way that the modules are situated in the appropriate direction and at the appropriate angle.

When determining the optimal location of the structure, keep in mind the visual impact and especially the risk of vandalism. When positioning the structure, a presence at the actual location is necessary, in order to determine the direction, so the installer should be familiar with the use of a compass, as well as the visual observation of the apparent path of the sun.

Positioning

There are two main operations involved in positioning: assembly and anchorage.

Assembly consists in joining the structural components and their mechanical supports, such as the mast, the frame, the shape, etc.

Anchorage consists in fastening the structure to the surface or fastening element, (floor, roof, façade, etc.) with the objective of providing the necessary resistance and stability to the structure, so that it can resist maximum predictable levels of wind and snow.

This stage of the installation may require a fair amount of civil construction, so all of the materials necessary should be determined during the design phase.

The most frequent practical civil construction solutions for anchorage are as follows: either a concrete foundation with a concrete brake shoe or direct fastening using anchorage blocks.

The structural support fulfills a dual purpose. On the one hand, a mechanical purpose, providing and ensuring a perfect assembly, to resist winds of up to 160 km/h, snow, ice, etc. On the other hand, a functional purpose, to obtain precise orientation and a suitable angle to make optimal use of solar radiation.

If planning to apply for subsidies, it is imperative that these structures comply with the specifications on the type of installation and with the technical conditions established by the IEDS. (ASIF, 2002)

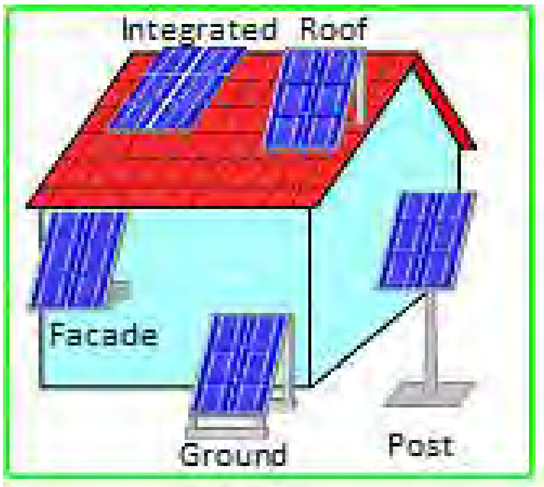
4.5.2.1. Fixed Structures

There are four fundamental locations for the panels:

- On the ground
- In posts and/or metallic towers
- On walls
- On the roof

The choice of position will depend on the features and characteristics of the location, bearing in mind easy access for eventual repairs and maintenance operations.

FIGURE 104.
DIFFERENT LOCATIONS (Source: Tknika, 2004)



4.5.2.2. Mobile Structures

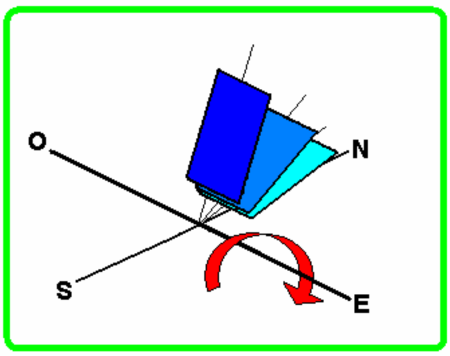
The performance of a PV module depends on the impact of direct solar radiation, among other things. In an ideal situation, the panels would be correctly oriented toward the sun at all times, ensuring a normal effect of the radiation.

There are different ways for the panels to track the sun:

Tracking the altitude of the sun

The panel can revolve around a horizontal axis placed in an East to West direction, allowing it to track the sun on a daily basis. The only parameter that varies is the angle of the PV generator.

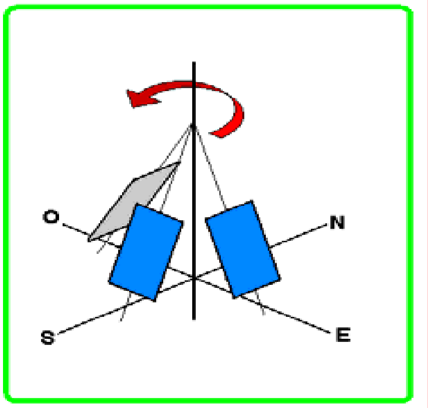
FIGURE 105.
TRACKING THE ALTITUDE OF THE SUN (Source: Tknika, 2004)



Tracking the solar azimuth

The panel can revolve around a vertical axis, perpendicular to the work plane, which allows it to track the azimuth of the sun on a daily basis. The only parameter that varies here is the azimuth or the change of direction from East to West of the PV generator.

FIGURE 106.
TRACKING THE SOLAR AZIMUTH (Source: Tknika, 2004)

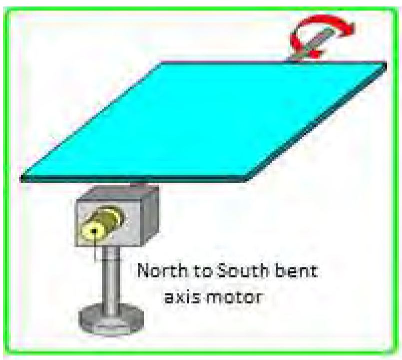


Tracking from a single north-south axis.

The panel can revolve around a North-to-South axis, tracking the path of the sun from East to West.

When the angle of elevation coincides with the latitude of that particular location, this type of tracking is called polar tracking. In this scenario, the production obtained is equivalent to 96% of that obtained by dual axis monitoring.

FIGURE 107.
RACKING FROM A SINGLE NORTH-SOUTH AXIS (Source: Tknika, 2004)

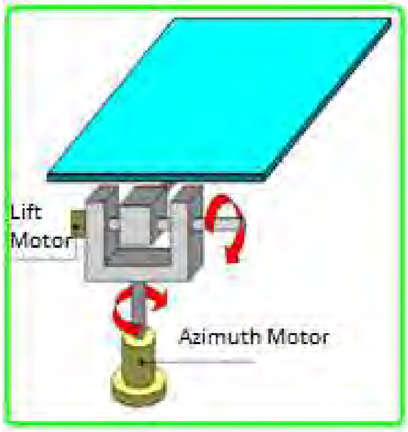


Dual-axis tracking

The panel revolves around two axes: one changes the elevation, from North to South, and the other changes the azimuth, along the East-West path of the sun.

In this type of tracking, the best angle of solar impact occurs at the angle of the azimuth axis that coincides with the latitude of that specific location, when the production obtained by the PV generator is at a maximum.

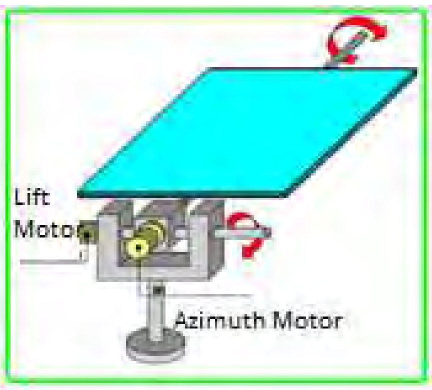
FIGURE 108.
A) DUAL-AXIS TRACKING (Source: Tknika, 2004)



There is also a further kind of tracking in which the panel revolves around both axes: one changes the elevation and the other moves around the North-South axis, following the path of the sun.

T

FIGURE 109.
B) DUAL-AXIS TRACKING (Source: Tknika, 2004)



4.5.3. Anchorage Systems

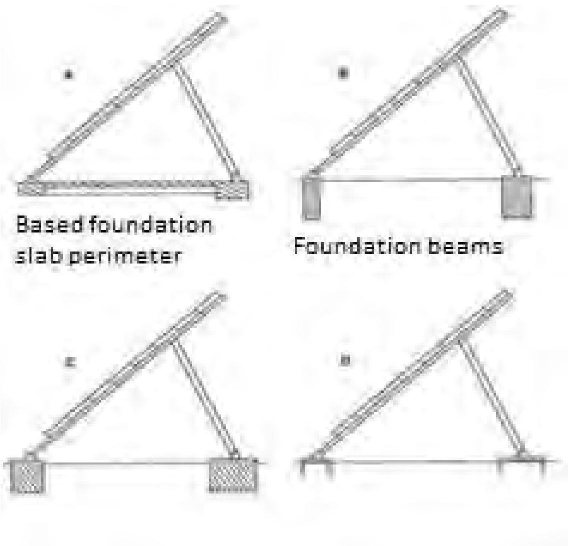
Points of Support

One of the most important structural aspects to consider is the points of support because the strength of the structure depends on them as a whole.

It is futile to calculate a structure that might support very strong winds, if we do not ensure that the structure is properly secured to the ground, roof, etc.

In FIGURE 110, we can see the four different types of bases for ground or roof structures.

FIGURE 110.
OINTS OF SUPPORT (Source: Tknika, 2004)



A) Foundations with concrete slabs and perimeter base.

B) Foundations with wooden beams with a shorter life.

C) Foundations with concrete blocks

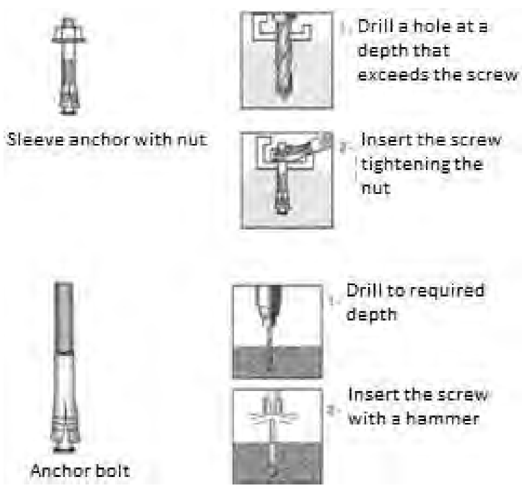
D) Metallic foundations firmly anchored to the ground.

Anchorage Elements

Two different ways of docking the leg of the structure to the foundation using screws may be seen in the diagram.

There is another procedure that consists in introducing pieces of metal into the base of the concrete, in such way that, when the concrete is laid, they will be solidly joined together.

FIGURE 111.
NCHORAGE ELEMENTS (Source: Tknika, 2004)



4.6. Grid-connected PV Systems

"Those systems in which the electric energy generated by the photovoltaic field flows directly into an external power supply"

The fact that we have a connection to an electric power supply does not impede us from making the most of PV solar energy. The energy generated can be injected directly into the electricity grid, using a special convertor, so we can avoid the expensive costs of batteries and regulators.

FIGURE 112. GRID-CONNECTED INSTALLATION
(Source: Tknika, 2004)

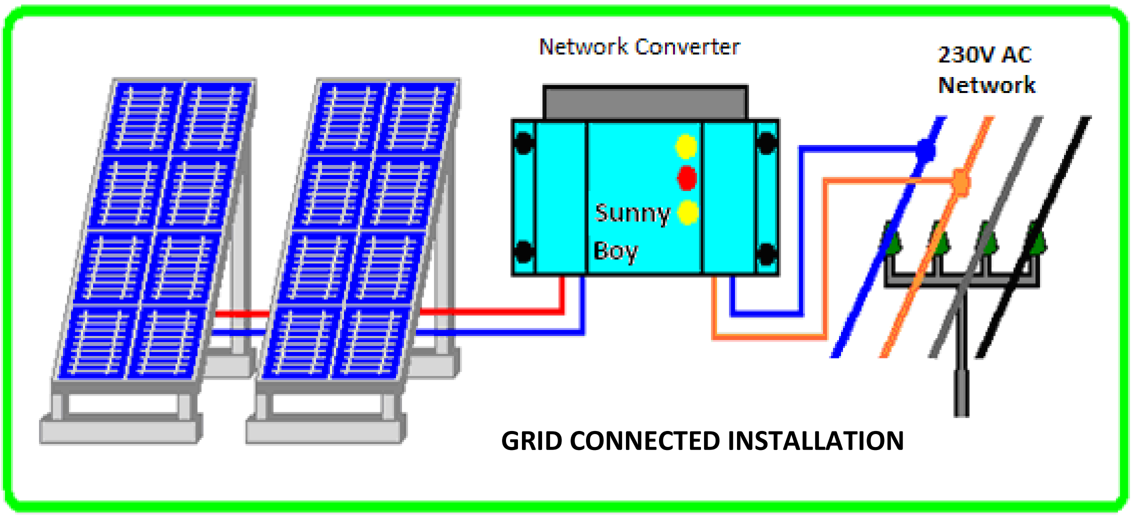
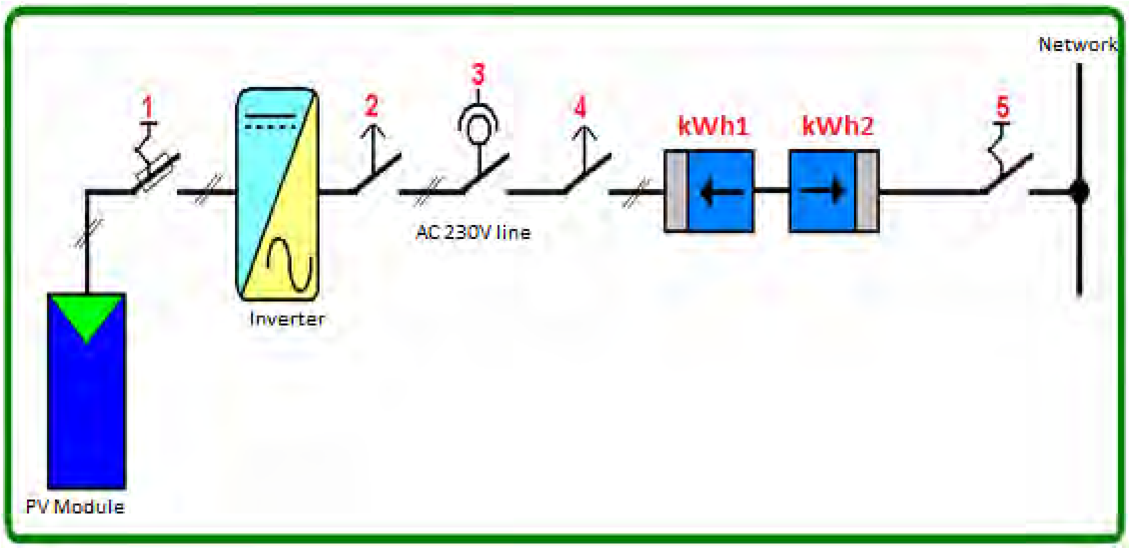


FIGURE 113. GRID-CONNECTED INSTALLATION A
SINGLE LINE ELECTRICAL SCHEMATIC (Source: Tknika, 2004)



4.6.1. Installation Topology

We can distinguish between two different parts of PV installations that are connected to the grid: DC (Direct Current) and AC (Alternating Current).

The first part deals with PV Generators, their circuit breakers and the convertor. The second category deals with the Convertor, its circuit breakers and electric meters.

Point of connection to the Power Grid

For installations connected to single-phase or triphased grids of 230V/400V, the connection will be established upstream of the electric meter that belongs to said grid.

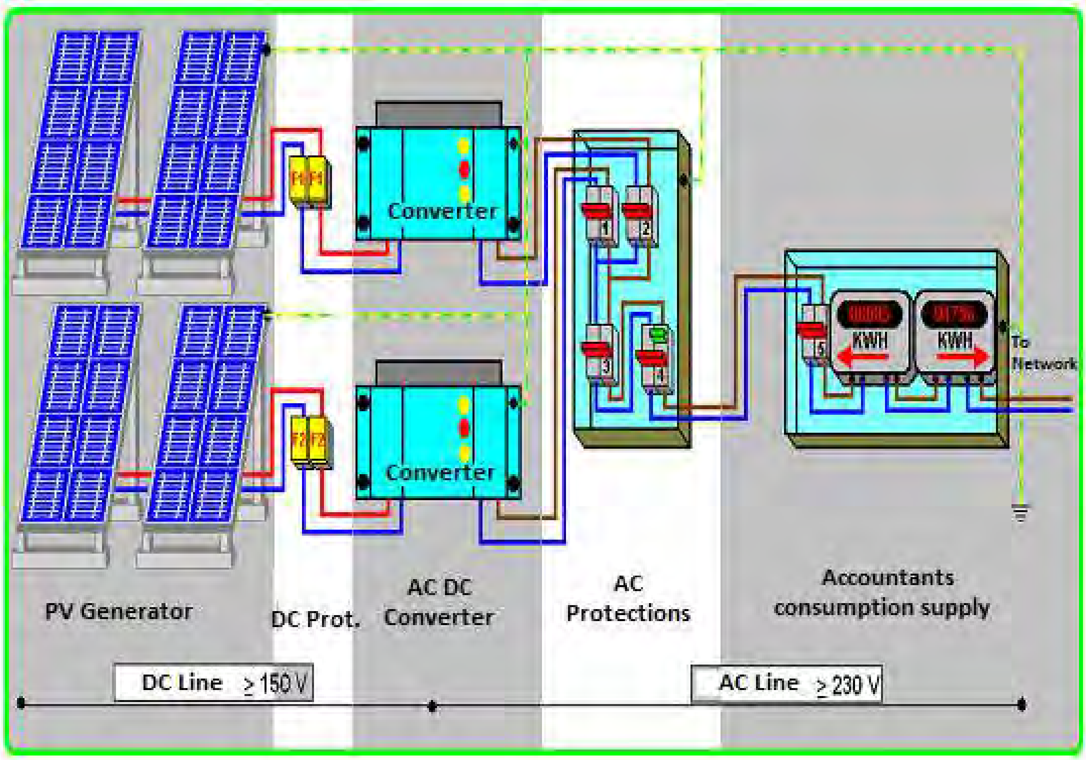


FIGURE 114.
A BLOCK DIVISION OF A GRID-CONNECTED INSTALLATION (Source: Tknika, 2004)

4.7. Stand-alone PV System

In stand-alone installations, the energy generated is stored and the owner of the facility consumes the power generated (individual consumption). Other installations connected to the electric grid are directly injected into an external power supply - void of any storage – and may be used by all consumers connected to this network.

No matter what the case, in both instances the owner of the installation may be an individual or a corporation.

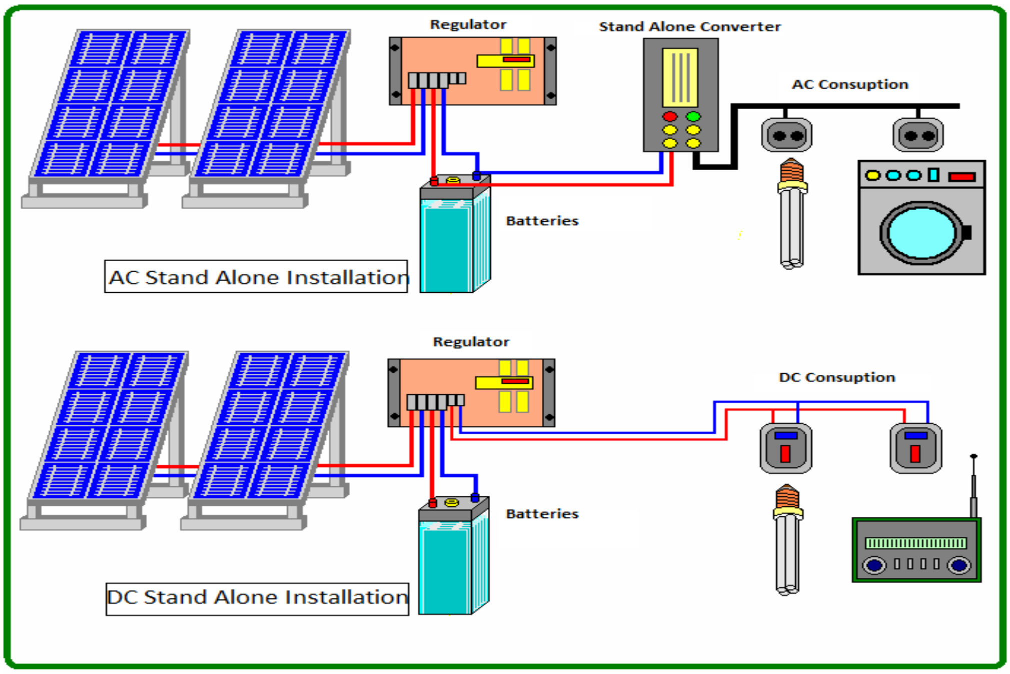
In general, these types of installations are used in remote areas where it is difficult or even impossible to connect to the electric grid for economic, technical or accessibility issues.

Stand-alone installations may be constructed for direct or alternating current.

The type of installation to construct will depend on the number and electrical features of the elements of consumption. Use a direct current of 12, 24 or 48 volts when constructing low-power installations. High-power installations require an alternating current of 230 volts to avoid large wire sections.

Certain recipient elements are manufactured in direct or alternating current, so the installation should be designed according to the type of electrical feed that is required.

FIGURE 115. STAND-ALONE PV SYSTEM (Source: TKNIKA)



When determining the size of a photovoltaic system, we need to keep in mind its application. We cannot use the same design criteria any more easily for a lighting system, or for a weekend getaway home, than for a radio link or road signalling apparatus.

In the first case, economic criteria concerning operational safety are a top priority, while in the second case, we should oversize the entire system and choose materials according to road safety and quality standards, in order to keep the probability of installation defects to a minimum.

Determining the size of an installation should begin by informing the user of the features, characteristics and limitations of the installation in a clear and concise manner.

Given the fact that a photovoltaic installation has no technical limitations regarding the power it is able to generate, the project manager should take down all of the necessary information from the user concerning:

- Location
- Purpose
- Amount of usage
- Technical features of recipient elements
- Number and characteristics of future potential users
- Credit history

4.8. Mounting system and building installation.

The quality of the system's installation strongly influences its ongoing performance and fulfilment of its anticipated lifespan and output levels. In the case of the BIPV installation, the following issues should be given special consideration:

Follow design considerations.

The installation and commissioning phases of the project are the right time to implement good design practices.

PV modules management

Some easy considerations should be taken into account when PV modules are managed.

- Be aware that PV modules are fragile! Avoid walking on them.

FIGURE 116.
DO NOT STEP ON PV MODULES (Source: ECN)

- PV modules are often large ($2m^2$ or more) and heavy (>50kg) and therefore require particular care when they are lifted and handled, particularly when working at height and in windy conditions.

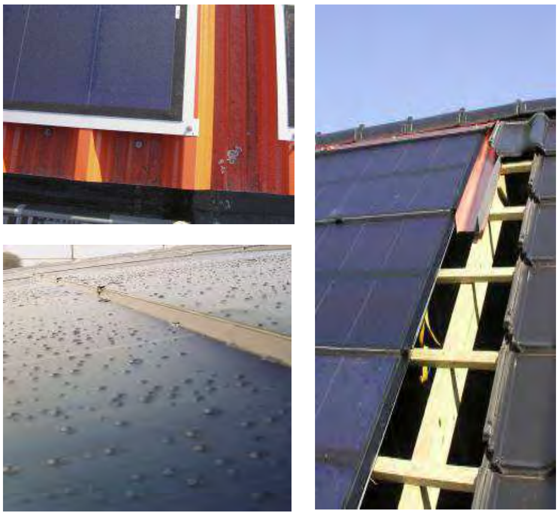
FIGURE 117.
MANAGEMENT OF PV MODULES (Source: ReSEL, TUC)

- PV modules impose both static and wind loads. The mounting structure should be assessed to ensure it is capable of withstanding these loads, and must be adequately ballasted or fixed to a suitable structural member.

FIGURE 118.
BALLAST AND ANCHORAGE (Source: TECNALIA)

- Brackets or mounting frames should also be adequately protected from corrosion.
- Where it is necessary to create penetrations in the skin of the building (e.g. during the installation of cables or of an integrated PV system) adequate steps should be taken to ensure that the building's fire resistance and weather tightness is maintained.

FIGURE 119.
ENSURE ROOF STABILITY AND WEATHER TIGHTNESS (Source: Biohause)



- Particularly in retrofit systems, a feasibility study or structural evaluation of the roof should be carried out, in order to ensure that the strength of the existing roof is sufficient to support the weight of the PV modules.

Follow manufacturer's recommendations.

Nowadays, there are a variety of photovoltaic products on the market for building integration. Having selected appropriate components for the PV system, it is important that they are installed in accordance with the manufacturer's recommendations, especially in terms of required fixings, ventilation, calibrations, operating temperature ranges and safety aspects. Failure to adhere to the correct operating conditions can lead to poor performance levels, reduction of component lifespan and even failure of the system, in some cases.

FIGURE 120.
INSTALLATION OF RUBBER BLANKETS WITH AMORPHOUS SILICON CELLS (Source: Gisscosa-Firestone)

FIGURE 121.
INSTALLATION OF FLEXIBLE PANELS (Source: Biohouse)

FIGURE 122.
INSTALLATION SEQUENCE OF SELF-ADHESIVE PANELS (Source: Lumeta Inc)

- Select the PV modules for the same string with similar manufacturing parameters; the chain is only as strong as its weakest link.
- Place sensors properly and calibrate them.

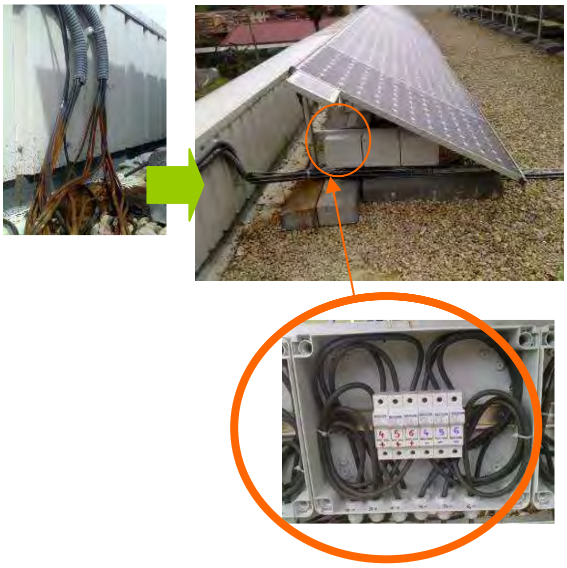
FIGURE 123.
SENSOR PLACING (Source: Ekain Taldea- Spain)

Wiring modules

When wiring cables besides taking into account the electrical risks, the following issues are important for the future performance of the PV system

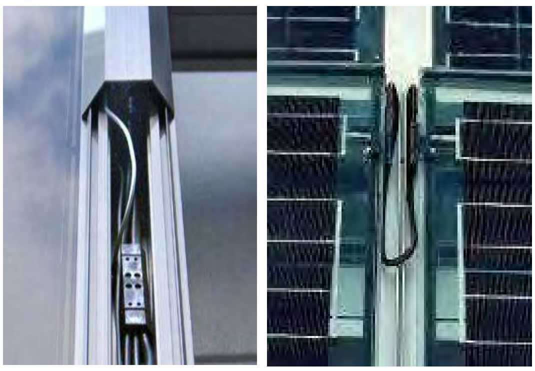
- Attention should be paid to minimising cable lengths and, particularly, to ensuring that all connections are correctly made and protected. The solar array wiring should be housed in a rack to avoid flooding and accumulations of dirt and rust. Whilst it may not affect the initial performance of the system, a poor connection can become more influential over time and lead to performance reduction in the long term.

FIGURE 124.
REPAIR OF WIRING AT A PV INSTALLATION (Source: Zubigune, Spain)



- The glass-glass modules for façades and skylights usually have a very easy-to-handle electricity connecting system. With these types of electrical connection, it is possible to hide the cables inside the structure to achieve a uniform, aesthetically appealing result with no distracting cableways

FIGURE 125.
DIFFERENT TYPES OF CONECTIONS IN GLASS-GLASS MODULES FOR FAÇADES (Source: MSK and Sheuten Solar)



4.9. Completing the PV installation

After installing the PV panel, the installer should perform the following procedures:

- Start up and running of the system
- Testing system security and all safety measures
- Deliver installation

Inspection and testing

Inspection and testing of the completed system in accordance with Wiring Regulations has to be carried out and documented.

Inspection and testing documentation typically comprises 3 forms – an installation certificate, which includes a schedule of items inspected and a schedule of test results.

The inspection and testing of D.C. circuits, particularly testing PV array circuits requires special consideration. Appendix C covers the inspection and testing of PV array circuits and documentation to be provided.

Array commissioning tests

PV array/string performance tests are recommended to verify performance and check for faulty modules. This may require a means of measuring solar radiation for larger installations if radiation levels fluctuate during testing.

Simultaneous monitoring of solar radiation can present practical difficulties unless the system has a radiation sensor installed and its cable is accessible at the place where testing is carried out. If radiation conditions are reasonably constant (ie no sudden obscuring of direct sunlight by clouds), comparing one open-circuit string voltage with another will identify faulty strings.

TABLE 22.
SCHEDULE OF TEST RESULTS. (Source: DTI, 2006)

Contrator . ... Test date .... Signature .... Method of protection against indirect contact .... Equipmen vulnerable to testing	Adress/ Location of distribution board:...............................	Type of Supply: TN-S/TN-C-S/TT Ze at origin: ...ohms PFC:.....................kA	Instruments Loop impedance: .... Continuity........... Insulation:............ RCD tester: ....
Description of Work:			

Circuit Description	Overcurrent Device Shor-circuit capacity:...... .....kA		Wiring Conductors		Test Results									
					Continuity			Insulation Resistance		Polarity	Earth Loop Impedance Z_s Ω	Functional Testing		Remarks
	type	Rating I_n A	Live mm²	Cpc mm²	(R1 + R2) * Ω	R2 * Ω	Ring	Live/ Live M Ω	Live/ Earth M Ω			RCD Time ms	Other	

Field insulation test procedure

Safety:

- Read and make sure this procedure is understood before starting any work.
- Insulation testing is an electric shock hazard use caution when performing the testing.
- Do not perform the test without the necessary practical training.
- Limit access to the working area.
- Do not touch and take measures to prevent any other persons from touching any metallic surface with any part of your body when performing the insulation test.
- Do not touch and take measures to prevent any other persons from touching the back
- of the module/laminate or the insulation test.
- Module/laminate terminals with any part of your body when performing the insulation test.
- Whenever the Insulation test device is energised there is voltage on the testing area. The equipment is to have to have automatic auto-discharge capability.

Note regardint test method

Two test methods are possible:

a) Test between array negative and the earth connection followed by a test between array positive and earth

b) Test between earth and short-circuited array positive & negative

Where the structure/frame is bonded to the ground, earthing may be to any suitable earth connection or to the array frame (where the array frame is utilised, ensure that a good contact is made and continuity of the whole metallic frame).

For systems where the array frame is not bonded to the grounded (eg where there is a class II installation) a commissioning engineer may choose to do two tests: i) between array cables and the earth connection and an additional test ii) between the array cables and the frame.

For arrays that have no accessible conductive parts (eg PV roof tiles) the test should be between the array cables and the earth connection of the building.

Test Zone Preparation:

1) Limit access to non-authorized personnel.

2) Isolate the PV array from the inverter (typically at the array switch disconnector).

3) Disconnect any piece of equipment that could have an impact on measurement of the protective insulation.

(i.e. overvoltage protection) in the junction or combiner boxes.

Equipment Required:

- Insulation resistance test device
- Insulation gloves
- Goggles.
- Safety boots.
- Short-circuit box (if required)

Procedure

1) The test should be repeated for each array as minimum. Individual strings may also be tested, if required.

2) Wear safety shoes, gloves and goggles.

3) Where the test is to be undertaken between the earth connection and short-circuited array positive and array negative cables - short-circuit the cables with an appropriate short-circuit junction box.

4) Connect one lead from the insulation resistance test device to the array cable(s) as per the above NOTE.

5) Connect the other lead from the insulation resistance device to the earth as per the above NOTE.

6) Secure all test leads (eg with cable ties).

7) Follow insulation resistance test device instructions to ensure that the test voltage is the same as in TABLE 23 and that the readings are in M Ohms.

8) Follow insulation resistance test device instructions to perform the test.

9) Ensure that the system is de-energised before removing test cables or touching any conductive parts.

TABLE 23.
TEST METHOD TABLE (Source: DTI, 2006)

Test method	System Voltage ($V_{oc\ stc}$ x1.25)	Test voltage	Minimum impedance
Array positive & negative short circuite Dining room Hall	120V	220V	0.25MΩ
	<600V	500V	0.5MΩ
	<1000V	1000V	1MΩ
Separate tests on array positive and array negative	120V	250V	0.25MΩ
	<600V	500V $V_{oc\ stc}$ (min 100V)**	0. 5MΩ
	<1000V	1000V $V_{oc\ stc}$ (min 100V)**	1MΩ

** Test Voltage adjusted to prevent peak exceeding module or cable rating

After running the newly installed system for a minimum of 240 hours without incident, the provisional act of certification may be signed.

Testing and Delivery

After preliminary testing, before delivering the finished product, the installer must:

- Clean up any excess material
- Thoroughly clean the zone occupied by the panels

The installer must also provide the user with an operations manual.

TABLE 24.
COMMISSIONING TEST SHEET (Source: DTI, 2006)

Note: This form is subjet to change as it is being worked on in the IEC Technical Committee

PV Array Test Report – d.c. circuits

Report reference No:	Contractors name and address
Installation address	
Test date	Signature
Description of work under test	Test instrument(s)

String		1	2	3	4	n
Array	Module					
	Quantity					
Array parameters	Voc (stc)					
	Isc (stc)					
Protective Device	Type					
	Rating (A)					
	d.c Rating (V)					
	Capacity (kA)					
Wiring	Type					
	Phase (mm^2)					
	Earth (mm^2)					
String test Test method: Annex-2	Voc (V)					
	Isc (A)					
	Sun					
Polarity check						
Earth continuity (Where fitted)						
Connected to inverter (serial No.)						
Array insulation Resistance Ref IEC 60364- 713-04 Test method: Annex-1	Test voltage (V)					
	Pos – Earth (MΩ)					
	Neg- Earth (MΩ)					
Comments:						

4.9.1. Customer Documentation

An authentic project should always respect the applicable legislation regarding the installation, taking into consideration all technical as well as environmental aspects. In this sense, there is a notable difference between stand-alone photovoltaic systems and those connected to the power grid, especially since the latter involves a much more extensive legal procedure.

At the start of a project, having ascertained the necessary information from the customer, an action plan should be followed the main sections of which comprise:

- Feasibility study
- Report
- Technical Drawings
- List of Conditions
- Budget
- Safety Plan

In this way, with the relevant information available, the installer will be able to perform the installation in the alloted time for the project and meet the applicable quality standards.

The installer will also provide the user with a copy of the project

Furthermore, the installer must also provide the user with an operations manual for the installation.

The user manual should include as a minimum the following information:

System data

- A copy of the basic system information
- A single line electrical schematic.
- A copy of the manuals and data sheets for the following system components:
  - PV modules
  - Inverter
  - Other relevant product documentation.

Test results & commissioning data

- A copy of the test & commissioning documentation
- Table of inverter protection settings (under/over voltage, under/over frequency, etc).

Operation & maintenance data

- Procedures for verifying correct system operation.
- A checklist of what to do in case of a system failure.
- Shutdown/isolation and startup procedures.
- Maintenance & cleaning recommendations (if any)
- Considerations for any future building works adjacent to the PV array (eg roof works) to avoid potential damage or shading of the PV array.

Warranty

- Warranty Information

4.10. Installation checklist

Once installation has been completed, we need to check how the system is running. The following chart includes the parameters needed to verify, as an example. In any case, this checklist may vary depending on the type and features of the installation.

TABLE 25.

PV Commssionning test sheets. Source:(BRE et al,2006)

PV system – Installation Check List

Installation address	Inspection by:	
	Date:	Reference:

General installation (electrical – ref IEC60364-6-61)

- ☐ Equipment compliant with standards, correctly selected & no damaged
- ☐ Equipment accessible for operation, inspection & maintenance
- ☐ Equipment and accessories correctly connected
- ☐ Particular protective measures for special location
- ☐ Equipment and protective measures appropriate to external influences
- ☐ System installed to prevent mutual detrimental influence
- ☐ Conductors connected and identified
- ☐ Conductors selected for current carrying capacity and voltage drop
- ☐ Conductors routed in safe zone or protected against mechanical damage
- ☐ Presence of fire barriers, seals and protection against thermal effects

General installation (mechanical)

- ☐ Ventilation provided behind array to prevent overheatin / fire risk
- ☐ Array frame & material corrosion proof
- ☐ Array frame correctly fixed and stable; Roof fixings weatherproof
- ☐ Cable entry weatherproof

Protection against overvoltage/electric shock

- ☐ Live parts insulated, protected by barrier/enclosure, placed out of reach or Class II
- ☐ Array frame equipotential bonding present (only relevant if required)
- ☐ Surge protection devices present (only relevant if required)
- ☐ RCD provided (only relevant if required)
- ☐ Frame correctly integrated with existing LPS installation

D.C System

- ☐ Physical separation of a.c. and d.c cables
- ☐ D.c switch disconnector fitted (to IEC60364-712.536.2.2)
- ☐ D.c cables – protective and reinforced insulation (only relevant if required)
- ☐ All d.c. components rated for operation at max. d.c. system voltage (Voc stc x 1,25)
- ☐ PV strings fused or blocking diodes fitted 8 only relevant if required)

A.C. System

- ☐ A.c. isolator lockable in off position only
- ☐ Inverter protection settings to local regulations

Labelling & identification

- ☐ General labeling of circuits, protective devices, switches and terminals (to IEC60364-6-61
- ☐ PV system schematic displayed on site
- ☐ Protection settings & installer details displayed on site
- ☐ Emergency shutdown procedure displayed on site
- ☐ A.c. isolator clearly labeled
- ☐ D.c. isolator / junction boxes suitably labeled
- ☐ Signs & labels suitably affixed and durable

4.11. Exercises

1. Which is the main characteristic of PV modules that makes them hazardous if exposed to daylight?
   a) PV modules generate DC electricity which cannot be switched off unless daylight is prevented from reaching the module.
   b) Development of extremely high temperatures on their surfaces may cause a fire
   c) Toxic gases can be released from the panels in case of high temperatures.
2. Which are the hazards that should be assessed when preparing a risk assessment and a method statement for the installation of a PV system?
3. Why is it not possible to use fuses to protect PV module wiring?
   a) PV modules are current limiting devices, which means that fuse protection is unlikely to be effective under short circuit conditions and an alternative approach to fault protection is required.
   b) PV modules are current limiting devices, which means that fuse protection is unlikely to be effective under open circuit conditions and an alternative approach to fault protection is required.
   c) Fuses can explode if exposed to low current running through wire connecting the components of the system.
4. The behavior of DC electricity is different from that of AC electricity; describe the hazards associated with each one.
5. The safety plan will be carried out by:
   a) The user of the installation
   b) The designer of the project
   c) The installer.
6. Personal Protective Equipment include (choose 3 answers):
   a) Eye and face protection
   b) Risk assessment plan
   c) Protection of extremities
   d) Elevating Work Platforms
   e) Hearing protection
   f) Mobile towers
7. The project report:
   a) Explains the purpose of the project and describes the procedure to be followed for completion.
   b) Contains the obligations of the installer when executing the project.
   h) Explains the potential risks and preventive measures to be taken.
8. A Feasibility Study has to: (choose 3 answers)
   a) Evaluate the energy needs and interests of the user
   b) Determine the potential level of solar power generation of the region
   c) Include a careful examination of what could cause harm to people, during the installation process,
   d) Formalize and make solar installation proposals according to the energy needs of the customer.
   e) Evaluate the extent of potential risks involved during maintenance, taking into account existing precautions
9. The structures used in a photovoltaic installation must be:
   a) Customised for each individual installation.
   b) There are no regulations regarding structures.
   c) Made of rustproof material and should be maintenance free.

10. The safeguards that should be used for a grid-connected photovoltaic installation:
    a) Are up to the criteria of the designer.
    b) Should fulfil the pertinent legal requirements.
    c) There are no pertinent legal regulations.

11. For installations connected to single-phase or triphased grids of 230V/400V, the connection to the stream will be connected
    a) Downstream of the electric metre.
    b) Upstream of the electric metre.
    c) Wherever the client desires.

12. It is not really important that all modules possess the same voltage - current characteristics in case of series connection
    a) True
    b) False

13. In a stand-alone installation, consumption takes place:
    a) Exclusively in DC
    b) Exclusively in AC.
    c) In AC, DC or both simultaneously.

14. To ensure that the DC conductor section is not too large, we should:
    a) Lower the strain-voltage.
    b) Increase the strain-voltage.
    c) Ensure that the distance between the generator and the point of consumption is as long as possible.

15. The amount of a drop in voltage admissible in power lines:
    a) Will be defined by the applicable regulation.
    b) Depends exclusively on the criteria set by the designer.
    c) Will be determined by mutual agreement between customer and designer.

16. Regulators are installed in a cabinet which will be:
    a) as far as possible from the batteries, not to be affected by battery vapours.
    b) as close as possible to the batteries, to avoid sudden drops in the voltage
    c) as close as possible to the batteries, to avoid sudden drops in voltage, but in such way that it is not affected by battery vapours.

17. The installer must provide the user with an operational manual for the installation.
    a) True
    b) False

18. Before handing over the provisional ownership of the installation:
    a) It is necessary to allow the installation running for a minimum of 240 hours.
    b) There is no need to test the installation operation.
    c) Final approval is given only by the customer.

19. It is necessary to run periodic checks on the operational parameters of the PV installation.
    a) True
    b) False

20. Which of the following components are required for a grid-connected PV installation?
    a) Photovoltaic panels
    b) Current / Voltage Regulator
    c) Batteries
    d) Stand-alone inverter
    e) Grid-connected inverter
    f) Water Expansion Vessel
    g) Electrical Power Metre

21. Number the following steps of a Grid-Connected PV Installation according to the proper order.
    a) Installation of PV Power Station
    b) Wiring of Components
    c) Installation of Safety and Measurement Control Panels
    d) Framework Installation
    e) Final Test Run
    f) Grid Connection
    d) Assembly of Electrical Power Metres

CASE STUDIES – BEST PRACTICES 5

5. CASE STUDIES – BEST PRACTICES

The Case Studies section of this Handbook presents various small-scale PV systems that employ different technologies on various types of buildings throughout Europe.

The selection criteria focused on technical and aesthetical aspects as well as the novelty of the systems, in order to showcase advanced technological systems and approaches.

The best practices presented in this section are likely to involve the kind of PV systems on which installers will work. The information that it includes will help prevent common mistakes and develop good practice in the installation of PV solutions.

5.1. PV installation in Aurinkolahti Comprehensive School

City (Country): Helsinki (Finland)

Type of application: roof mounted

Year: 2009

Summary

The City of Helsinki is committed to many energy efficiency agreements as well as to the reduction of its CO_2 emissions. Through those agreements, the City of Helsinki has also committed itself to use increasing amounts of renewable energies. The Aurinkolahti solar power station is a pilot project for testing renewable energy sources. Targeted annual energy saving at Aurinkolahti comprehensive school is 6.5% every year, when compared to its consumption of electrical energy purchased off the national grid.

Description of the solution

Background description

- **Description of the site/building type:** School building
- **Partners and stakeholders involved:** the City of Helsinki, Public Works Department, PWD Construction Management
- **Duration of the pilot project**: ± six months
- **Duration of the installation works:** ± two weeks

FIGURE 126.
AURINKOLAHTI SCHOOL. (Source: City of Helsinki)

Technical description

- **Total installed power:** 20.4 kWp
- **Area needed per kW:** 7.35 m^2/kW
- **PV technology used:** Crystalline silicon technology
- **Type of Inverter:** SMC6000TL (6300 W, 600 V, 26 A)
- **Maintenance, warranties and lifetime of solution:** the system is nearly maintenance free; duration of guarantee 25 years, expected lifetime of 30 years

Economic aspects

- **Total cost of solution and cost of PV:** €140,783, 6.90 €/W
- **Funding for implementation and sources:** 35% of total costs funded by Ministry of Employment and the Economy.
- **Feed-in tariffs, subsidies, local/regional or national grants:** There is no Feed-in tariff in Finland for decentralized electricity production.
- **Internal rate of return (IRR) for the solution:** Payback time (without interest) 25 to 50 years depending on electricity market prices.

Results/achievements

- **Energy production:** 14 691 kWh/first year of action (L3 phase inverter failure from June 2010 to August 2010 influenced 5000 kWh loss of energy production)
- **CO_2 emissions reduction:** 3482 kg CO_2 (emission factor used: 237 g CO_2/kWh)
- **Other benefits:** educational purpose when teaching natural sciences

Replication

Advice on how to replicate the solution and on steps to follow/barriers to look-out for.

The solution can be replicated elsewhere. All solar panels power stations have to be carefully sized on a case-by-case basis before installation, for accurate constructional and electrical dimensioning.

Contact details

- Contact:

sirpa.eskelinen@hel.fi

5.2. PV plant on the Kungsmad School

City (Country): Växjö, Sweden

Latitude/Longitude: 56° 53' N / 14° 49' E

Type of application: roof mounted

Year: ***2008***

Summary

The City of Växjö has a very ambitious climate and energy plan, to become free from fossil fuels by 2030. So far the main focus has been biomass, but in recent years, solar energy has attracted greater interest. The PV plant on the Kungsmad School was the second PV plant to be built in Växjö and it is still the largest in the area. In fact, it is one of the biggest of its kind in Sweden. It consists of 780 panels over an area of 1 021 m2. The plant generates about 130 000 kWh of electricity every year, which is estimated to represent 1/6 of the school's annual electricity use. Current energy production and CO_2 savings are displayed to the public on an electronic panel.

FIGURE 127.
PV SYSTEM DISPLAY (Source: Kari Ahlqvist)

FIGURE 128.
PV SYSTEM ON SCHOOL. (Source: Kari Ahlqvist)

Description of the solution

Background description

- **Description of the site/building type:** The PV plant is mounted on the roof of a secondary school.
- **Partners and stakeholders involved:** The municipal real estate company Vöfab, and the installation company Glacell AB
- **Duration of the installation works:** about 1 month

Technical description

- **Total installed power:** 137 kWp
- **Area needed per kW:** 7.45 m2/kW
- **PV technology used:** Polycrystalline silicon
- **Type of Inverter:** IG 500HV
- **Maintenance, warranties and lifetime of solution:** There is a warranty time of 25 years. We have no calculation of expected lifetime. So far, no specific maintenance has been performed. There may be a need for cleaning later on.

Economic aspects

- **Total cost of solution and cost of PV**: €500,000 (3.65 €/Wp)
- **Funding for implementation and sources:** Governmental subsidy 70%, Vöfab 30%
- **Feed-in tariffs, subsidies, local/regional or national grants:** Governmental subsidy of 70 %.
- **Internal rate of return (IRR) for the solution:** No internal rate of return has been set.

FIGURE 129.
PV SYSTEM ON ROOF. (Source: Kari Ahlqvist)

Results/achievements

- **Energy production:** Approximately 130 000 kWh per year
- **CO_2 emissions reduction:** 78,000 kg CO2

Replication

Advice on how to replicate the solution and on steps to follow/barriers to look-out for. This is the first PV plant in Växjö and it has paved the way for more frequent usage of and a higher interest in PV systems in the city. It is quite a simple solution. This installation shows that it is possible to produce electricity from the sun even in Sweden.

Contact details

- **Online information:**

www.vofab.se

- **Contact:**

Henrik.johansson@vaxjo.se

5.3. Solar power plant BERDEN

City (Country): Bogojina, Slovenia

Latitude/Longitude: 46°/16°

Type of application: BIPV

Year: 2011

Summary

Solar PV modules are integrated in the roof of a new building. This integrated solution was made with a view to save additional roof covering costs. The roof is covered with 216 PV modules Upsolar UP-M230P. We used five 10kW Riello inverters, for a 49.68 kW power plant. Power plants will bring annual savings of 30 t Co_2.

Description of the solution

Background description

- **Description of the site/building type:** The building is located in NE Slovenia and is used for business purposes.
- **Partners and stakeholders involved:** The investor is a self-employed farmer.
- **Duration of the installation works:** Work was carried out within a period of one month.

Technical description

- **Total installed power:** 49.68 kWp
- **Area needed per kW:** 7.1 m2/kW
- **PV technology used:** Crystalline silicon
- **Type of Inverter:** Riello HP 1000065, 10 kW
- **Maintenance, warranties and lifetime of solution:** Project lifetime is estimated at 30 years, warranties were issued for PV modules (10 years), inverters (5 years), and general warranty (2 years.)

-

FIGURE 130.
BERDEN SOLAR PLANT. (Source: www.plan-net.si)

Economic aspects

- **Total cost of solution and cost of PV:** 3.14 €/Wp; cost of PV: 1.97 €/Wp
- **Funding for implementation and sources:** Equity capital
- **Feed-in tariffs, subsidies, local/regional or national grants:** 0.444 €/kWh
- **Internal rate of return (IRR) for the solution:** 10%.

Results/achievements

- Energy production: 49 MWh per year

- CO_2 emissions reduction: 30 000 kg CO2, (based on a global average 0.6 kg of CO2 per KWh.)

Replication

- Advice on how to replicate the solution and on steps to follow/barriers to look-out for.

The solution can be replicated at every similar building with similar orientation. A well-prepared project is the basis for good execution.

Contact details

- **Online information:**

www.plan-net-solar.si

- **Contact:**

Femc Marko (info@plan-net.si)

5.4. PV system on school in Šmartno ob Dreti

City (Country): Šmartno ob Dreti, Slovenia

Latitude/Longitude: 46.28406/ 14.88854

Type of application: BAPV

Year: 2010

Summary

The MFE OŠ Šmartno ob Dreti Solar power plant in Slovenia is a roof-top PV system installed on a primary school. The investor, BISOL, used 99 BISOL 245 W photovoltaic modules. Installed power is 24.25 kW. Production to date (October 27, 2011) is of 24 MWh, which exceeds the expected energy yield by 8.5%.

Description of the solution

Background description

- **Description of the site/building type:**

The primary school in Šmartno ob Dreti is an old facility with a brick roof. The roof is in good condition; therefore the replacement of the roofing was not necessary. 99 BISOL multi-crystalline silicon photovoltaic modules, each with power 245 W, were installed on 160 square meters. As BISOL modules have strictly positive power output tolerances the

FIGURE 131.
PV SYSTEM ON ROOF. (Source: BISOL Group d.o.o)

total installed and measured capacity of the PV system is 24.25 kW. Orientationof the PV modules is 13° southwest. In the immediate vicinity of the PV system is a block of flats, which does not cast shadows on the PV system.

- **Partners and stakeholders involved**

Investor: BISOL Group d.o.o.

- **Duration of the works:**

The Easement Agreement was signed on September 1, 2010; the solar power plant was connected to the grid on December 14, 2010. Works on the roof started on November 10 2010, and the whole PV system (together with laying the cable conduits) was installed 8 days later. Another 3 weeks passed before the official documentation from the utility company was issued.

Technical description

- **Total installed power (kW):** 24, 25 kW
- **Area needed per kW:** Approx. 7 m²
- **PV technology used:** Crystalline silicon technology

- **Type of Invertor (power and rating):** one SMA 1500 TL and two SMA SB 400 TL
- **Maintenance, warranties and lifetime of solution:** Maintenance and monitoring contract with BISOL Group d.o.o.; Warranties: 10-year product warranty; 12-year warranty on 90% power output, 25-year warranty on 80% power output, 1-year warranty on flawless working of the PV system (until December 14, 2011). Expected lifetime: more than 40 years

Economic aspects

- **Total cost of solution:** 70,325.00 EUR
- **Funding for implementation and sources:** 80% bank credit, 20% own resources
- **Feed-in tariffs, subsidies, local/regional or national grants**: BISOL rented the school's roof area for 25 years. All produced electricity is sold to the Centre for Renewable Energy Sources Support at a guaranteed purchase price. Feed-in tariff for year 2010 (for micro solar power plants on buildings) was 386, 38 €/MWh. This is a guaranteed purchase price for 15 years.
- **Internal rate of return (IRR) for the solution:**
    - *after 7 years 5.4%*
    - *after 10 years 10.7%*
    - *after 15 years 13.7%*
    - *after 20 years 15.3%*

Results/achievements

- **Energy production:** annual energy production to date (October 27, 2011) is 24 MWh, expected annual energy production is 22. 1 MWh, surplus 8.5%
- **CO_2 emissions savings:** 14,400 kg
- **Jobs created:** Many people worked on the project: salesmen, project managers, and purchasing and warehouse division, 5 installers and many others.
- **Other benefits:** For educational purposes BISOL placed an LCD panel in the school, which enables pupils to monitor solar power plant operation. This contributes to the learning process and increases environmental awareness among the children.

Replication

Advice on how to replicate the solution and on steps to follow/barriers to look-out for.

As with all PV power plants a detailed review of the site is needed, the roof has to be in a good shape, special attention should be paid to orientation of the building, shading etc.

Contact details

- **Online information:** www.bisol.com
- **Contact:** info@bisol.si

5.5. Athens Metro Mall

City (Country): Athens, Greece

Latitude/Longitude: 37.941363 /23.739974

Type of application: BIPV

Year: 2010

Summary

Designed with the aim of saving resources and being environmental friendly, Athens Metro Mall combines various characteristics that make it a bioclimatic building with very low energy consumption. Solar panels cover 400sqm on the south side of the building achieving a reduction in energy consumption of up to 5%.

Description of the solution

Background description

- **Description of the site / building type:** The BIPV consists of two façades and the south side of the Trade center “Athens Metro Mall”.
- **Partners and stakeholders involved:** The entire project was financed by the owner of the trade center: TALIMA VENTURE INC.
- **Duration of the works:** 20 days.

Technical description

- **Total installed power:** 51 kWp
- **Area needed per Kw:** 7.72 m^2
- **PV technology used:** Crystalline silicon
- **Type of modules:** SCH660P from SOLAR CELLS HELLAS SA
- **Type of Inverter:** Sunergy ELV 230/5000W

FIGURE 132.
ATHENS METRO MALL.

- **Maintenance:** Maintenance services are delivered under contract by ACE POWER ELECTRONICS
- **Warranties:** 5 years for Inverter and PV panels
- **Lifetime of solution:** approximately 25 years.

Economic aspects

- **Total cost of solution and cost of PV:** €142,000, 2.78 €/Wp

- **Feed-in tariffs, subsidies, local/regional or national grants:**

The system feeds energy into the public grid. The energy is paid according to the feed-in tariff – 0.394€/KWh by the public power corporation (PPC). In theory the system will produce approximately 39.9MWh/year which means that the total investment will paid in 9 years.

Results/achievements

- **Energy production:** 39,900 kWp /year
- **CO_2 emissions savings:** 23.940 kg

Replication

Advice on how to replicate the solution and on steps to follow/barriers to look-out for.

The system can be easily replicated in other buildings.

Contact details

- **Online information:**
  www.schellas.gr , www.acepower.gr
- **Contact:**
- Ms. Eirini Komessariou (ekomessariou@schellas.gr)
- *Mr. Ioannis Aggelos* (service@acepower.gr)

5.6. Roof and wall mounted system in Finland

City (Country): Helsinki (Finland)

Type of application: roof and wall mounted

Year: 2009

FIGURE 133.
ATOKARTANO SCHOOL. (Source: City of Helsinki)

Summary

The City of Helsinki is committed to many energy efficiency agreements as well as to reductions in its CO_2 emissions. Through those agreements, the City of Helsinki is also committed to use increasing amounts of renewable energies. The solar power station of Latokartano is one of the pilot projects when testing renewable energies. The annual target for energy saving at Latokartano school is around 4%.

Description of the solution

Background description

- **Description of the site/building type:** School building
- **Partners and stakeholders involved:** the City of Helsinki, Public Works Department, PWD Construction Management
- **Duration of the pilot project:** new building construction, about two years

Technical description

- **Total installed power:** 10.6 kWp
- **Area needed per kW:** 7.35 m2/kW
- **PV technology used:** Crystalline silicon
- **Type of Inverter (power and rating):** SMC4600TL (5250 W, 600 V, 26 A)
- **Maintenance, warranties and lifetime of solution:** The system is nearly maintenance free; duration of guarantee is 25 years, expected lifetime about 30 years.

Economic aspects

- **Total cost of solution and cost of PV:** €87,275, 8.23 €/W
- **Funding for implementation and sources:** 35% of total costs funded by Ministry of Employment and the Economy
- **Feed-in tariffs, subsidies, local/regional or national grants:** There is no feed-in tariff in Finland for decentralized electricity production
- **Internal rate of return (IRR) for the solution:** Payback time (without interest) 25 to 50 years depending on the electricity market prices

Results/achievements

- **Energy production:** Approximately 9500 kWh/first year of action
- **CO_2 savings**: 2252 kg CO2 (emission factor used: 237 g CO2/kWh)
- **Other benefits:** Educational purpose when teaching natural sciences

Replication

Advice on how to replicate the solution and on steps to follow/barriers to look-out for.

The solution can be replicated elsewhere. All solar panels power stations have to be carefully sized on a case-by-case basis before installation, for accurate constructional and electrical dimensioning.

Contact details

- **Contact:**
  sirpa.eskelinen@hel.fi

5.7. Blackpool Centre for Excellence in the Environment

City (Country): Blackpool (United Kingdom)

Latitude/Longitude:

53°47'0"N 3°3'27.56"W

Type of application:

Inclined roof - transparent roof

Year: 2004

Summary

A derelict seafront solarium in Blackpool has been renovated and refurbished to act as a Regional Centre of Excellence in Environmental Sustainability in the North West of England. Sustainable energy is a key element of the refurbished building with onsite energy generation from a photovoltaic (PV) installation, two wind turbines and a combined heat and power (CHP) plant. This innovative project provides a focus and platform for delivering and promoting sustainable development across the tourism, manufacturing, commercial, education and community sectors, both locally and regionally. The PV array supplies up to 44% of the building's annual electricity requirements.

Description of the solution

Background description

- **Description of the site/building type**: Non-residential buildings - 2 floors

FIGURE 134.
BLACKPOOL CENTRE FOR EXCELLENCE IN THE ENVIRONMENT. (Source: Blackpool City Council)

- **Partners and stakeholders involved:**
  The Centre for Excellence in the Environment, also known as Solaris, is a sub-regional multi-agency partnership. The project was commissioned by Blackpool Borough Council and is intended to contribute to tackling the major regeneration challenge facing Blackpool. Other partners in the project include Lancaster University, Blackpool and the

Fylde College and Blackpool Environmental Action Team

- **Duration of the pilot project:** From 2003 to August 2004

Technical description

- **Total installed power:** 18.067 kWp
- **Area needed per kW:** 9.08 m2/kW
- **PV technology used:** Multi-Crystalline silicon technology
- **Type of Inverter (power and rating):** SMA (4 types -SMR1700, SMR3000, SMR2500, SMR850)
- **Combined nominal inverter power:** 14.85kW

Economic aspects

- **Total cost of solution and cost of PV:** 306 054 €, 16,93 €/W
- **Funding for implementation and sources:** The grant from the Major PV Demonstration Programme funded 65% of the PV installation (€151,000) with the remainder coming from the overall project budget.

Results/achievements

- **Energy production:** 12.776MWh
- **Other benefits:**

The building was designed to meet best practice guidelines and has attained an excellent rating from the BREEAM environmental assessment. The energy usage within the building is monitored and optimised via real time monitoring.

Solaris was built as a foundation for the education and promotion of sustainable design and incorporation of renewable energy in the area. The building is of passive design, taking advantage of natural energy flows to maintain thermal comfort and negate the need for mechanical heating and cooling.

The building fabric comprises recycled and sustainable materials: the building's concrete blocks contain pulverised fuel ash, a by-product from the power industry; and recycled newspapers are used as insulation in the external cavity wall.

Contact details

- Online information: www.solariscentre.org
- **Contact:** andy.duckett@blackpool.gov.uk duncan.broadbent@blackpool.gov.uk

FIGURE 135.
BLACKPOOL CENTRE FOR EXCELLENCE IN THE ENVIRONMENT. (Source: Halcrow Group ltd)

Replication

Advice on how to replicate the solution and on steps to follow/barriers to look-out for.

During the installation of the PV system, relatively few problems were encountered. Some of the PV modules were damaged during shipping but replacement modules were simply ordered to replace them. Closecontact was maintained between the installation partners to reach agreement on a satisfactory design, before ordering the innovative double-glazed PV modules.

The close liaison allowed the effect of design changes, including shading issues, to be catered for in the choice and positioning of the PV units and also enabled a coordinated effort in the renovation of the solarium and installation of the new technology. Prior to installation there was some concern over the effect of wind-blown sand and salt build up from the nearby shore, however this problem has not become evident.

EXAMPLE INSTALLATION OF A SMALL SCALE PV ON BUILDING 6

6. EXAMPLE INSTALLATION OF A SMALL SCALE PV ON A BUILDING

6.1. Description of the building

The selected building, situated in an urban environment of the city of Zagreb, serves as a public building (theatre). The building is connected to the local distribution grid via an existing consumer connection with a connected supply of 96 kW.

FIGURE 136.
ORTHOPHOTO OF BUILDING AND SUROUNDINGS

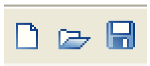
This three-storey building also has three terraces (flat roofs) on the top of building. The southern terrace (hatched in FIGURE 137) was selected for the installation of the PV modules. An external air conditioning device is situated on this terrace, which will be removed to the northern terrace. The roof is a concrete construction with satisfactory static parameters that can campaign the load from PV modules and the supporting structure.

FIGURE 137.
SOUTHERN TERRACE (view from NW)

6.2. Software Tool – PV*Sol

PV*Sol is a computer software used for simulation and calculation of PV systems, both off-grid and on-grid.

PV*Sol has a toolbar just below Menu bars, similar to the most Windows applications. A short description of these icons follows:



New project – opens new project

Open project – opens existing project

Save project – saves project

Technical data – selection of technical parameters and equipment

Climate data – selection of climate data

Feed-in tariff – selection of appropriate tariff system

Shadings – allows assessment of the shadings for location

Losses – defines other losses in system

System Check – determinates if system is sized correctly

Simulation – runs the simulation

Economic efficiency calculation – calculated financial payback of the project

Annual energy balance – presents technical calculated production of energy

Energy data – presents calculated energy production and other technical parameters of the system

Summary project report – creates short project report

Variant comparison – compares selected project with other project

Language selection – used for local language setup

MeteoSyn – used for loading/entering climate data

6.3. Pre-site visit calculations

Before the site visit, certain preliminary calulations are made, in order to ensure that reliable data is shared with the client. Firstly, the climate conditions upon which the productivity of the PV array depends – solar radiation and air temperarture. On the other hand, the economic parameters of the project should be explained to the client – estimated price of the system as well as annual earnings and payback period. All the data in this step are basically rough estimates of the real data.

6.3.1. Determination of climate conditions

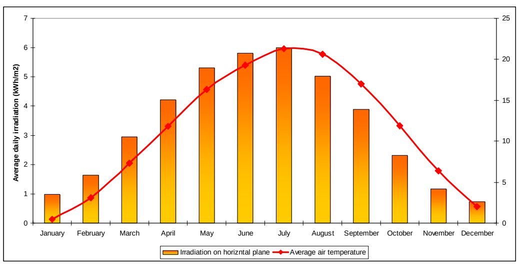
The productivity of a PV system basically depends on two climate factors: solar irradiation and air temperature. These data can be retrieved from local publications on solar energy potential, or from some on line services, such as PVGIS.

In the selected case, data on solar irradiation on horizontal surfaces and average monthly air temperatures are available in the Solar Atlas of Croatia, which has compiled atmospheric data for 30 years. Under "Climate data", data for a specific location can if available be selected. Such data may also be entered under the MeteoSyn button.

The city of Zagreb is situated in the interior of Croatia, an area that has somewhat lower solar irradiation than the coast, although the use of PV systems is economically feasible. Annual solar irradiation on the horizontal plane generates 1.20 MWh/m^2. If inclined at an optimal angle, which is possible in this case, annual solar irradiation should reach 1.37 MWh/m^2. Over the months, average daily irradiation on a tilted plane will range from a low of 0.96 kWh/m^2 for December, to a high of 6.12 kWh/m^2 for July.

Average air temperature ranges from a low of 0.8°C for January to a high of 20.1°C for July.

FIGURE 138.
SOLAR IRRADIATION AND AIR TEMPERATURE FOR SELECTED LOCATION



6.3.2. Provisional determination of PV productivity

Climate conditions determine the natural potential of any given location; however, the client will require further data. Instead of daily solar irradiation data, the energy that the system will produce will be of greater interest to the client. Experience from other PV plants in nearby areas show that expected PV productivity will be between 1000 kWh/kW$_p$ and 1100 kWh/kW$_p$, depending on the year and the equipment that is used. However, in this step, we can only share estimated data with the client. Real data will be calcauted when the equipment is selected. To do so, an on-line software tool (i.e. PVGIS see section 2.3Simulation software) is used, which estimates PV productivity in this case annually for 1040 kWh/kW$_p$.

6.3.3. Provisional financial calculations

The cost of a specific PV system depends on several factors. In this step, we only need to know the specific cost of the PV system. This is generally estimated on the basis of several offers from PV equipment distributors. The typical cost for smaller PV systems ranges from 3000 €/kW to as much as 3500 €/kW. In this case, the higher amount should be used, to ensure conservative calculations and sufficient room for adjustment.

6.3.4. Provisional calculations of annual income and payback period

Provisional calculations of annual revenue can be based on a 1 kW system, to ensure modularity of calculations. In which case, we may assume the following:

Annual energy yield: E = 1040 kWh/kW$_p$

Typical price for PV system: p = 3500 €/kW

Feed-in tarrif: t = 0.51 €/kWh (3.4 HRK/kWh)

With these data, an installed PV system of one kW will produce 1040 kWh each year, with an annual revenue of around €468. A simple calculation using this data will show that the payback period would be 7.5 years. However, it shoud be emphasized that no extra costs are taken into account, such as documentation, annual maintenance and inflation, meaning that after adjustment of the figure the client will be presented with a somewhat longer payback period.

6.4. Site visit

A site visit is made in order to get more detailed information on the potential site, such as surrounding shading, roof structure, possible cabling routes, etc. All the parameters are provisionally checked on site.

Before the site visit, a check list for the location is prepared. The following parmeters are checked at the site:

1. Roof structure
2. Dimensions of the roof
3. Shading analyisis
4. Grid connection point
5. Inverter placement
6. Possible cabling routes
7. Earthing and lightning protection
8. Possible ways of transporting the equipment

Relevant information is noted on the check list, along with photographs and copies of the relevant documentation.

6.5. PV system dimensioning

Dimensioning and selection of equipment used for the PV plant mainly depend on financial and technical factors, but also on the availability of the specific type of equipment. When selecting PV modules and inverters, their compatibility with IEC and national standards should be checked. Taking into account the profitability of the PV system, electricity production versus price should be considered for several offers. This is usually an iterative process.

In this case, the equipment is selected on the basis of several offers from different distributors.

6.5.1. Selection of the PV modules

Several different systems were simulated, in order to ensure selection of PV modules with a high energy yield at a reasonable price.

In this example, 230 W PV monocrystalline modules from local manufacturers were selected. These modules are certified by EN IEC 61215 and EN IEC 61730. The manufacturer's warranty on modules was 10 years, with a limited warranty on output power of 90% output power over a 12-year period, and 80% output power over 25 years. In general, this was in line with most of the monocrystalline and polycrystalline modules available on the market. The dimensions of the modules were 1.663x0.998 [m x m].

As an alternative, another offer was considered, with somewhat more expensive, but more technically advanced PV modules. The alternative modules had a slightly lower temperature coefficient, which should allow them to produce a little bit more energy at the same location than the former. These modules are also certified by EN IEC 61215 and IEC 61730, with a manufacturer's warranty of 10 years and a similar limited warranty on output power.

The final decision over which modules to install was made after presentation to the client of the simulation results showing their energy production and financial details.

6.5.2. Orientation and tilt of PV modules

Flat roofs have one big advantage over pitched roofs for installing PV modules, as the modules will face the south (in the northern hemisphere).

The optimal tilt of the PV modules depends of the geographic location and climate conditions. This angle is very similar for the most locations over a larger area with similar climate conditons on the same latitude.

For the selected area, the optimal angle is presented in the "Solar radiation handbook", and it is 28° at this location.

If the optimal angle is not known, it is possible to calculate it with PV*Sol. Once the climate and geographical data are programmed in PV*Sol, the optimal angle may be calculated by pressing the "Tilt angle Max Irradiation" button.

In the case of a flat roof, the optimal angle is recommended for calculation purposes. The angle of the roof as well as its orientation should be estimated or measured and entered in the appropriate fields (Orientation and Inclination) under the Technical Data→PV Array .

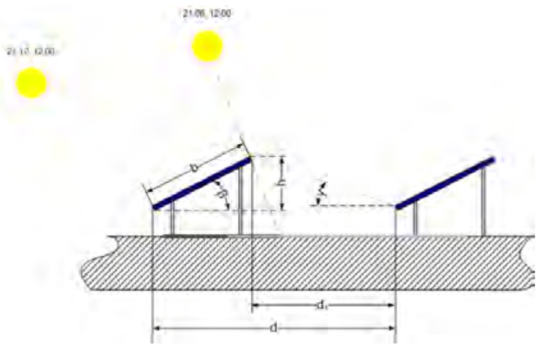
6.5.3. Determination of the appropriate size for a PV system

The physical dimensions of the roof, either flat or pitched will determine the maximum possible size (installed power) of the PV system on the building. Only the dimensions of the southern (or south-east/south-west) side should be assessed for a pitched roof, in order to calculate the efficiency of solar energy electricity production. Flat roofs may also be used for installing entire PV modules, but a minimum distance between modules should be observed in order to avoid shading. Whether a flat or a pitched roof is used, special care should be taken to avoid shading from existing objects on the roofs (chimneys, antennas, walls, etc) as well as other nearby objects.

In the selected case, the dimensions of the flat roof are 20 m in height (direction south-north) and 126 m in width (direction east-west).

On flat roofs, PV modules are mounted on fixed structures set at the optimal angle Modules should be placed in rows at a distance from each other, in order to avoid shading in the the worst possible scenario (winter solstice – 21 December at 12:00). Distance can be roughly estimated as at least 1.5 of the width of modules. Distance could be calculated more accuraly using the equation given in Chapter 2, or it can be simulated in PV*Sol which suggests appropriate distances between modules for selected cases.

FIGURE 139.
DISTANCE BETWEEN MODULES



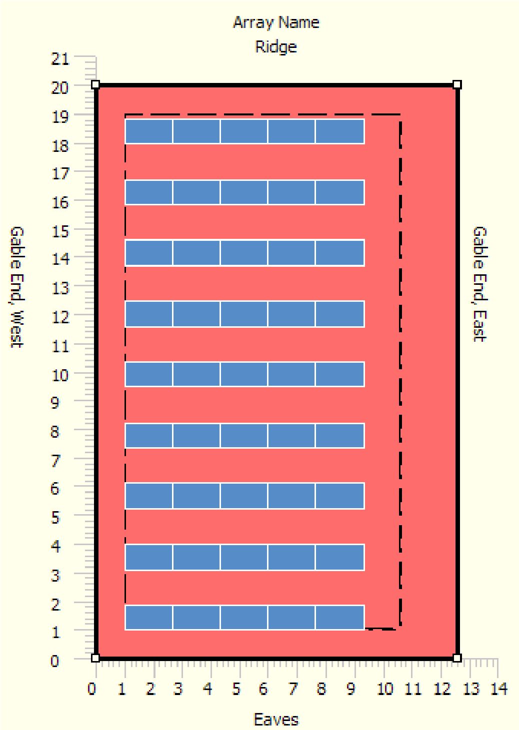
Determination of the appropriate size of the PV system on a roof may be done with either the software tool, or by manual calculation.

In PV*Sol, before determination, the “Free standing” installation type should be selected, as well as “Determinate Output from Roof area”.

Under the ‘Technical data → Roof parameters → Min Distance between Modules’ tab it is necessary to check “Use minimum Distance for Mounting” In the next tab (No of modules per roof), the dimensions of the roof should be entered, as well as margins from the edge of the building. In this case, the margins from the west and the south are set at 10 m, while the margin from the east is set at 2 m, in order to have a clear corridor, as the entrance to the roof is from that side. The margin from the north is selected as 0 m, as another terrace is behind it and the “Cover roof” button will cover the whole roof with PV modules. One single PV module may be removed with the ‘Delete element’ button, if necessary.

Taking the above mentioned parameters into account, for the first case (230 W PV modules), it is possible to cover the roof with 45 modules with a total installed capacity of 10.35 kW. In the second case (200 W PV modules), a total of 66 modules may be installed, with a total installed capacity of 13.20 kW. As some countries have different groups of PV plants which vary by size and receive different feed-in tariffs, the size of the PV array should be considered. In this case, PV plants with an installed capacity of over 10 kW receive less feed-in tariff than those below 10 kW. Thus, in the first case two modules are removed in order to meet 10 kW margin (not shown in the figure). Also, for the second case, 16 modules should be removed in order to allow a margin of 10 kW. When the modules are removed, there is extra space on the roof, which can be used if shadings need to be avoided. However, the final decision over the array size is taken when selecting an inverter.

FIGURE 140.
DISTIBUTION OF PV MODULES ON FLAT ROOF – MAXIMUM SIZE



In the case of pitched roof, either the "With ventilation" or the "Without ventilation" (according to the real process) option should be selected and only roof dimensions and margins should be entered.

6.5.4. Selection of an inverter

The inverter should be selected, in order to match the output values of PV system – output power, voltage and current. This calculation may easily be done with one of the numerous software tools, many of which are recommended by the manufacturers of the inverters. Under the Technical data → Inverter, PV*Sol will suggest suitable inverters for the system.

In the first case, 43 modules are selected although no inverter is found to match these arrays, thus a different number of modules should be selected. With 42 modules, PV*Sol suggests various matching inverters. In this case, one inverter with a 10 kW capacity was selected; however, various other choices could be made.

In the second case, we selected a similar inverter with an output power of 10 kW. A further two modules are removed, leaving a total of 48 modules, which was the selected option for the second case in order to meet the input voltage requirements of the inverter.

After selection of the inverter, the factors that affect production, such as cable length or cable cross-section, are entered using the "Losses" button, .

6.5.5. PV array configuration

Having selected an inverter, the PV array configuration is straightforward – PV module arrays must meet the input parameters of the inverter, e.g. input voltage and inverter current. This calculation may either be done manually or with one of the software tools, usually given by the inverter manufacturer.

PV*Sol has a built-in function for the configuration of the PV array, according to the input characterstics of the inverter. The programme will suggest a number of modules in strings and number of parallel strings.

The following configuration was arranged for the two cases:

- First case: 3 parallel strings of 14 modules in series,
- Second case: 4 parallel strings of 12 modules in series,

It should also be checked that the output parameters of PV modules and the input parameters of the inverter match each other. With the "Check" button, PV*Sol will check whether any discrepancies are found. Parameters such as Output check, MPP Voltage Check, Current Check and Upper Voltage Threshold Check are performed. PV*Sol will signal if any of these parameters are outside suitable borders. The parameters that have been checked in this way are presented in **¡Error! No se encuentra el origen de la referencia.**.

TABLE 26.
PV ARRAY AND INVERTER MATCHING PARAMETERS

	System 1	System 2
PV output per inverter [kW]	9.66	9.6
Inverter AC power rating [kW]	10	10
Sizing factor	97	96
Permisable sizing factor	78 – 108	78 - 108
Power check	✓	✓
Inverter MPP Tracking range [V]	333-500	333-500
PV Array MPP Voltage	382-471	382-471
MPP Voltage check	✓	✓
Inverter Max. System Voltage [V]	700	700
Module Max. System Voltage [V]	1000	1000
PV Array Open Circuit Voltage [V] (at G = 1000 W/m^2, T = -10°C)	604	600
Upper Voltage Threshold Check	✓	✓
Current though Cabling under STC [A]:	23	21
Max. Capacity of wiring [A]	171	136
Max. Current through Inverter [A] (1000 W/m^2, 25°C)	23.3	21.1
Max. Inverter Input Current [A]	31.0	31.0
Currents check	✓	✓
Sizing factor	97	96

Finally, the PV array configuration must be presented as a schematic diagram, which will give the installer an idea of how to connect the modules to the inverter, and the final inverter to the power meter and to other equipment that may be installed for the grid connection system. It should be noted that this is not a detailed schematic layout, as protection devices, such as surge protectors, earthing connections and blocking diodes are not included.

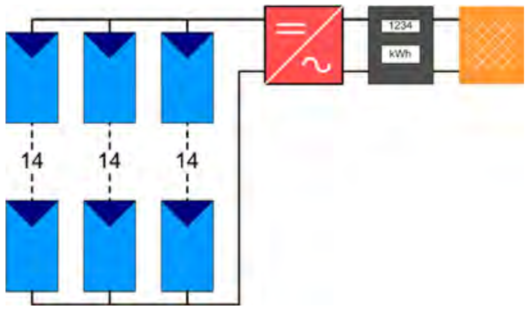
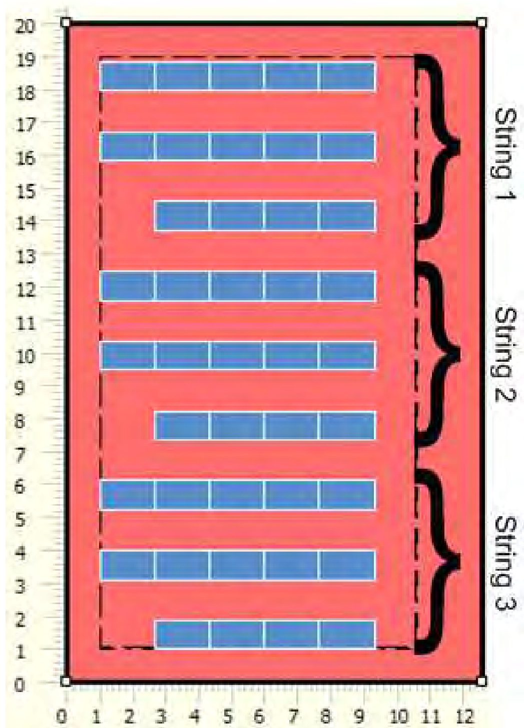


FIGURE 141.
SCHEMATIC LAYOUT OF PV SYSTEMS FOR FIRST CASE

6.5.6. Final distribution of PV array

The physical layout of the PV modules on the surface should be in line with the electrical layout and the connection between the modules. If possible, the modules placed in nearby rows should be connected to same string. FIGURE 142 presents the final layout of the modules on the roof, where three rows of modules are connected into one string.

FIGURE 142.
FINAL LAYOUT OF PV ARRAY

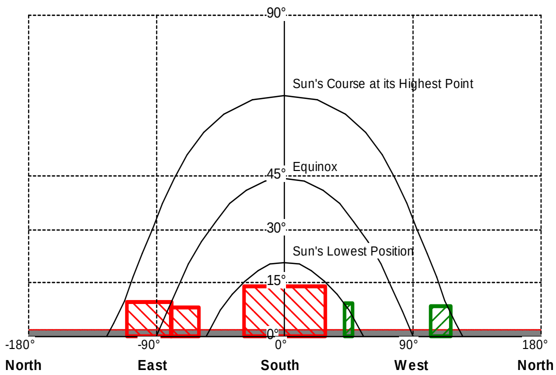


6.6. Estimation of shadings

Shading can affect the performance of a PV system. Shadings from nearby objects are especially dangerous, as even only partial shading of a PV module is enough to affect the output of whole array. Shading from trees should be also be given careful consideration, as trees will grow over time.

In PV*Sol, shading assessment is done under the "Shade" window, either by defining the distance and the height of the surrounding object, or by calculation of shadings from far away objects. Under the "List of objects", it is possible to define shading from surrounding objects by entering their height, distance and azimuth, which can be easily estimated on the field. Two types of shading can be selected: Building and Tree. Moreover, solar diagram shading can be assessed by entering the points (azimuth, height). The easiest way to determine shading in this way is by using shade analysis aids, such as Solar Pahtfinder.

FIGURE 143.
EXAMPLE OF SHADINGS AT THE LOCATION



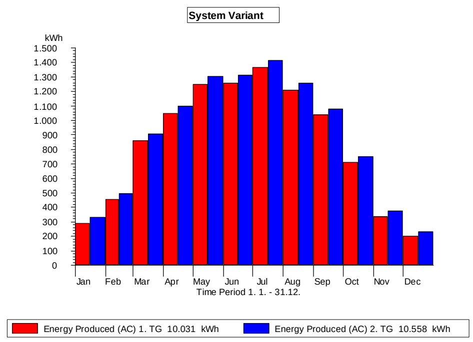
6.7. Estimating energy production

Energy production is expected energy generated by the PV system for average climate parameters. This figure can vary according to the climate parameters of a specific year, which are virtually impossible to predict. However, the simulation provides a reliable estimation of electricy production.

Having specified and entered all the technical and climate parameters, the performance of the PV system can be simulated by clicking on the "Simulation" button. After simulation, several selections of results may be viewed: Economic efficiency, Annual balance, Project report and Graphics.

The Graphics Report generates a graphic display of energy production per month, as well as other system parameters, such as inverter efficiency, module temperature etc.

FIGURE 144.
SIMULATION OF RESULTS – ELECTRICITY PRODUCTION



Estimated annual energy production in the first case is 10.031 kWh, while for the second case it is a little bit higher at 10.558 kWh. The difference between the two systems is obvious – the second system, even with slightly less installed power produces more energy. This is largely attributed to the lower temperature coefficient of the PV modules in the second case.

Estimated PV productivity for the area around the city of Zagreb is 1040 kWh/kW_p – in which case the calculated PV productivity in the first case is 1038 kWh/kW_p, and 1100 kWh/kW_p in the second case.

Estimated figures could be compared with real values from PV plants operating nearby. The figures for a PV plant of a similar size (in this case 9.59kW) is presented in TABLE 27.

TABLE 27.
PRODUCTION OF ELECTRICITY IN A 9.59 kW PV PLANT OVER THREE YEARS

Year	Generated electricty [kWh]	PV Productivity for year [kWh/kWp]
2008.	9,418	982
2009.	9,881	1,030
2010.	8,802	917

6.8. Financial calculation

The financial aspect of the PV plant is a strong motivation for many PV plant developers. As many developers are aware of the feed-in tariffs, they should also be fully informed about the financial consequences: equipment cost, project development cost, annual income, maintenance cost, payback period, internal rate of return etc.

6.8.1. Equipment cost

Equipment costs may generally be estimated from previous offers or from previous experience, but the best way to estimate real equipment costs are quotes from local PV equipment distributors. Therefore, quotes for equipment were requested from several distributors for this project, and two of about ten quotes were selected for analyisis. These quotes have already been presented in previous subchapters. The equipment costs are presented in TABLE 28.

TABLE 28.
BREAKDOWN OF OFFERS FOR PV EQUIPMENT (€)

	System 1	System 2
PV modules	14,179.2	19,289.6
Inverter	2,906.6	3,133.3
Cables, boxes and other BOS	2,340	2,600
Support structure	3,200	2,866.6
Installation works	2,466.6	2,800
Total (€)	25,092.5	30,689.6

The figures in the table are based on the quoted prices in HRK. Exchange rate 1€=7.5 HRK. Figures for illustrative purpose only.

According to these two quotes, the total cost in the first case is around €5,000 less than in the second case. However, it should be noted that the energy production in the second system was higher in the simulation.

6.8.2. Cost of project development

Equipment costs are considerable in the case of the PV system. However, project development costs (documentation, eligible producer status procedure) should not be neglected. This cost depends on the specific legislative requirements in each country and should therefore be estimated by a local expert. Estimates for Croatia, based on the administration of previous projects, rounds the cost of project development up to €5,000, which is quite high compared with the equipment costs alone. Maintenance costs for a PV system often include an annual check-up of the system and cleaning of the PV modules. Although generally considered a low cost that may be neglected, the fact is that these costs should not be ignored in calculations. In general, this cost may be estimated as a percentage of the total investment (1 – 2 %). In this case, based on quotes from equipment distributors, the maintenance costs are estimated at 400 €/year.

6.8.3. Annual income

Annual income is the sum paid by the market operator to the owner of the plant, in accordance with its electricity production. Generally, it is based on two factors: level of feed-in tariff and electricity production. Module deterioration should be taken into consideration, when calculating depreciation over the entire lifetime of the PV equipment. It is expected that this factor will influence electricity production by 10% over 12 years, and by a further 25% over 25 years.

In these cases, the income of the first system under the Croatian feed-in tariff system will be €5,115 in its first year of operation. This is lower than the income of the second system, in its first year of operation, which is €5,384.

6.8.4. Economic efficiency calculation

Calculation of economic efficiency can either be done manually, or with the calulators included in the PV simulation software. PV*Sol has a tool for quick economic efficency calculation. This is done by selecting Calculation → Economic efficiency calculation on the toolbar.

In the first step, the feed-in tariff system should be selected, as well as the start date of the PV plant operation and annual depreciation. If not available, feed-in tarrifs can be set in the Feed-in tariff window.

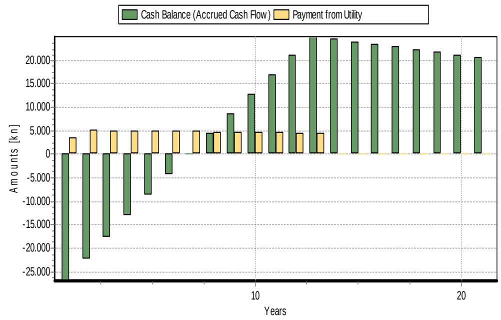
The second step offers general parameters for economic calculation, where it is possible to select an assessment period in years (20 in this case) and interest on capital (4% in this case).

The third step is the cost sheet, where all the costs are summerized. Under the first three fields, tax deductible and undeductible costs are entered, as well as direct subsidies (if any). All of these costs can be itemized as specific costs. Another field calculates annual operating costs, annual consumption costs and other annual cost and savings.

In the fourth step, the type of financing can be selected. In this case, we will assume that the project developer has own capital for the PV plant and that no loans are needed.

The next step is to present the results of the economic efficiency calculation (Capital Value, Amortization Period and Net Yield). The results of the economic simulation for the first system are shown in FIGURE 145. Note that the cash balance reaches a positive value when the investment is paid back. The depreciation factor for the PV modules can be seen from the utility payment graph that decreases over the time. The Croatian feed-in tariff payment is guaranteed for 12 years, and no further payment from the utility may be expected after that period.

FIGURE 145.
ECONOMIC SIMULATION RESULTS – CASH BALANCE AND PAYMENT FROM UTILITY



The final decision to select one of the two systems will be based on a range of parameters, but it will mainly be based on economic-financial factors. TABLE 29 shows basic results from the economic simulation. System 2, with higher productivity estimates, which led to higher revenues from the utility, had a longer amortization period than System 1. It also had a lower Net Yield than the first one. This is mainly due to the fact that it is a little more expensive than the first one. However, investment in both systems is quite profitable, as they will both provide revenue over their working life.

TABLE 29.
CONOMIC COMPARISON OF TWO SIMULATED SYSTEMS

	System 1	System 2
Capital Value (€)	10,010	6,864
Amortization period (years)	8.1	9.3
Net Yield	9.3 %	7.1 %

6.9. System Installation

6.9.1. Installation workplan

The installation workplan should clearly set out the steps and procedure that an installer should follow when installing the PV system. This process requires the PV installer to cooperate closely with other personnel, especially DSO personel, responsible for the grid connection of the system. The main steps are as follows.

1. Preparation works,
2. Mount support structure (prefabricated),
3. Earth support structure on the existing earthing,
4. Mount DC combiner box,
5. Laydown conduits and cables from modules to combiner box, and from combiner box to inverter,
6. Mount inverter and DC disconect switch (in “OFF” position),
7. Place power meter and AC switch (“OFF” position) – done by DSO personnel,
8. Laydown cables from inverter to power meter,
9. Place modules on the support structure and secure it,
10. Connect electrical wiring from PV combiner box to DC switch, and between DC switch and inverter
11. Connect cables from strings into the PV combiner box,
12. Connect modules into strings,
13. Check voltages inside combiner box,
14. Turn DC switch on,
15. Turn AC switch on – to be performed by DSO personel

6.9.2. Preparation works

The roof of the building where a PV array will be mounted must be cleared prior to the instalation of the system. Easily movable devices, such as antennae should be removed from previouly identified locations on the roof. Other objects should be removed from the roof, if possible.

Once the roof area is cleared with no unnecesary objects on it, the area should be made easily accessible for the installer.

The PV modules, support structure and other equipment must be carefully transferred to the roof. This may either be done manually or with an appropriate crane. If done by hand, the weight and dimensions of the PV modules should be given careful consideration. In this case, the modules were lifted from the ground to the roof by a crane mounted on the northern terrace of the building.

PV modules, supporting structures and other equipment should be stored in an easily accessible position. Stored PV modules and supporting structures should not hamper the installer at work. The northern terrace was selected for storage location, as it was close to the crane and the PV array was not mounted in this area.

6.9.3. Mounting the support structure

Support structures for PV modules come in many different forms. Metal support structures are widely used, as are plastic containers filled with gravel or even wooden support structures. Support structure must be mounted according to the manufacturer’s instructions, and checked to see that they are properly fastened.

FIGURE 146.
EXAMPLE OF PREFABRICATED METAL SUPPORT STRUCTURE (WITH MODULES) FOR METAL ROOFS

In most cases, the support structure is mounted on a foundation. Foundations are either concrete blocks or large metal frames. These structures are often fastened to the roof, which should be done with care in order to avoid eventual leakage points. FIGURE 147 shows a metal foundation frame on the flat roof of a public building. It can be seen that metal rails are mounted directly on the roof. Two metal rails are laid in place along an east-west axis (horizontal) for each PV module row, and additional ones are laid in place along a north-south axis (vertical).

FIGURE 147.
METAL FOUNDATION FRAME

The support structure is mouted on the foundations. It consists of three rails, which are fastened together in the shape of a triangle. If necessary, the angle of the modules should be checked, and the support structure should be adjusted at an optimal angle. Two additional rails are mounted over the support structure along the entire length of the rows of PV modules, to which the PV modules are secured.

FIGURE 148.
SIDE VIEW ON MODULE SUPPORT STRUCTURE (Source: ETEK)

6.9.4. Mounting of conduits and cables

Conduits should protect cables from severe weather, direct sunlight and different mechanical impacts. Conduits can be placed on the ground or on the support structure behind the PV modules, and routed to the combiner box in the victinity of the PV module rows.

Cables in the conduit should not be loosely placed; however, they should they be fastened too tightly. In this case, the cables were placed inside plastic conduits mounted on the back of the module support structure. Cables should also be placed in the conduit to avoid any possible unauthorized access.

FIGURE 149.
CABLES AND CONDUIT PLACED BEHIND PV MODULES

All the cables must be routed inside the conduits to the PV combiner box. The entrance of the cables into the combiner box should be properly sealed to prevent leakage into the box. If possible, cable entrances should be placed facing downwards.

6.9.5. Placing and inverter

The inverter should be placed in a previously selected location. Some inverters may be placed outside, near the PV array. Others should be placed inside. Inverters are often wall mounted, thus additional space between two inverters or an inverter and other equipment should be secured, in order to satisfy the requirements for inverter ventilation.

FIGURE 150.
PLACING OF INVERTER

DC and AC switches should be placed near the inverter. It is neccesary to ensure access to these two switches.

6.9.6. Placing a modules on support structure

PV modules should be placed on the support structure after all preparatory work (mounting of support structure, laying down conduits and cables, mounting inverter and switches) has been completed. Modules should be placed on two parallel rails over the support structure. The modules are fastened on these rails with special tools and mechanisms (FIGURE 151). However, as these systems differ from one manufacturer to another, the manufacturer's instructions should be followed. Modules should be placed one next to another, bearing in mind that they need to be electrically connected.

At this point, no module should be electrically connected.

FIGURE 151.
FASTENING A PV MODULE TO A RAIL (Source: SOLVIS)

6.9.7. Electrical connection

The electrical connection of the system should be done with great care, as in some cases it is imposible to turn off some parts of system, which means that some wires are live during the connection process. This safety measure mainly concerns the connection of PV modules and the grid connection. Thus, these two tasks should be performed at the end. The electrical connection should be done with both the DC and the AC switches in the "OFF" position.

Before the electrical connection of the different componets, the voltage across the lines should be checked.

The first step is to connect the PV combiner box with the DC disconnect switch, the inverter and the AC disconnect switch. When connecting DC cables to the inverter, the correct polarity should be observed. In the PV combiner box, the polarity, as well as the differences between cables from different strings should be observed.

Electrical connection of the PV modules to the strings is done with special connectors. PV modules should have connector boxes with a sufficient length of cable, so that they can easily reach the cables and the connectors on two nearby modules. Connectors are easily inserted into each other, while loose cables should be fastened at the nearest point.

If possible, this task should be done at nightime or with covered PV modules, in order to avoid a risk of electrocution.

FIGURE 152.
ELECTRICAL CONNECTION OF THE MODULES – BACKSIDE

The final step is to connect the power meter and the whole system to the grid. This is usually performed by personnel from the local DSO. In most cases, this task should only be perfomed by authorized personnel, as it implies working with a live mains power supply. At this stage, the mains electrical supply is connected to a power meter and then to the AC switch.

6.9.8. Testing and commissioning

During the testing and commissioning phase, all of the electrical parameters of the system should be checked in accordance with the established procedure. It is also important to test the impact on the electrical network and the parallel working of the system. The PV plant should comply with any special DSO regulation or requirement. During the testing phase, the following parameters should be checked and measured:

- Irradiation level
- DC Voltage over the strings
- DC Current over the strings
- AC Voltage from grid
- Frequency of voltage from grid
- AC Current from the inverter

DSO personnel should check for any requirement on the PV plant or any impact of the PV plant on the electrical grid. This usually includes checking for flickers, disconnections in case of failure etc, and should only be done by authorized personnel from the DSO.

6.10. Small-scale installation safety plan

Preventing electric shock by working on de-energized circuits is a key to electricity safety Solar electric systems have two sources of electricity: the utility and the solar electric system. Turning off the main breaker does not stop a solar electric system from having the capacity to produce power. Photovoltaic installations can be made inherently safe, as can most building services installations, provided any hazards associated with their installation and use in buildings are properly addressed

The process of improving safety during construction, operation and maintenance requires:

- compliance with the requirements of the law, PV system codes and standards
- following manufacturers' recommendations
- following best practice

In this project, the safety and protective measures were systematically applied in accordance with all applicable Croatian and European standards for such systems

To ensure safe and continuous operation of PV systems through their lifetime, it is necessary to ensure complete protection from lightning and induced surges right from the planning and the project implementation phase. Protection must be provided not only on the output side of the inverter, but also on the output side of the PV modules

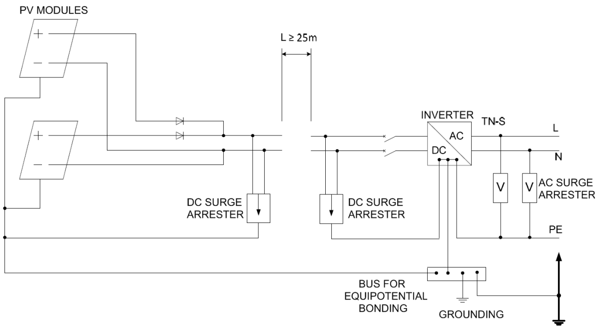
Photovoltaic systems are usually installed on rooftops, where there is a higher probability of lightning strikes (i.e. lightning surges). In accordance with standard EN 62305-2 direct or indirect lightning strikes are categorized as an expected risk of damage to a photovoltaic system

For this project, the photovoltaic system protection of atmospheric and induced surge was performed in accordance with European Union standards EN 60364-7-712, EN 61 173 and groups of standards EN 62305

As the core of a photovoltaic system is the inverter, protection from lightning and surges must focus on the inverter, and at the same time that protection should include the entire photovoltaic system

As the distance between the bus terminal array of photovoltaic modules and inverter was greater than 25 m, the surge arresters were installed at both points. An outline of the PV system is shown in the following diagram.

FIGURE 153.
OUTLINE OF THE PV SYSTEM



The PV modules are mounted on the roof with the existing lightning arrester installation, which minimizes damage to the PV system at the permitted distance between the PV modules and lightning arrester installation As in this example, the distance has to be greater than 0.5 m.

When a distance greater than 0.5 m is not possible, it is necessary to establish a conductive connection between the PV modules and the lightning arrester installation, which is connected to the earth. Its purpose is to prevent lightning currents flowing through the structural framework of photovoltaic modules. If the construction of PV modules is not conductively connected to the lightning arrester installation or the house does not have lightning protection installation, then it is necessary to connect the structure of PV modules to the earth. Grounding provides a rapid discharge of current into the surrounding soil. Deeply embedded steel or copper rods or plates are used for grounding

The inverter is protected by surge arrester on DC and AC side. The surge arresters on the DC side were selected according to the open circuit voltage of the photovoltaic source.

Due to weather conditions, rainfall, solar radiation and high temperature, the photovoltaic modules are connected between each other by a H07RN-F cable.

20 Amp DC switches were used for the modules protection and 16 Amp and 25 Amp circuit breakers type B were used for the converter protection, as recommended by the manufacturer.

The minimum request to achieve parallel operation is set in a way that protection of the inverter starts functioning (i.e. to act on switch) and insulates the PV system from the network, if there is any frequency or voltage deviation (overvoltage or under-voltage). The boundaries of possible deviations are factory settings for each inverter and meet EU standards.

6.11. Exercises

1. What actions should be undertaken prior to the site visit? (choose 3)
   a) Initial estimation of the plant with respect to the available roof area,
   b) Collection of climate data,
   c) Plan in details the wire runs
   d) Draft estimation of the output
   e) Plan the precise location of BoS

2. Use PVGIS http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php to estimate the expected PV output in Istria (Croatia). (Poly-Si, module, optimized slope)
   a) Approximately 1,200 kWh/kWp
   b) Approximately 1,600 kWh/kWp
   c) Approximately 800 kWh/kWp

3. Check the feed-in tariff in your area for different sizes of PV system (10 kW, 30 kW).

4. If the cost of a 10 kW PV system is €33,000, estimate the payback period for an area with an average annual production is 1,220 kWh/kWp and the FIT is of 0.51 €/kWh.
   a) Approximately 9 years
   b) Approximately 5 years
   c) Approximately 2 years

5. Estimate PV annual production for the system of question 2 facing southwest with an inclination of 15°. What is the difference regarding a system with optimal tilt?
   a) Almost 100 kWh/kWp reduction
   b) Almost 100 kWh/kWp increase
   c) There was no difference

6. What data should be collected on site? (Choose 3)
   a) roof orientation and inclination
   b) equipment characteristics
   c) location of shadings
   d) climate data
   e) possible locations for placing BoS

7. The building has a two-pitched roof. One faces south-east, and another north-west. The inclination of the roof is 15° and its dimension is 10 x 5 [m x m]. Select one module type of 200 W.

   7i. Choose part of the roof on which to place the PV modules.
   a) north-west
   b) southeast slope

   7ii. Estimate the possible power of PV plant in case PV modules are placed in landscape (module's dimensions 1.58m x0.808m, 200 W, and from each end of the roof, 0.5 m for margin must be selected).

a) 4 kW (4x5x200 W)
b) 5,6 kW
c) 8 kW

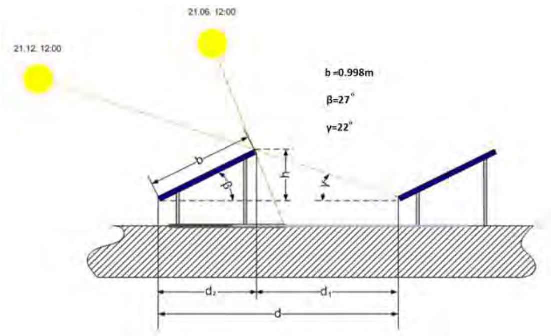
7iii. Estimate the possible power of PV plant in case PV modules are placed in portrait.
a) 4 kW
b) 4,4 kW (2x11x200W)
c) 8 kW

8. In case of a 4.4kW PV system with 22 modules in 2 series, select an inverter that will match the output characteristics of PV array. Present the configuration of the array and the inverter/s. (note: multiple inverters could be selected).

9. Calculate the angle of shading from a pole that is located 25 m to the east of the PV array, at a height of 10 m above the modules. Place it in a solar diagram. Does it obstruct direct sunlight to the PV system?

10. Calculate the angle of shading from a tree situated 10 meters to the south at a height of 5 meters above the modules.
a) 30°
b) 26.6°
c) 60°

11. For the PV system in the figure below estimate distance d so that the second row is not shaded.



a) 0.998m
b) 2.0 m
c) 2.7m

MAINTENANCE AND TROUBLESHOOTING 7

7. MAINTENANCE AND TROUBLESHOOTING

This chapter aims to provide valuable information on maintenance and troubleshooting of the PV systems.

7.1. Maintenance plan

7.1.1. Periodical inspection

Photovoltaic systems have proved that they need very little maintenance, assuming that good design rules have been followed and the appropriate quality control procedures have been applied to the installation and commissioning process. Many installers and PV owners claim that the PV systems are “maintenance free”. Nonetheless, photovoltaic systems require a periodical inspection to confirm that the system is working properly and has no faults or failures. Inspection frequency and maintenance of the photovoltaic systems should be once annually. More specifically, at the first year of the operation of the PV system; the inspection can be performed more frequently because most of the problems are usually encountered at the beginning of their life. Nevertheless, the frequency of inspections and maintenance is determined by the “maintenance contract” agreed between the owner and the installer.

In the case of stand alone PV systems, batteries require more maintenance which is dependent on their type, the charge/discharge cycles and application. In the periodical inspection, a checklist has to be carried out and followed for the whole installation, to check performance of the parts of the system. A “small” fault in the PV system (especially in larger systems) may have obvious negative results on the performance level of the system and therefore on its electricity generation. The PV system can be inspected through monitoring, but the annual site inspection is necessary to check each part of the system. For stand-alone systems, the installer should provide the owner with some basic maintenance instructions.

For PV systems which are grid connected, energy production should be recorded (kWh, Amperes, Volts) and checked. These results, which should be sent to the installer (depending also on their contract/ agreement) may reveal possible defects in the system. Keeping monthly and yearly records of the energy production is very useful to confirm the proper operation of the PV system (NABCEB, 2005).

FIGURE 154.
KEEPING RECORDS FOR ELECTRICITY PRODUCTION FROM PV GRID CONNECTED SYSTEMS, CYPRUS. (Source: Cyprus Energy Agency)

7.1.2. Dirt accumulation

The most common maintenance task for solar modules is the cleaning of the glass area to remove excessive dirt. The arrays are cleaned when the temperature is not very high, typically in the morning or late afternoon.

Layers of dust and dirt from the modules can be removed by washing the module with water. In most situations, cleaning is only necessary during long dry periods when there is no rain to provide natural cleaning.

The frequency of cleaning depends on each installation's conditions. For example, when a PV system is installed close to a dusty area, the arrays should be cleaned more frequently. During periods when rainwater is frequent, the dirt on the array is cleaned from the rain and doesn't need any further cleaning. In case of thick dirt on the surface of the array, warm water or a sponge may be used to remove the accumulation of dirt. Any sharp tool or detergent should be avoided (Nicola M.Pearsall & Robert Hill, 2001).

FIGURE 155.
PERIODICAL INSPECTION OF A PV GRID CONNECTED ROOF SYSTEM, CYPRUS. (Source: Conercon Ltd, Cyprus)

If any obvious defects (e.g. crack) are observed in the module at the time of cleaning or during the annual inspection, this should be noted and monitored, in order to ensure the correct operation of the array. The frames of the modules should be inspected and observed for any defects.

7.1.3. Battery maintenance

Regarding stand-alone systems, battery maintenance is perhaps the most important maintenance task.

FIGURE 156.
BATTERY INSPECTION IN STAND-ALONE PV SYSTEMS, CYPRUS. (Source: Cyprus Energy Agency)

Battery maintenance depends on the type, the charge/discharge cycles and application of the batteries. The two tasks which have to be performed are the addition of water and the performance checks. Performance checks may include specific gravity recordings, conductance readings, temperature measurements, cell voltage readings, and even a capacity test. Battery voltage and current readings during charging can be helpful in determining whether the battery charge controller is operating properly. Flooded lead-antimony batteries require the most maintenance with regard to water additions and cleaning. Sealed lead-acid batteries including gelled and AGM types remain relatively clean during operation and do not require water additions. Battery manufacturers provide maintenance recommendations for the use of their battery (James P.Dunlop, 1997).

7.1.4. Inverter maintenance

The main task regarding inverter maintenance is to check its diagnostic system. When the inverter is installed in an internal space, the inspection and the cleaning of the inverter should take place more often. Thus, it is important to check that the inverter is functioning correctly by observing LED indicators, metering and/or other displays. Moreover, the area around the inverter should be kept clear to allow good air flow for proper cooling. Furthermore, checking several inverter protections is also important.

FIGURE 157.
INSPECTION OF INVERTERS IN GRID-CONNECTED PV ROOF SYSTEMS, CYPRUS. (Source: Conercon Ltd)

When an inverter breaks down and there is a “Guarantee” from its manufacturer, then, it should be replaced by the manufacturer within a few days. The terms and provisions included in the Contract between the installer and the owner are very important. They should include an indemnity clause to cover production losses and failure to repair the system within a certain period (less than 48 hours).

7.1.5. Charge controller maintenance

Charge controller maintenance occurs during the same period with the other PV parts inspection. It consists of diagnostic procedures and voltage testing. Charge controller instructions and displays should be followed.

7.1.6. Maintenance tools and equipment

Multimeters and DC and AC clamp-on ammeters are used for the measurement of the voltage and the current at the DC and AC side. The multimeter may also be used to check the connectivity of the cables during the installation.

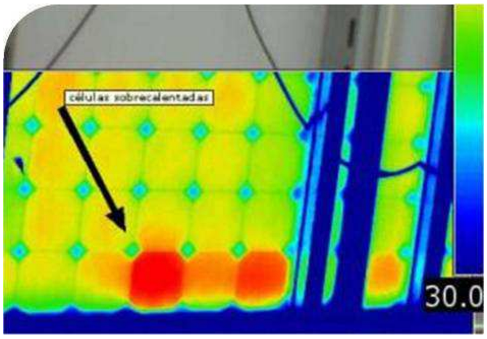
A portable instrument that measures resistance is used to measure grounding resistance and the insulation resistance of the cables.

A pyranometer or irradiance meter is used to measure sunlight irradiance. The pyranometer that is used by the PV troubleshooter has to be an instrument that can measure total irradiance on the array from all directions (i.e., direct and scattered). The pyranometer must be facing the same direction as the array to properly register the irradiance incident on the array. If the PV array has multiple orientations, the irradiance must be measured for each orientation.

In the case of battery maintenance in stand-alone PV systems, a hydrometer is usually used to check the specific gravity of the electrolyte in battery cells. The caps of the cells are removed and the hydrometer is used to withdraw electrolyte into the hydrometer. The hydrometer incorporates a float that will float higher at a higher specific gravity and lower at a lower specific gravity. If the specific gravity is significantly lower in one cell more than in the other cells of a battery, it is an indication of a bad cell. If after a normal charging period, filling the cell with distilled water and then applying an equalizing charge to the battery does not increase the specific gravity, then the cell or battery will need to be replaced. Additionally, protective mask, gloves and other protective equipment should be used during battery maintenance.

An infrared camera (thermographic camera) can also be used during inspection and maintenance, in order to identify hot spots in the PV system (e.g. on cells, junction boxes, PV panels) (NABCEB, 2005).

FIGURE 158.
DETECTION OF A HOT SPOT IN A PV PANEL USING A THERMOGRAPHIC CAMERA (Source: http://www.leonardo-energy.org/)



7.1.7. Shading

Shading sources can be avoided during the design and installation of the PV system. Shading from other buildings or other equipment can be avoided from the start of the project.

In general, when the PV array is placed on the roof shading sources related with vegetation, such as trees, are more severe. However, the conditions might change if actions not taken to control the growing of trees, which can cause substantial loss in the energy generation of the system. It is not necessary to remove the trees or other vegetation but just to ensure that they stay low enough to prevent significant shading of the array.

The owner of the system should understand the importance of the absence of shading and during maintenance –apart from pruning any vegetation– should look for shading equipment on nearby roofs e.g. installation of aerials, TV satellite etc. Moreover, the owner has to ensure that nothing is installed on his own roof that might cause shading to the PV array (DTI,2006).

FIGURE 159.
POSSIBLE SHADING FROM GROWING VEGETATION. (Source: Terza Solar Ltd)

7.1.8. Electrical connections check

The electrical circuit should be checked on a regular basis (usually every 4-5 years), to ensure that there are no problems with loose connections, corrosion etc.

FIGURE 160.
ELECTRICAL CONNECTIONS MAINTENANCE. (Source: Conercon Ltd)

7.1.9. Other damages

A PV system can be damaged by many unforeseen factors such as: extreme weather conditions (earthquakes hail, storms, lightning, flooding, etc), fire, explosion, intentional acts of third parties, sabotage, theft, animal bites, war, intentional acts of the owner, nuclear energy. Lightning, especially, can cause damage to the PV modules and inverters. Surge arrestors on the DC side (and sometimes on the AC side) should be installed for the protection of the inverters for lightning. Structures and PV module frames must be properly grounded.

Photovoltaic insurance cover damages to the PV system from several types of unforeseen damage (Electric Market Authority, 2011).

7.2. Common mistakes and failures

7.2.1. Introduction

As PV systems have now been in operation for many years, a store of useful information has been accumulated on their typical faults and problems.

7.2.1.1. Insulation failures

Over recent years, the quality of module connections has significantly improved since the widespread introduction of plug connectors. The use of cable ties or wiring that is not UV or temperature resistant has proven highly problematic. Insulation also needs to withstand mechanical loads. All insulation ages over the course of time. For electrical power supplies, the physical operating life of power cables is generally specified as 45 years. Insulation can also be damaged by UV radiation, excessive voltage and mechanically. Suitable protection for cables is readily available on the market. Any insulation fault – whatever the cause - on the DC side can result in arcing, which is a serious fire risk. In consequence, all wiring should be periodically checked for any mechanical or thermal damage. The best way to do this is to measure the insulation resistance.

Automatic insulation monitoring, as performed by many inverters, is therefore a very useful feature. It signals an insulation fault and the inverter then isolates the system from the grid. However, the illuminated PV array will still supply direct current to feed the arc. Consequently the fault cannot be isolated by the inverter. If an insulation fault is indicated, the cause of the fault should be traced as quickly as possible. In a system with one or two strings, wiring faults can be detected by checking the inverter.

7.2.1.2. Inverter failures

The most frequently reported faults according to a great many studies are inverter faults (63%). However, there have been considerable improvements in this sector over time. A common fault is incorrect dimensioning and/or incorrect cable or voltage matching with the PV array. Most PV installation firms have now overcome this problem, and simulation software programs and design tools from inverter manufacturers also provide support in this area. Other sources of inverter trouble are voltage surge effects caused by electrical storms or grid switching, ageing and thermal overload. Further failures are simply due to device faults (DGS, 2008).

7.2.1.3. Construction failures

A common failure regarding PV mounting systems is the distortion of the PV modules when they are installed on the roof, in order to form a flat array surface mechanically. Under the influence of temperature and wind, or over the course of time, the module glass may shatter. Typical faults in PV mounting systems are an absence of expansion joints between modules or too few roof hooks to take account of the wind load. Moreover, the wrong choice of materials can cause corrosion on the mounting frame and compatible materials should be used at all times (DGS, 2008).

7.2.2. Common mistakes

Mistakes in a PV installation can be minimized, by ensuring appropriate design, installation and maintenance. Usually, most mistakes occur in PV installations during installation. In this sub-section, the most frequent installation mistakes are listed (Brooks Engineering, 2010).

Common Installation Mistakes with Array Modules and Configurations:

1. Changing the array wiring layout without changing the submitted electrical diagram.
2. Changing the module type or manufacturer as a result of supply issues.
3. Exceeding the inverter or module voltage due to improper array design.
4. Putting too few modules in series for proper operation of the inverter during high summer array temperatures.
5. Installing PV modules without taking account of the Impp of each module (grouping).

Common Installation Mistakes with Wire Management:

1. Human mistakes regarding the wire connection during installation.
2. Not enough supports to secure the cable properly.
3. Conductors touching roof or other abrasive surfaces exposing them to physical damage.
4. Not supporting raceways at proper intervals.
5. Multiple cables entering a single conductor cable gland
6. Not following support members with conductors.
7. Pulling cable ties too tight or leaving them too loose.
8. Not fully engaging plug connectors.
9. Bending conductors too close to connectors.
10. Plug connectors on non-locking connectors not fully engaged

Common Installation Mistakes with Module and Array Grounding:

1. Not installing a grounding conductor on the array at all.
2. Not connecting the different parts of the modules together to achieve equal potential grounding
3. Using indoor-rated grounding lugs on PV modules and support structures.
4. Assuming that simply bolting aluminium frames to support structures provides effective grounding.
5. Installing an undersized conductor for grounding
6. Not installing lightning protection properly

Common Installation Mistakes with Electrical Boxes, Conduit Bodies, and Disconnecting Means:

1. Installing disconnects rated for vertical installation in a non-vertical application.
2. Installing incorrectly rated fuses in source combiners and fused disconnects.
3. Covering boxes or conduit bodies leaving them almost inaccessible for service.
4. Not following manufacturer’s instructions for wiring disconnect on the DC side.
5. Installing dry wire nuts in wet locations and inside boxes that routinely get wet.
6. Using improper fittings to bring conductors into exterior boxes.

Common Installation Mistakes with Mounting Systems:

1. Not using supplied or specified hardware with the mounting systems.
2. Not installing flashings properly.
3. Not using the correct roof adhesives for the specific type of roof.
4. Not attaching proper lag screws to roofing members.
5. Not drilling proper pilot holes for lag screws and missing or splitting roofing members.

7.2.3. Troubleshooting

The fault correction method depends upon the type of fault and the type of PV system. First, customers should be asked when and how the fault came to their attention. Circuit diagrams and a technical description of the system are very helpful. Before taking measurements, a visual check of the PV system should be carried out – in particular, of the PV array – to check for mechanical damage and soiling. Wiring and electrical connections should also be checked.

The measurements required to find faults in grid-connected systems are essentially the same as those required for commissioning. Today, increasingly, remote diagnostics via a modem and PC are also possible with more modern inverters.

The step-by-step troubleshooting procedure is described in the following paragraphs:

<u>Step 1: Inverter and PV combiner/junction box</u>

Firstly, the measurement check of the inverter and the PV combiner/junction box should start with the respective connecting wires. Test the inverter operating data, by checking the LED or error code, or by using remote software and a laptop. The inverter's operating data records can give useful information for the localization of the faults. For the measurement check, test the AC side and then the DC side at the inverter. Then, check the DC cable and the DC main disconnect/isolator switch. When measuring the insulation resistance, the resistance to the ground potential should be at least 2MOhm.

<u>Step 2: Ground and short-circuit faults</u>

Ground and short-circuit faults can be detected by following the troubleshooting procedure, but the PV strings should first be separated and measured individually. To do this, first switch off the inverter and, if present, switch off the DC switch or DC switches. Then one module per string should be completely darkened by covering it from sunlight. Now the strings can be separated without the danger of arcing and measurement can begin.

<u>Step 3: String fuses/diodes/modules</u>

The voltage at the string fuses and diodes can be measured during operation by using a voltmeter in parallel. If excessive differences are present in the individual string voltages and/or string short-circuit currents, this is either an indication of excessively high mismatching in the generator or an indication of an electrical fault in one or more strings. It may therefore be necessary to take individual measurements at the modules of the corresponding string. For longer strings, divide the string in half and find out which is the faulty half of the string. Then, use the same method on the faulty half of the string to identify the faulty module. The module connections and bypass diodes should also be tested.

<u>Step 4 Open-circuit voltage and short-circuit current</u>

Measurement of the open-circuit voltage and the short-circuit current is very important for monitoring the operation of the system but the current irradiance of the area should also be recorded.

Some typical failures which are encountered in PV installations are listed in TABLE 30 below. On the right side column the possible reasons for these failures are reported alongside corrective measures in order to troubleshoot the problem and put the system back in operation (DGS, 2008).

TABLE 30.
TYPICAL FAILURES, CORRECTIVE MEASURES AND TROUBLESHOOTING (Source: Karamchetti M, 2011)

Typical failures	Corrective measures and troubleshooting
No current from array	Switches, fuses, or circuit breakers open, blown, tripped, wiring broken or corroded
Array current low	Some modules shaded, full sun not available, Array tilt or orientation incorrect, Some modules damaged or defective, Modules dirty
Battery is not charging	Measure PV array open circuit voltage and confirm it is within normal limits. If voltage is low or zero, check the connections at the PV array itself. Disconnect the PV from the controller when working on the PV system. Measure PV voltage and battery voltage at charge controller terminals if voltage at the terminals is the same the PV array is charging the battery. If PV voltage is close to open circuit voltage of the panels and the battery voltage is low, the controller is not charging the batteries and may be damaged.
Voltage is too high	Disconnect PV array, disconnect lead from the battery positive terminal and leave PV array disconnected. The green charging light on charge controller should not be lit. Measure the voltage at the solar panel terminals of the charge controller. If green light is on, or battery voltage is measured at the terminals the controller may be damaged.
Load not operating properly	Check that no fuses are defective or circuit breakers have been tripped.
Low voltage shutdown	Shorten cables or use heavier cables, recharge battery, allow unit to cool, improve air circulation, locate unit to cooler environment.
Fault light on, AC load not working	AC products connected are rated at more than the inverters power rating, overload shutdown has occurred The AC products connected are rated at less than the inverters continuous power rating. The product exceeds the inverters surge capacity.
Reverse Polarity connection on inverter	Check connection to battery, the inverter has likely been damaged and needs to be replaced.
Loads disconnecting improperly	Controller not receiving proper battery voltage, check battery connection. Adjustable low voltage disconnect is set too high. Reset adjustable low voltage disconnect using a variable power supply,
Array fuse blows	Array short circuit test performed with battery connected. Disconnect battery to perform test. Array exceeds rating of controller, add another controller in parallel if appropriate or replace with controller of higher capacity.
Loads disconnecting improperly	Controller not receiving proper battery voltage, check battery connection. Adjustable low voltage disconnect is set too high. Reset Adjustable low voltage disconnect using a variable power supply
Array fuse blows	Array short circuit test performed with battery connected. Disconnect battery to perform test. Array exceeds rating of controller, add another controller in parallel if appropriate or replace with controller of greater capacity.
No output from inverter	Switch, fuse or circuit breaker open, blown or tripped or wiring broken, corroded. Low voltage disconnect on inverter or charge controller circuit is open, High battery voltage.

7.3. Diagnostic procedures

7.3.1. Visual inspection procedures

The mechanical problems are generally evident due to something that is loose or bent or broken or corroded. They can generally be identified with a visual check. The instructions given in the previous paragraphs should be followed.

7.3.2. Performance monitoring

7.3.2.1. User feedback

User feedback can range from a simple LED on the inverter lid or an electronic display in a domestic corridor, to a large interactive wall display in the entrance hall of a corporate building. All these displays provide users with an indication that the system is functioning. A clear display gives much added value to the system, especially if combined with some graphics or text that explains the concepts.

7.3.2.2. Performance verification

A system may be financed on the basis of its output through support schemes (Feed-in Tariffs), in which the user is authorized to measure the output and compare it with consumption by the system. The complexity and expense of such metering is determined by the number and accuracy of the measurements to be made.

FIGURE 161.
MEASUREMENTS ON A ROOF GRID CONNECTED PV SYSTEM (Source: Conercon Ltd)

7.3.2.3. Displays

Displays are the backbone of monitoring. The easiest one of all is a simple indication built into the inverter. Most PV inverter manufacturers offer an optional display. However this can place severe constraints on the placing of the inverter, which would normally be in a roof void, electrical switch room, or some other secluded place. If the display is to be effective it must be in a place where it is visible in everyday activities. Remote displays are easier to site, and may be provided with data from the inverter itself, or by a meter in the cabling from inverter to distribution board. A significant cost to installing this is the routing of the cabling to the display, but there are instruments on the market that avoid this by utilizing short-range radio transmission.

Many different data formats can be displayed: the most popular are the instantaneous power now being generated and total energy generated to date. However, large displays often include derived values that mean more to the public, such as numbers of lights that are being powered, or the amount of carbon production being offset. A computer-based monitoring system can often embed that information at an information point with a touch-screen or have it displayed on the website for the building.

7.3.2.4. Data Acquisition Systems

The main system tends to fall into two types: loggers and computers. The advantage of a logger is its simplicity and robust construction, but its disadvantage is its inflexibility and cost. A computer system, in contrast, may be slower to set up and commission, but has the advantage of a wider choice of operational modes and custom settings, while the cost may be less for a system based on a desktop PC. The choice between the types may well be dictated by the type of monitoring strategy.

7.3.2.5. Sensors

There is no limit to the inputs that may be monitored for a PV System, but most systems will need to measure input and output energy, and some environmental and system variables.

7.3.3. Calibration and Recalibration

The system should be set up and calibrated preferably in situ. The need for recalibration should be determined whilst considering the length of time for the monitoring, and the accuracy required of the system. The reference cell is particularly critical, but often the most difficult item to access. If annual recalibration is not practical in the laboratory, an on-site comparison with a reference device nearby may be sufficient. The entire monitoring system can also benefit from a comparative calibration using a hand-held reference device (ambient temperature sensors, voltage and current meters, etc.).

7.3.4. Data Storage and Transmission

The data is generally stored in situ using RAM for a logger, or using a hard drive for a computer system. Loggers often include removable RAM cards, discs, or other magnetic media, as a form of storage/retrieval. PCs may use multiple drives, or daily downloads, as a backup storage method.

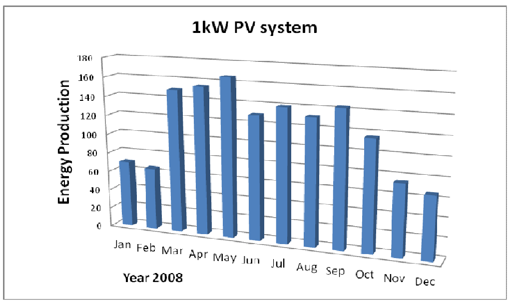
Having recorded the data, it may be transmitted back to the monitoring organization by many means. The simplest logging systems may have to be physically carried back to the laboratory and plugged into a special reader device, or a PC serial port.

Removable media allow the swapping of the storage medium on site allowing monitoring to continue uninterrupted. The only disadvantages are that the new media may not be inserted correctly, or the logger may not be restarted, and the loss of data will not be noticed until the next visit. Telephonic transmission is often used, as it allows frequent downloading of data (reducing the length of any 'lost' periods), and also the chance to 'upload' any changes to the logging schedule. The more sophisticated loggers can initiate a call to a fax or PC to report any faults or out of range signals immediately they are detected. The advent of the internet has allowed PCs to connect to a local portal via a local phone line, thus making downloading less expensive anywhere in the world. If a telephone line is not available at a remote site, a cellular phone connection can provide an equivalent facility.

7.3.4.1. Data Analysis

After collecting the PV system data, a detailed analysis should be conducted. In this way, the stored data can be a useful tool for system monitoring and evaluation. Monthly performance ratio values, array yields, etc. have become the normal way of defining the performance of a PV system and continued use of this method will make it easier to compare existing systems. Bar graphs can also be embellished with sub-categories of capture losses, system losses, etc. For example, keeping a bar graph record of daily and monthly energy output is a simple way to guarantee PV system performance and to analyze possible system failures (Source of 7.3: Rudkin E. & Thornycroft J. 2008).

FIGURE 162. EXAMPLE OF A BAR GRAPH OF A 1KW PV SYSTEM



7.4. Customer Documentation

After the installation has been completed, the installer tests and checks the system extensively and records the results of the test on a commissioning report. This process can take from few days to several days depending on the size of the PV installation. This will be signed by an authorized signatory to confirm the work is satisfactory.

A copy of the commissioning report should be given to the owner together with relevant conformity certificates and guarantees. Guarantee for each system part is given to the owner (usually manufacturer's warranties). Also full operating and maintenance instructions should be given, along with a full description of the system.

Usually, the owner asks some performance guarantees for the system from the installer. The installer makes a commitment for the yearly energy production of the system by giving a minimum kWh produced per year. If the real energy production is lower than that given, then the installer has to compensate the owner (investor), depending on the terms of the agreement (Rudkin E. & Thornycroft J., 2008).

7.5. Maintenance checklist

A PV system field inspection and maintenance should be carried out. The creation of a detailed maintenance checklist is necessary for this purpose in order to ensure the smooth operation of the system. A maintenance checklist should include several checks as given in TABLE 31 below.

TABLE 31.
MAINTENANCE CHECKLIST. (Source: http://www.contractorsinstitute.com/)

PV system – Maintenance Check List

Installation address	Inspection by:	
	Date:	Reference:

Array Installation and Wiring

- ☐ Condition
- ☐ Proper insulation on module wiring
- ☐ Proper connectors on array wiring extensions
- ☐ Proper grounding of array & array mount
- ☐ Grounded conductors installed
- ☐ Array mount properly secured and sealed
- ☐ Suitable transition from open wiring to enclosed wiring
- ☐ Metallic conduit through attics to array disc
- ☐ Damages of modules observed
- ☐ Dirt accumulation observed
- ☐ Shading observed on modules

DC Connections

- ☐ Source Circuit Combiner Boxes
- ☐ DC-rated circuit breakers or fuses with adequate voltage rating
- ☐ Listed equipment

DC Component Enclosures

- ☐ Proper conductor sizes and insulation types
- ☐ Proper conductor terminations
- ☐ DC ratings on DC components
- ☐ Listed equipment
- ☐ SINGLE POINT GROUNDING!
- ☐ Optional grounding electrode conductor

AC Component Enclosure

- ☐ Isolated Neutral busbar
- ☐ Listed components
- ☐ Labelled disconnects and C/B

Utility Disconnect

- ☐ Labelled
- ☐ Visible, lockable, accessible, load break, external handle

Building Main Disconnect

- ☐ Labelled

Inverters

- ☐ Listed inverters (type, serial number, configuration)
- ☐ Status/Condition
- ☐ Defects founded
- ☐ Noise levels
- ☐ Open circuit voltage (V)
- ☐ Impp (A)
- ☐ Input and output disconnects labelled
- ☐ Proper wire sizes
- ☐ Grounded

Batteries (Battery backup systems only)

- ☐ Terminals protected from shorting
- ☐ Cables properly terminated (no set screw lugs on fine stranded wire)
- ☐ Maintenance-free vented for cooling
- ☐ Flooded vented to outside
- ☐ Labelled with proper safety procedures

Charge Controllers (Battery backup systems only)

- ☐ Status/Condition
- ☐ Input and output disconnects labelled
- ☐ Listed charge controllers
- ☐ Proper wire sizes
- ☐ Grounded

Standby Circuits (Battery backup only)

- ☐ Watch for multiwire if 120V
- ☐ Labelled

Point of Utility Connection

- ☐ Labelled
- ☐ Compliance

Handover of PV system

- ☐ Mentioned faults

7.6. Exercises

7.6.1. Maintenance plan

1. The frequency of the inspection and maintenance of a photovoltaic system should be:
   a) Every 3 years
   b) At least once a year
   c) Every 5 years

2. Most of the problems in a PV installation usually occur during the:
   a) First year of operation
   b) Second year of operation
   c) Third year of operation
   d) Fourth and sixth year of operation

3. The suggested frequency of cleaning the PV modules surface is:
   a) Twice a year for all the systems
   b) Once a month for every installation
   c) Depends on each installation's conditions

4. While measuring the total irradiance of a PV array, the pyranometer should:
   a) Be placed in the same direction as the array
   b) Be placed in the opposite direction of the array
   c) always face the north
   d) always face the south

5. In order to check the specific gravity of the electrolyte in the battery cells the meter usually used is the:
   a) ammeter
   b) voltage meter
   c) hydrometer
   d) ambient meter
   e) thermometer

6. Regarding the protection of the inverters against lightning:
   a) No additional equipment is used
   b) Surge arrestors are used
   c) Equipment for shortcut protection is used

7.6.2. Typical mistakes and failures

1. One of the common failures regarding the installation of PV mounting systems is the distortion of the PV modules when they are installed on the roof.
   a) True
   b) False

2. The most frequently reported faults according to a great number of studies are ______ faults.
   a) inverter
   b) battery
   c) panel
   d) wiring

3. While installing and connecting PV modules, the I_{mpp} of each module should be taken into account.
   a) True
   b) False

4. For electrical power supplies, the physical operating life of power cables is generally specified as:
   a) 25 years
   b) 45 years
   c) 15 years
   d) 35 years

5. A reason for exceeding the inverter voltage could be:
   a) The unpredictable weather conditions
   b) The improper PV array design
   c) A shortcut in the PV system

6. If there isn't any current coming from the PV array, a possible reason is broken or corroded wiring.
   a) True
   b) False

7.6.3. Diagnostic procedures

1. The main advantage of the computer operating as a data acquisition system for PV systems is:
   a) Its simplicity and robust construction
   b) It has always lower cost than a logger
   c) It is faster than the logger
   d) It has wider choice of operational modes and custom settings

2. The system should be set up and calibrated preferably in the laboratory
   a) True
   b) False

3. Keeping records of the bar graphs of the daily and monthly energy output:
   a) Is used only to compare the yearly energy performance of the PV system with the yearly energy performance of the commissioning report
   b) It is a simple method to ensure the PV system's performance and perceive a possible failure on the system.
   c) It is useless because the data is stored on the inverters of the PV system.

4. The mechanical problems can generally be identified with a visual check
   a) True
   b) False

5. Wiring faults can be detected by checking the inverter.
   a) True
   b) False

7.6.4. Documentation to the customer

1. After the installation is completed, the installer should make a commitment for the yearly energy production of the system by giving a minimum kWh produced per year.
   a) True
   b) False

7.6.5. Maintenance checklist

1. A maintenance checklist for the inverter should include (Choose 3 answers) :
   a) Noise levels
   b) Terminals condition
   c) Open circuit voltage (V)
   d) I_{mpp} (A)
   e) Flooded vented to outside
   f) Dirt accumulation

QUALITY MANAGEMENT AND CUSTOMER CARE 8

8. QUALITY MANAGEMENT AND CUSTOMER CARE

8.1. Quality principles

Once best practice has been established within an installation company, it is essential to be able to install systems to the same consistently high standard. This is where a Quality Management System (QMS) can help.

The essential idea is that the whole process, from first customer contact through quoting, installation, commissioning and hand-over, is set out in a written plan which the installer makes an effort to use for all installations.

The standard forms, procedures and software programs that make up the QMS can all contribute to consistency of operation and traceability. Traceability becomes important in the event of a problem after commissioning, perhaps many months or years later. It helps the installer understand where the process went wrong, or proves that the installer did not make any mistakes and the fault lies elsewhere (particularly useful if the complaint progresses to a legal challenge).

ISO 9001 is an example of a quality management system used by many medium and large sized companies and can act as a useful guide for anyone considering how to set up a QMS for their own business. However, it is important to remember that every business is different and so each business must develop its own QMS which is best suited to its activities. It is not necessary to implement a full ISO 9001 system in order to set up a basic QMS. A scaled-down version may be more suitable for smaller companies and sole traders.

One method of defining and implementing a QMS is to think through each stage of the process and write down exactly how it should be approached.

For example, when a new enquiry is received, it is essential to capture certain details eg contact details, location & post code, basic customer requirements, roof orientation and pitch (if possible), etc. If there is a standard form to fill in, the job of capturing this information may be delegated to non-expert staff. However, if there is no form, it will generally fall to an expert to have the phone conversation with the prospective customer, thus occupying the valuable time of the expert to perform a task which could be covered by lower cost staff This is just one example of how the very first stage of the selling/installation process can be made more consistent, efficient and lower costs through the use of a standardised process.

So, the QMS is built up by thinking through each stage and writing down the procedure to be followed. The QMS could also be thought of as a set of ‘Operating Procedures’.

The list below is an example of some of the items which could be considered when writing operating procedures to be included in the QMS for a solar installation company:

- Procedure for processing customer enquiries, possibly using a standard ‘Customer Enquiry’ form (as discussed in example above).
- Procedure for conducting site surveys. This may also include details of how to complete a ‘Site survey’ or ‘Building Assessment’ form.
- How to prepare a quotation, including a quotation template.
- A standard customer contract.
- A standard sub-contractor contract template for employing subcontractors.
- The procedure to be used for designing systems and the software tools to be used: e.g. software for mechanical and

electrical design calculations and energy predictions.

- Procedure for completing site-specific risk assessments and/or method statements. This could also include an appropriate template.
- Procedure for inspecting delivered goods (e.g. for correctness, damage, missing parts or documentation etc).
- Procedure for reviewing the contents of the QMS, including defining when and how the documents are updated and who is responsible for this.
- Other documents that should be contained in the QMS include: a document identifying the relevant national; technical regulations; building regulations; industry guides etc...
- Product Manufacturers' instructions for each of the PV products installed by the company.
- List of documents to keep in each customer's job file.
- List of documents to hand over to each customer.
- Standard terms and conditions (if not included in the contract) and standard warranty information.
- Health and Safety Policy.

Other documents which may occasionally be used that could also appear in the QMS:

- A list of equipment (including serial numbers) which requires calibration, who is responsible for ensuring the equipment is calibrated and dates for when the next calibration is due.
- Staff Training Records - useful for recording who is competent to operate each procedure and to have a visible skills improvement path to help motivate staff and plan workforce requirements.
- A complaints procedure and log of all complaints received (whether substantiated or not) to record individual instances of issues and, if appropriate, how these were resolved.

It is also very helpful to write an overview document of the QMS to say which of the procedures will be used at each stage from customer contact to hand-over and after sales service. This is sometimes known as a Quality Plan and should include a definition of who is competent to complete each procedure.

Once a QMS has been established, it is generally worthwhile reviewing how well it is operating on a regular (eg quarterly) basis, and recording the outcome of each review. This ensures that previous mistakes are not repeated and that good practice is identified and included in the day-to-day operation of your business. Such reviews also provide an opportunity to check for changes in regulations and standards that are relevant to PV installations, to look at any complaints received so that common causes can be identified and corrected and to receive feedback from staff/sub-contractors.

8.2. EU standards for PV

There are numerous EU standards for PV which contains the requirements for manufacturing and testing PV products. These standards are also updated from time to time, or new standards are published, to take account of changes in technology and testing methods. Consequently it is not practical to provide a comprehensive list of standards here. A list of standards is provided in Annex iii and an extensive list of standards may also be found on the European Photovoltaic Industry Association website (www.epia.org). There are many standards that cover PV products, nevertheless, those that define the requirements for module qualification and type approval include:

- EN 61215 (for crystalline PV modules)
- EN 61646 (for Thin Film PV modules)
- EN 61730 (PV module safety)

It is often an eligibility requirement (e.g. for financial incentives) that any PV modules installed be certified according to the requirements of at least one of the above-mentioned standards.

Although not a European Standard, the MCS installation standard for microgeneration PV systems (MIS 3002) specifies the requirements for the design, supply, installation, set to work and handover of PV systems for permanent buildings.

MIS 3002 is available from the MCS website (www.microgenerationcertificaton.org).

MIS 3002 also calls upon guidance contained in 'Photovoltaics in Buildings – Guide to the installation of PV systems', currently in its 2nd edition and shortly to be updated.

8.3. Customer care

8.3.1. General

It is important that the whole process from first customer contact, through to commissioning and hand-over of the system, is precise, transparent, clearly documented and understood by the customer. Departing from this general principle will inevitably result in problems and complaints.

Therefore all stages of the process must be documented in a form that the customer can understand, all key points should be explained verbally and the project must not proceed until the customer is comfortable and a written acceptance of the quotation has been received by the installer.

8.3.2. Selling Solar

The following points should be adhered to during the pre-sales process:

Advertising

Advertising and promotional activities will portray the products and services fairly and will not make unsupported claims for performance or financial returns.

Staff Training

Sales staff will be trained to a level enabling them to perform a detailed solar survey and provide advice on any required upgrade of services. They will also be competent to provide a basic building energy survey and advice on energy efficiency.

Training for sales staff will include a module on acceptable selling techniques, in order to avoid the use of high pressure sales tactics Staff should be briefed on the likely sanctions should any member be found to be using such tactics.

In general sales staff:

- May not offer incentives for signing a contract during the initial sales meeting.
- May not remain on the property for more than a period of 2 hours, including surveying time.
- May not accept any payment at the initial sales visit.
- Must inform the customer of the sales process (see Quotations below), including the 'cooling off' period subsequent to signing of a contract.
- Must inform the customer of any permits or approvals that are needed (eg planning permission, grid connection) before the installation begins and must clearly specify the person responsible for obtaining them.

8.3.3. Quotations and contracts

Energy Yield Estimates

The quotation, together with your terms and conditions of business, will often form the contract between the installer and the customer. It is therefore essential that quotations are clear, easily understood and contain all the necessary information.

Even before a quotation is issued it is good practice to provide your customers with an estimate of the annual energy performance of the proposed PV system. This is because the generation of energy from a renewable source (and the receipt of any associated financial incentives) is usually the main objective for the customer. Thus, providing a reasonably accurate estimate of the predicted energy performance of the system before entering into any contract for installation is of key importance.

Such energy yield figures can only ever be approximate and the calculation can become very complex, depending on the level of accuracy required. Thus, it is important to explain to your customer the key factors: climate, orientation & tilt, shading, temperature and to state what method of calculation has been used (whether by manual means or by use of a software modelling package). The key assumptions behind the calculation should also be presented to allow checking of the estimate. It is also essential, not least for your own benefit as much as the installer's, to accompany any estimate of performance with a disclaimer that explains that the performance of a PV system cannot be accurately predicted, because of the variation in the amount of solar energy available from location to location and from year to year.

Other items on the quotation

Other items which should be supplied at the quotation stage are:

- An explanation of any financial incentives (eg feed-in tariffs, grants, etc).
- The resulting value for money of the proposed system, including advice that the inverter may need replacing during the lifetime of the system and the approximate cost of this.
- List of all the main components to be supplied, including make and model numbers.
- Expected duration of the installation process.
- Allowed “cooling off” period (this may vary according to local legislation or codes of practice).
- What to expect during the installation eg.
- Scaffolding.
- Any services required (eg power).
- Any temporary storage space required for securely storing equipment prior to fitting.
- Forms of payment which are acceptable and payment terms.
- Your other terms and conditions of business.

If a deposit is required before installation work starts, this will constitute a small part of the total value of the project. The deposit and any other advance payment, if required, should be kept in an account specially set up in the customer's name (eg a 'client' or other third party account). This must be separate from those accounts linked to the installer' own credit and banking facilities. Guidelines for setting up and administering these arrangements are available from most banks. The deposit will be returned to the customer in the event of cancellation during the cooling off period .

In the event of small changes to the specification, these must be agreed in writing with the customer. In the event of large changes to the specification, by either party, then a new quotation must be produced and accepted before work may continue.

8.3.4. Completing the work

The installation stage may only proceed following written acceptance of the quotation (in the event of multiple quotations, it will be made clear to which quotation the acceptance refers). Also, the installation should not begin until the installer has seen evidence that all necessary permissions and approvals have been obtained.

If subcontractors are employed, these will at all times be under the supervision and control of the installer who has signed the contract with the customer. The installer remains responsible to the customer for the quality and correctness of any subcontracted work.

During Installation

Customers and their premises must be treated with respect at all times. Precautions must be taken to minimise any noise, disturbance or damage to the property (eg protection from dirt & dust when working inside, replacing any cracked roofing tiles, etc).

The customer must be advised of any health and safety issues, such as the possibility of falling objects, electrical risks, etc, and appropriate barriers must be erected to prevent injury according to local health and safety regulations.

If the installation is likely to be delayed for any reason (e.g. bad weather), the customer must be kept fully informed and be given information on the new likely times of resumption of the work and how this will impact on the date of commissioning.

8.3.5. Final testing, commissioning and handover

At the end of the installation process, the final stage is testing and commissioning. This stage will follow the installer's written test and commissioning procedure, including those specified in the PV equipment manufacturer's installation instructions. A copy of the results must be supplied to the customer.

After the commissioning of the system, a certificate must be provided to the customer stating the following points:

- property address
- installer contact details
- type & serial numbers of equipment installed
- date of commissioning
- rated power of system
- annual energy yield estimate
- installer warranty period (ref terms)
- PV module & inverter manufacturer warranties

Declaration: "This installation has been commissioned by <Company name, engineer's name>. <Company> hereby declares that on the date of commissioning this system was inspected and found to be safe, functional and installed in accordance with all applicable regulations".

8.3.6. Warranties and after-sales service

It is important that after the installation process, the customer has reassurance that there is support available in the event of any problems with the system.

Details of warranties covering the quality of the products and installation work should be included in the commissioning documentation handed to the customer on completion of the installation (see above). Installers should offer a maintenance contract, but not insist that it is taken up. It is good practice to leave a copy of a user manual on site, which details the maintenance requirements of the system.

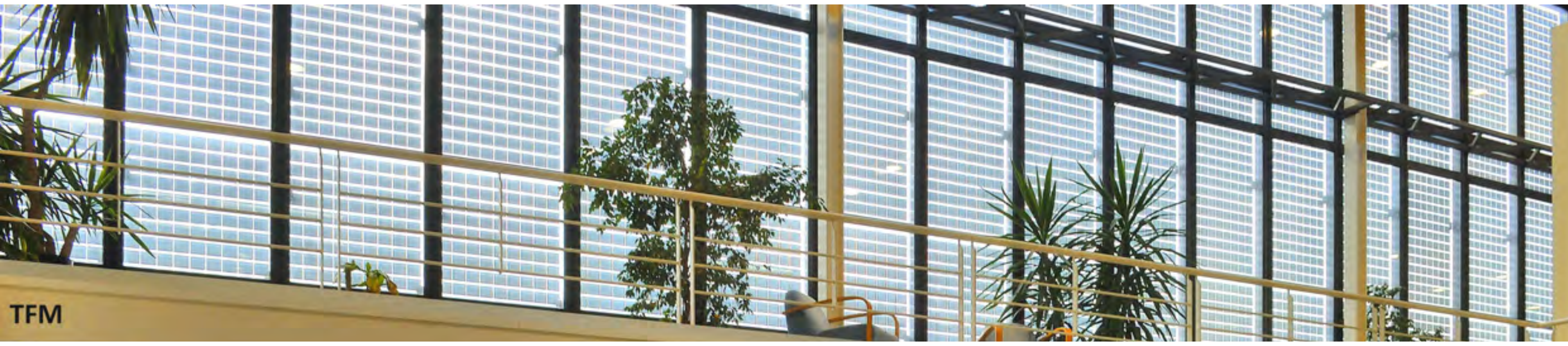
All installers shall have and operate a transparent complaints procedure and a written copy of the process shall be left with the customer.

A useful tool for the installer to monitor customer satisfaction, and to help reassure clients, is a customer feedback form. It is therefore good practice to include one of these in the customer's hand-over pack.

8.4. Exercises

To help develop an appropriate QMS to monitor the business, read the text in this chapter and use the guidance contained in it to prepare the following:

- A 'Customer Enquiry' form
- A 'Site survey' or 'Building Assessment' form
- A quotation template
- A standard customer contract
- A standard sub-contractor contract
- A standard procedure for designing PV systems
- A risk assessment form
- A generic method statement
- A goods-in inspection form
- A procedure for reviewing the contents of your QMS
- A list of relevant national Technical Regulations, Building Regulations and industry guides
- A list of documents to keep in each customer's job file
- A List of documents to hand over to each customer
- Standard terms and conditions (if not included in the contract) and standard warranty information
- A health and safety policy for your business
- A complaints handling procedure



9. GLOSSARY OF TERMS

A

Alternating current: electric charge periodically reverses direction. In (DC), the electric charge only flows in one direction.

Ampere: unit of electrical current or flow rate of electrons. One volt across one ohm of resistance causes a current flow of one ampere.

Amorphous semiconductor: non-crystalline semiconductor material, easier and cheaper to make than crystalline, but less efficient.

Ampere Hour: a measure of current over time, commonly used to measure battery capacity.

Azimuth: Angle between the north direction and the projection of the normal surface onto the horizontal plane measured clockwise to the north.

B

Balance-of-system (BOS): all of the PV system components except from the PV modules. It is the auxiliary equipment which is related to supporting and security structures, inverters, disconnects and overcurrent devices, charge controllers, batteries, and junction boxes.

Battery: electrochemical cells enclosed in a container and electrically interconnected in an appropriate series/parallel arrangement to provide the required operating voltage and current levels.

Battery bank: group of batteries connected together to store energy of a a PV system.

Blocking diode: device that controls current flows inside the PV system, blocking reverses leakage current backwards through the modules.

Building applied photovoltaics: PV installations fixed over the existing elements of a building envelope such as roofs, skylights, façades, balconies and shelters.

Building-integrated photovoltaics: PV materials (sheets, tiles, glasses, etc.) used instead of conventional building materials in parts of the building envelope.

Bypass Diode: a diode connected in parallel to a PV module to provide an alternate current path in case of module shading or failure.

C

Cadmium (Cd): chemical element used in making certain types of solar cells and batteries.

Cadmium Telluride (CdTe): a polycrystalline Thin Film photovoltaic material.

Clamp-on ammeter: An electrical meter with integral AC device having two jaws which open to allow clamping around an electrical conductor.

Conversion efficiency: The ratio of the electric energy produced by a PV device over the energy from sunlight incident upon the cell.

Converter: device that converts a dc voltage to another dc voltage.

Crystalline silicon cells: made from thin slices (wafers) cut from a single crystal or a block of silicon.

Current-voltage: the applicable combinations of current and voltage output of a PV panel.

D

Depth of discharge: the ampere-hours removed from a fully charged cell or battery, expressed as a percentage of rated capacity.

Diffuse Irradiance (DIF): the amount of radiation received per unit area by a surface that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere or reflected by the ground and comes equally from all directions.

Diode: An electronic device that allows current to flow in one direction only.

Direct-current: electric charge in one direction.

Direct Normal Irradiance (DNI): the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky.

Distributed system: A power generating system that is installed where the energy is needed.

E

Earthing system: the total set of measures used to connect an electrically conductive part to earth.

Electric Current: the flow of electrical energy (electricity) in a conductor.

Electric Circuit: path followed by electrons from a power source (generator or battery) through an external line

Electrolyte: medium that provides the ion transport mechanism between the positive and negative electrodes of a battery.

Encapsulation: protection placed around the cells when modules are made, designed to last for over 20 years.

Energy Pay-Back Time: the time in which the energy input during the PV system life-cycle (production, installation, disassembling and recycling) is compensated by electricity generated by the PV system.

Equipotential Zone: temporary protective grounds placed and arranged so that they will prevent workers from exposure to hazardous differences in potential.

Equivalent carbon dioxide: emissions of greenhouse gases expressed in $kgCO_2e$.

F

Feasibility Study: report on the viability of a project, with an emphasis on identifying potential problems and risks and on highlighting the prospects for success

Feed-in-Tariff: mechanism designed to accelerate investment in RES, by offering long-term contracts to producers.

Filling factor: factor informing of the extent to which a module deviates from the ideal operation.

Fixed Tilt Array: a photovoltaic array set at a fixed angle with respect to horizontal.

Fuse: electrical protection device that breaks the electrical circuit if too much current is present

G

Gallium (Ga): chemical element, metallic in nature, used in making certain kinds of solar cells and semiconductor devices.

Gallium Arsenide (GaAs): a crystalline, high-efficiency compound used to make certain types of solar cells and semiconductor material.

Global Horizontal Irradiance: the total amount of shortwave radiation received from above by a horizontal surface. It includes both Direct Normal Irradiance and Diffuse Horizontal Irradiance.

Global In-Plane Irradiance: the total amount of radiation (both DNI and DIF) received from above by an inclined surface.

Grid: Transmission line network used to distribute electric power.

Grid-connected system: PV system connected to the local electricity network

Grounding conductor: conductor used to connect the frame of an electrical device to the ground. The grounding conductor is often copper.

Grounding system: see Earthing system

H

Hot spot: phenomenon of PV device operation where one or more cells within a PV module or array act as a resistive load, resulting in local overheating or melting of the cell.

Hybrid System: mix of energy generations that may include conventional generators, cogeneration, wind turbines, hydropower, batteries, PVs, fuel cells, biomass and other inputs.

I

Inclinometer: device for measuring angles of slope and inclination of an object with respect to its gravity by creating an artificial horizon.

Ingot: molten and subsequently solidified silicon cubes or cylinders, ready for cutting into wafers

Internal Rate of Return: the actual annual profit rate of an investment. It equates the value of cash returns with cash invested.

Inverter: a converter which transforms DC voltage and current from PV modules into single or multiphase AC voltage and current.

Irradiance: the instantaneous intensity of solar radiation on a surface (W/m^2).

Islanding: any situation where the grid electricity is off-line and one or more inverters from a grid-connected PV system maintain a supply of electricity to that section of the grid or to a consumer installation.

Isolating transformer: the input and output windings of the transformer that are electrically separated by double or reinforced insulation.

J

Junction Box: an enclosure on the module where PV strings are electrically connected and where protection devices can be located.

K

Kilowatt hour: a unit of energy equal to 1000 watt hours or 3.6 megajoules.

L

Learning curve: a graph presenting the rate of learning. In PVs this is often related to the world PV production price.

Life Cycle Analysis: assessment to quantify and evaluate the environmental burdens (air emissions, water effluents, solid waste, and the consumption of energy and other resources) over the life cycle of a product, process, or activity.

M

Metering: the system includes meters to provide information on overall performance. Some meters also indicate domestic energy usage.

Mismatch losses: losses caused by the interconnection of solar cells or modules which do not have identical properties.

MPP regulator: a device that searches for the best operating point of a module and ensures that the module delivers the maximum possible power under all conditions.

Multimeter: device that can measure voltage, current and resistance.

N

Nominal Voltage: a reference voltage used to describe batteries, modules, or systems

O

One-axis tracking: a system capable of rotating about one axis, usually following the sun from East to West.

Open circuit voltage: voltage produced by PV with no load applied when the cell is exposed to STC.

P

Parallel connection: interconnection of two or more panels, so that the voltage produced is not increased and the current is additive.

Peak (Maximum) Power Point (MPP): The point on the I-V curve's knee where the maximum power output is achieved

Peak Sun hours: The equivalent number of hours per day when solar irradiance averages 1 kW/m^2.

Performance ratio: the performance of the system in comparison to a lossless system at the same design and rating at the same location.

Personal Protective Equipment (PPE): equipment used to reduce employees exposure to hazards, when engineering and administrative controls are not feasible or effective.

Protective earthing: network of conductors transferring current to the main earth terminal for safety purposes.

PV array: PV modules linked together

PV phenomenon: creation of a voltage in a material exposured to light

PV module: PV cells wired in series and enclosed in a protective case.

Pyranometer: device used to measure broadband solar irradiance on a planar surface. The solar radiation flux density measured in W/m^2

Q

Quality management system: organizational structure, and processes to implement quality management.

R

Regulator: device to prevent overcharging of batteries by controlling the charge cycle- usually adjustable to conform to specific battery needs.

S

Safety plan: a list of basic points for health and safety during the construction phase.

Semiconductor: a material of a crystalline structure that will allow current to flow under certain conditions, making it a good medium for the control of electrical current.

Series connection: interconnection of two or more panels so that the voltage is additive but the same current passes through them.

Series Controller: a controller that interrupts the charging current by open-circuiting the PV array. The control element is in series with the PV array and battery.

Shunt Controller: charge controller that redirects or shunts the charging current away from the battery.

Silicon: a non-metallic element, sensitive to light and capable of transforming light into electricity. Silicon is the basic material of most beach sand, and is the raw material used to manufacture most PV cells.

Solar Spectrum: the total distribution of electromagnetic radiation emanating from the sun.

Stand-alone PV system: autonomous PV system not connected to the grid.

Standard test conditions: radiation: 1000W/m^2, temperature: 25°C, and air mass: 1.5.

Stratification: the condition in which acid concentration varies from top to bottom in the battery electrolyte.

String: number of modules or panels electrically interconnected in series to produce the operating voltage required by the load.

Sulfation: the formation of lead-sulfate crystals on the plates of a lead-acid battery.

T

Thermomagnetic switch: a current limiter (electromechanical device) that prevents excessive hired power.

Tracking system: a system that traces the position of the sun during the day so that sunrays hit the panel at right angles, and its efficiency is improved.

V

Volt (V): unit of electrical force equal to that amount of electromotive force that will cause a steady current of one ampere to flow through a resistance of one ohm.

Voltage: The amount of electromotive force, that exists between two points, measured in volts.

W

Wafer: thin sheet of semiconductor

Watt: unit of power in the International System of Units.

Winter Solstice: the shortest day and the longest night of the year, the sun's daily maximum position in the sky is the lowest.

Z

Zenith: imaginary point directly above a particular location, on the imaginary celestial sphere

Zenith angle: the angle between the direction to the zenith and the direction of a light ray.

10. ANNEXES

i. Abbreviations and Acronyms

TABLE 32.
ABBREVIATIONS AND ACRONYMS

Acronym	Explanation
AC	Alternating Current
ASTM	American Society for Testing and Materials
BAPV	Building Applied Photovoltaics
BIPV	Building Integrated PhotoVoltaics
BOS	Balance Of System
CEN – European	Committee for Standardization
DC	Direct Current
DIF	Diffuse Irradiance
DIN	Direct Normal Irradiance
DOD	Depth of Discharge
EPBT	Energy Pay-Back Time
FIT	Feed-In-Tariff
IEC	International Electrotechnical Commision
Impp	Current at maximum power point
IRR	Internal Rate of Return
ISO	International Organisation for Standardization
LCA	Life Cycle Analysis
LED	Light-Emitting Diode
MPP	Maximum Power Point
PPE	Personal Protective Equipment
PR	Performance Ratio
PSH	Peak Sun Hours
PV	Photovoltaic
STC	Standard Test Conditions
UL Standards	Underwriter Laboratories Inc

ii. Symbols and Units

TABLE 33.
SYMBOLS AND UNITS

Symbol	Explanation	Units
$A_{DC\ cable}$	Cross-section of the DC cable	mm^2
C_{INV}	Inverter sizing factor	%
d	Diameter of the obstacle	m
d_s	Diameter of sun	km
E	Daily energy requirement, Wh	Wh
FF	Filling factor	%
G	Average daily number of PSH	h
H	Height of an obstacle	m
$I_{z\ cable}$	Current rating of the cable	A
$I_{max\ INV}$	Maximum permitted DC input current of the inverter	A
$I_{n\ string}$	Nominal string current	A
$I_{n\ String\ fuse}$	Trigger current of the string fuse	A
$I_{n\ AC}$	AC nominal current of the inverter	A
I_{SC}	Short circuit current	A
$I_{SC\ PV}$	PV generator short-circuit current	A
$I_{SC\ String}$	Short-circuit current of one string	A
I_{ST}	String current	A
k_{MMP}	MPP voltage factor	-
$L_{AC\ cable}$	Simple line length of the AC connect	m
L_m	Simple wiring length	m
L_{min}	Minimum distance between PV and obstacle	m
L_{opti}	Optimum distance between PV rows	m
L_s	Distance Earth to sun	km
n	Number of strings of the PV generator	-
n_{PV}	Module's efficiency	
P	Consumer power	W
$P_{AC\ c\ able}$	Cable loss	
$P_{INV\ DC}$	DC power rating of the inverter	W
P_N	Maximum power point	W
P_{PV}	PV array power rating	W
PR	Performance Ratio	%
Q	Minimum required battery capacity	Ah
R	Electrical resistance	Ω (ohm)
T_C	Voltage temperature coefficient	V/°C
T_{min}	Minimum expected module temperature	°C
T_{max}	Maximum expected module temperature	°C
T_{stc}	Module temperature at STC (25 °C)	°C
$V_{max(INV)}$	Maximum input voltage of the inverter	V
$V_{MPP(INV-min)}$	Minimum input voltage of the inverter at the MPP	V
$V_{(MPP\ -T)}$	V_{MPP} at different temperature	°C
$V_{MMP-STC}$	MPP-voltage of the PV array at STC	V
V_{OC}	Open circuit voltage	V
V_{OC-STC}	Open circuit voltage at STC	V
$V_{oc-Tmin}$	Maximum open circuit voltage of the array at irradiance $1kW/m^2$ and T_{min}	V
$V_{oc-Tmax}$	Maximum open circuit voltage of the array at irradiance $1kW/m^2$ and T_{max}	V
W_{PV}	Peak wattage of the array	
ΔV	Voltage drop	V
ϕ	Latitude	°
β	Optimum Tilt	°
κ	Electrical conductivity,	$m/\Omega\ mm^2$
N	Loss factor	%

iii. International and EU standards with relevance to PVs

TABLE 34.
STANDARDS FOR TEST METHODS AND REFERENCE CELLS (Source: www.pvresources.com, 2011)

Test methods and reference cells

ASTM E973	Standard Test Method for Determination of the Spectral Mismatch Parameter Between a PV Device and a PV Reference Cell
ASTM E1021	Test Methods for Measuring Spectral Response of PV Cells
ASTM E1040	Standard Specification for Physical Characteristics of Nonconcentrator Terrestrial PV Reference Cells
ASTM E1143	Standard Test Method for Determining the Linearity of a PV Device Parameter with Respect To a Test Parameter
ASTM E1125	Standard Test Method for Calibration of Primary Non-Concentrator Terrestrial PV Reference Cells Using a Tabular Spectrum

TABLE 35.
STANDARDS FOR SOLAR MODULES (Source: www.pvresources.com, www.epia.org, 2011)

Solar Modules

EN 50380	Datasheet and nameplate information of PV module
IEC 61215	Crystalline silicon terrestrial PV (PV) modules - Design qualification and type approval
IEC 61277	Terrestrial PV power generating systems - General and guide
IEC 60891:2009	PV devices – Procedures for temperature and irradiance corrections to measured I-V characteristics
IEC 60904 Series	PV devices (principals for measurements)
IEC 61345	UV test for PV (PV) modules
IEC 61646	Thin-film terrestrial PV modules - Design qualification and type approval
IEC 61701	Salt mist corrosion testing of PV modules
IEC 61730-1	PV module safety qualification - Part 1: Requirements for construction
IEC 61730-2	PV module safety qualification - Part 1: Requirements for testing
IEC 61829	Crystalline silicon PV array - On-site measurement of I-V characteristics
IEC 62108	Concentrator PV modules and assemblies - Design qualification and type approval
IEEE 1513	Recommended practice for qualification of concentrator PV modules
ASTM E1038	Standard Test Method for Determining Resistance of PV Modules to Hail by Impact with Propelled Ice Balls
ASTM E1171	Standard Test Method for PV Modules in Cyclic Temperature and Humidity Environments
ASTM E1462	Standard Test Methods for Insulation Integrity and Ground Path Continuity of PV Modules
ASTM E1596	Test Methods for Solar Radiation Weathering of PV Modules
ASTM E1597	Standard Test Method for Saltwater Pressure Immersion and Temperature Testing of PV Modules for Marine Environments
ASTM E1799	Standard Practice for Visual Inspections of PV Modules
ASTM E1802	Standard Test Methods for Wet Insulation Integrity Testing of PV Modules
ASTM E1830-09	Standard Test Methods for Determining Mechanical Integrity of PV Modules
ASTM E2047	Standard Test Method for Wet Insulation Integrity Testing of PV Arrays
ASTM E2236	Standard Test Methods for Measurement of Electrical Performance and Spectral Response of Nonconcentrator Multijunction PV Cells and Modules
ASTM E2481	Standard Test Method for Hot Spot Protection Testing of PV Modules
UL 1703	Standard for Flat-Plate PV Modules and Panels

TABLE 36.
STANDARDS FOR GRID-CONNECTED PV SYSTEMS **(Source:** www.pvresources.com, 2011)

Grid-Connected PV Systems

IEC 60364-7-712	Electrical installations of buildings – Part 7-712: Requirements for special installations or locations – Solar PV (PV) power supply systems
IEC 61727	PV (PV) systems – Characteristics of the utility interface
IEC 61683	PV systems – Power conditioners – Procedure for measuring efficiency
IEC 62093	Balance-of-system components for PV systems – Design qualification natural environments
IEC 62116	Test procedure of islanding prevention measures for utility-interconnected PV inverters
IEC 62446	Grid connected PV systems – Minimum requirements for system documentation, commissioning tests and inspection
IEC 60364-7-712	Electrical installations of buildings – Requirements for special installations or locations – Solar PV power supply systems

TABLE 37.
STANDARDS FOR OFF-CONNECTED PV SYSTEMS (**Source:** www.pvresources.com, 2011)

Off-Grid PV Systems	
IEC 61194	Characteristic parameters of stand-alone PV (PV) systems
IEC 61702	Rating of direct coupled PV (PV) pumping systems
IEC/PAS 62011	Specifications for the use of renewable energies in rural decentralized electrification
IEEE Std 1526	IEEE Recommended Practice for Testing the Performance of Stand-Alone PV Systems
IEC 62124	PV Stand-Alone Systems – Design Qualification and Type Approval
IEC PVRS11	Portable solar PV lanterns – blank detail specification Approval under the IEC system for conformity testing and certification of electrical equipment (IECEE)
IEC PVRS11A	Portable solar PV lanterns – design qualification and type approval Amendment 1, extension to include lanterns with nickel-metal hydride batteries

TABLE 38.
STANDARDS FOR RURAL ELECTRIFICATION (**Source:** www.pvresources.com, 2011)

Rural Electrification	
IEC/TS 62257-1	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 1: General introduction to rural electrification
IEC/TS 62257-2	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 2: From requirements to a range of electrification systems
IEC/TS 62257-3	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 3: Project development and management
IEC/TS 62257-4	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 4: System selection and design
IEC/TS 62257-5	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 5: Protection against electrical hazards
IEC/TS 62257-6	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 6: Acceptance, operation, maintenance and replacement
IEC/TS 62257-7	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 7: Generators
IEC/TS 62257-7-1	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 7-1: Generators – PV arrays
IEC/TS 62257-7-3	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 7-3: Generator set – Selection of generator sets for rural electrification systems
IEC/TS 62257-8-1	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 8-1: Selection of batteries and battery management systems for stand-alone electrification systems – Specific case of automotive flooded lead-acid batteries available in developing countries
IEC/TS 62257-9-1	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-1: Micropower systems
IEC/TS 62257-9-2	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-2: Microgrids
IEC/TS 62257-9-3	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-3: Integrated system – User interface
IEC/TS 62257-9-4	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-4: Integrated system – User installation
IEC/TS 62257-9-5	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-5: Integrated system – Selection of portable PV lanterns for rural electrification projects
IEC/TS 62257-9-6	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 9-6: Integrated system – Selection of PV Individual Electrification Systems (PV-IES)
IEC/TS 62257-12-1	Recommendations for small renewable energy and hybrid systems for rural electrification – Part 12-1: Selection of self-ballasted lamps (CFL) for rural electrification systems and recommendations for household lighting equipment
IEC 62116	Test Procedure of Islanding prevention measures for utility –interconnected inverters

TABLE 39.
STANDARDS FOR MONITORING (Source: www.pvresources.com, 2011)

Monitoring	
IEC 61724	PV system performance monitoring – Guidelines for measurement, data exchange and analysis
IEC 61850-7	Communication networks and systems for power utility automation – Part 7-420: Basic communication structure – Distributed energy resources logical nodes
IEC 60870	Telecontrol equipment and systems

TABLE 40.
STANDARDS FOR INVERTERS (Source: www.pvresources.com, www.epia.org, 2011)

Inverters	
EN 50524	Datasheet and nameplate information of PV inverters
IEC 62109-1	Safety of power converters for use in PV power systems – Part 1: General requirements
IEC 62109-2	Safety of power converters for use in PV power systems – Part 2: Particular requirements for inverters
IEC 61683	PV systems – Power conditioners – Procedure for measuring efficiency
UL 1741	Standard for Inverters, Converters, and Controllers for Use in Independent Power Systems
EN 50530	Overall efficiency of grid connected PV inverters

TABLE 41.
STANDARDS FOR CHARGE CONTROLLERS (Source: www.pvresources.com, www.epia.org, 2011)

Charge Controllers	
IEC 62509	Battery charge controllers for PV systems - Performance and functioning
IEC 62093	Balance-of-system components for PV systems - Design qualification natural environments

TABLE 42.
STANDARDS FOR BATTERIES (Source: www.epia.org 2011)

Batteries	
IEC 61427	Secondary cells and batteries for solar PV energy systems - General requirements and methods of test
IEEE Std 937	Recommended practice for installation and maintenance of lead-acid batteries for PV systems
IEEE Std 1013	Recommended Practice for Sizing Lead-Acid Batteries for PV (PV) Systems
IEEE Std 1361	Recommended practice for determining performance characteristics and suitability of batteries in PV systems

TABLE 43.
STANDARDS FOR MOUNTING STRUCTURES (Source: www.pvresources.com, 2011)

Standards related to mounting structures	
EN 1991-1-2	Eurocode 1: Actions on structures - Part 1-2: General actions - Actions on structures exposed to fire
EN 1991-1-3	Eurocode 1 - Actions on structures - Part 1-3: General actions - Snow loads
EN 1991-1-4	Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions
EN 573-1	Aluminium and aluminium alloys - Chemical composition and form of wrought products - Part 1: Numerical designation system
ISO 1461	Hot dip galvanized coatings on fabricated iron and steel articles - Specifications and test methods
EN 10088-1	Stainless steels - Part 1: List of stainless steels
EN 10088-2	Stainless steels - Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes
EN 10088-3	Stainless steels - Part 3: Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes
EN 10027-1	Designation systems for steels - Part 1: Steel names
EN 10027-2	Designation systems for steels - Part 2: Numerical system

TABLE 44.
STANDARDS FOR JUNCTION BOXES (Source: www.pvresources.com, 2011)

Junction Boxes	
DIN V VDE 0126-5	Junction Boxes for PVs
EN 50548	Junction Boxes for PVs

TABLE 45.
STANDARDS FOR WIRES/CABLES (Source: www.epia.org, 2011)

Wires/Cables	
UL-SU 4703	PV wire
UL 854	Service Entrance Cables
TUV Rheinland 2Pfg1169	Requirements for cables for PV systems

TABLE 46.
STANDARDS FOR CONNECTORS Source: www.epia.org, 2011

Connectors	
EN 50521	Connectors for PV systems-Safety requirements and tests
UL-SU 6703	Connectors for use in PV systems
UL 486A/486B	Wire Connectors

TABLE 47.
OTHER BOS STANDARDS (Source: www.pvresources.com, 2011)

Other BOS standards	
IEC 61173	Overvoltage protection for PV (PV) power generating systems - Guide

TABLE 48.
STANDARDS FOR GLASS AND ITS APPLICATIONS IN BUILDINGS WITH DETAILED REFERENCE TO BIPV SYSTEMS (Source: www.pvresources.com, 2011)

Glass and its applications in buildings with detailed reference to BIPV systems	
EN 410	Glass in building - Determination of luminous and solar characteristics of glazing
EN 356	Glass in building - Security glazing - Testing and classification of resistance against manual attack
EN 673	Glass in building - Determination of thermal transmittance (U value) - Calculation method
EN 572-1	Glass in building - Basic soda lime silicate glass products - Part 1: Definitions and general physical and mechanical properties
EN 572-2	Glass in Building - Basic soda lime slicate glass products - Part 2: Float glass
EN 572-5	Glass in Building - Basic soda lime silicate glass products - Part 5: Patterned glass
EN 572-8	Glass in building - Basic soda lime silicate glass products - Part 8: Supplied and final cut sizes
EN 572-9	Glass in building - Basic soda lime silicate glass products - Part 9: Evaluation of conformity/Product standard
EN 1748-1-1	Glass in building - Special basic products - Borosilicate glasses - Part 1-1: Definition and general physical and mechanical properties
EN 1748-2-1	Glass in building - Special basic products - Glass ceramics - Part 2-1 Definitions and general physical and mechanical properties
EN 1748-1-2	Glass in building - Special basic products - Borosilicate glasses - Part 1-2: Evaluation of conformity/Product standard
EN 1748-2-2	Glass in building - Special basic products - Glass ceramics - Part 2-2: Evaluation of conformity/Product standard
EN 13024-1	Glass in building - Thermally toughened borosilicate safety glass - Part 1: Definition and description
EN 13024-2	Glass in building - Thermally toughened borosilicate safety glass - Part 2: Evaluation of conformity/Product standard
EN 12600	Glass in building - Pendulum test - Impact test method and classification for flat glass
EN 1288-1	Glass in building - Determination of the bending strength of glass - Part 1: Fundamentals of testing glass
EN 1288-2	Glass in building - Determination of bending strength of glass - Part 2: Coaxial double ring test on flat specimens with large test surface areas
EN 1288-3	Glass in building - Determination of the bending strength of glass - Part 3: Test with specimen supported at two points (four point bending)
EN 1288-4	Glass in building - Determination of the bending strength of glass - Part 4: Testing of channel shaped glass
EN 1288-5	Glass in building - Determination of the bending strength of glass - Part 5: Coaxial double ring test on flat specimens with small test surface areas
EN 14449	Glass in building - Laminated glass and laminated safety glass - Evaluation of conformity/Product standard
ISO 3585	Borosilicate glass 33 -- Properties
ISO 16293-1	Glass in building -- Basic soda lime silicate glass products -- Part 1: Definitions and general physical and mechanical properties
ISO 12543-1	Glass in building -- Laminated glass and laminated safety glass -- Part 1: Definitions and description of component parts
ISO 12543-2	Glass in building -- Laminated glass and laminated safety glass -- Part 2: Laminated safety glass
ISO 12543-3	Glass in building -- Laminated glass and laminated safety glass -- Part 3: Laminated glass
ISO 12543-4	Glass in building -- Laminated glass and laminated safety glass -- Part 4: Test methods for durability
ISO 12543-5	Glass in building -- Laminated glass and laminated safety glass -- Part 5: Dimensions and edge finishing
ISO 12543-6	Glass in building -- Laminated glass and laminated safety glass -- Part 6: Appearance
ASTM C1172	Standard Specification for Laminated Architectural Flat Glass
ASTM F1233	Standard Test Method for Security Glazing Materials And Systems

PV-related standards can be downloaded from BSI (British Standards Institute) Online http://shop.bsigroup.com/en/Navigate-by/BSOL/ by subscription. All standards can also be purchased through the webstore of each standards organisation (ISO, IEC, ASTM etc).

iv. National standardisation organizations

TABLE 49.
NATIONAL STANDARDISATION ORGANISATIONS

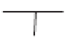
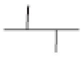
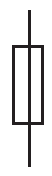
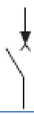
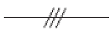
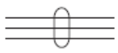
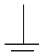
Country	Standardisation Organisation	Link
Belgium	Institut belge de normalisation (IBN)	www.ibn.be
Bulgaria	The Bulgarian Institute for Standardisation	http://www.bds-bg.org
Croatia	Croatian Standards Institute	www.hzn.hr
Cyprus	Cyprus Organisation for Standardisation	www.cysorg.cy
Greece	Hellenic Organization for Standardization (ELOT)	http://www.elotg r
Spain	Asociacion Espanola de Normalizacion y Certificacion (AENOR)	http://www.aeno r.es
Romania	Asociatia de Standardizare din România (ASRO)	http://www.asr.or o/engleza2005/de fault_eng.html
United Kingdom	British Standards Institution (BSI)	http://www.bsigr oup.com

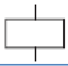
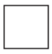
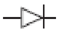
v. Graphical Symbols

IEC 60617 contains graphical symbols for use in electrotechnical diagrams. The database is the official source of IEC 60617 including more than1750 symbols.

Some of the most commonly found are presented in the table below.

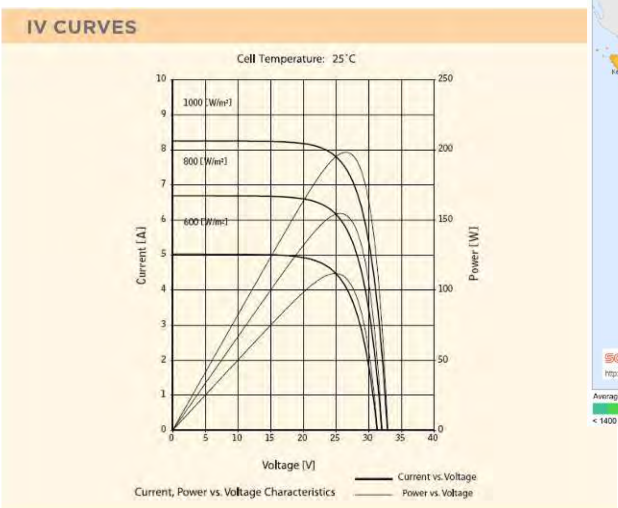
TABLE 50.
GRAPHICAL SYMBOLS (Source: Simmons and Maguire, 2004)

Links	Description
	Direct current
	Alternating current
	Positive polarity
	Negative polarity
	Propagation, energy flow, signal flow, one way
	Junction of conductors
	Double junction of conductors
	Primary cell or accumulator
	Inductor, coil, winding, choke
	Machine, general symbol The asterisk is replaced by a letter designation as follows: C synchronous converter G generator GS synchronous generator M motor MG machine capable of use as a generator or motor MS synchronous motor
	Battery of accumulators or primary cells
	Fuse, general symbol
	Fuse with the supply side indicated
	Connecting link, closed
	Connecting link, open
	Circuit breaker
	Make contact normally open, also general symbol for a switch
	Conductor, group of conductors, line, cable, circuit, transmission path
	Three conductors
	Conductors in a cable, three conductors shown
	Earth or ground, general symbol
	Ammeter
	Voltmeter
	Contactor, normally open
	Contactor, normally closed

	Operating device (relay coil), general symbol
	Wattmeter
	Semiconductor diode, general symbol
	Tunnel diode
	Resistor, general symbol
	Watt-hour meter
	Signal lamp, general symbol
	Photovoltaic cell

vi. Characteristic I-V curves for modules

FIGURE 163.
HARACTERISTIC I-V CURVES FOR MODULES (Source: www.energygridsolutions.com/solar-sharphtml, October 2011)



vii. Radiation maps

FIGURE 164.
EUROPE RADIATION MAPS (Source: http://re.jrc.ec.europa.eu/pvgis/, October 2011)

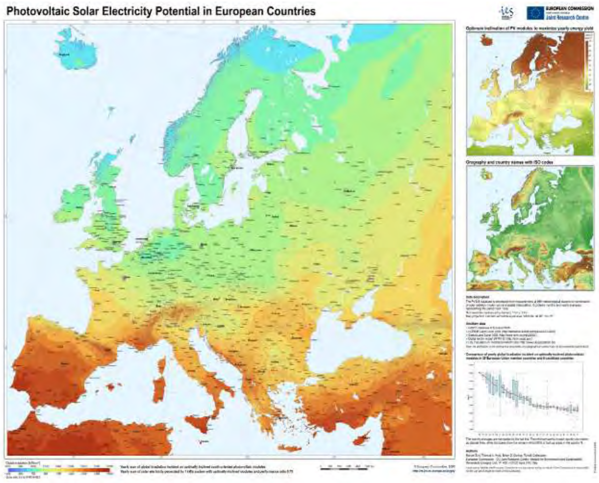
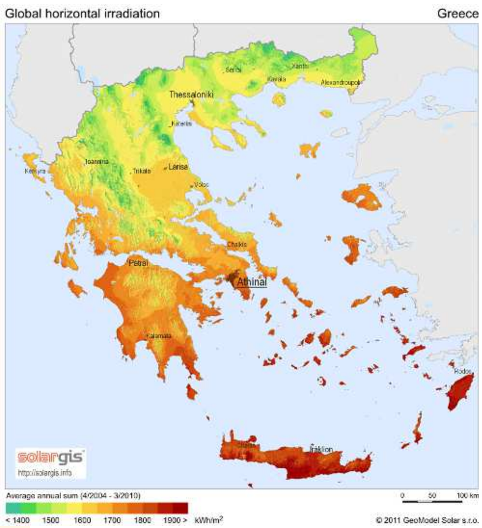


FIGURE 165.
RADIATION MAPS (Source: http://mappery.com, October 2011)



viii. Useful links

Links	Description
www.pvresources.com	Information on solar power and its applications large scale PV power plants database on reports simulation tools
www.pvdatabase.org	Data on best practices, urban PV projects, BIPV products
www.iea-pvps.org	National reports and statistics on PV market
www.pvlegal.eu	Detailed information on the administrative processes that need to be followed in order to install a PV system in each of the participating countries
www.eupvplatform.org/	Platform aiming to develop a strategy and corresponding implementation plan for education, research & technology development, innovation & market deployment of PV energy
www.enf.cn/database/panels.html	Information on production equipment, solar components (eg inverters, batteries), solar materials, solar panels, sellers, solar system installers
www.posharp.com/photovoltaic/database.aspx	Extensive database with characteristics of many PV panels
http://pvbin.com	Database of all commercially available solar panels with functionality to search and sort by different data parameters
http://en.wikipedia.org/wiki/List_of_photovoltaic_power_stations	List of PV power stations larger than 25 MW in current net capacity
www.renewableenergyworld.com/rea/home	Access to RE focused services, including daily news, products, technology overview, energy events calendar, job opportunities etc
www.solarplaza.com	Plenty of information in different segments of the PV market
www.solarserver.com	Portal dedicated on PV energy covering different issues (solar magazines, funding, events, job market etc)
www.solarbuzz.com	News, research, analysis and consulting on different PV fields is provided
www.bipv.ch/index.php?option=com_content&view=article&id=209&Itemid=176&lang=en	
www.nrel.gov/pv/performance_reliability/failure_database.html	Information on failures observed in PV installations
www.iec.ch	IEC provides a platform to companies, industries and governments for meeting, discussing and developing the International Standards they require
www.astm.org	American Society for Testing and Materials international standards for materials, products, systems and services used in construction, manufacturing and transportation
www.cen.eu	Committee for Standardization platform for the development of European Standards and other technical specifications
www.ul.com	Underwriter Laboratories Inc database with more than 1.000 Standards for Safety
www.iso.ch	International Organisation for Standardization Worldwide federation of national *standards* institutes, promoting the development of *standardization* of goods and services
http://shop.bsigroup.com/Navigate-by/BSOL/	Database of more than 50.000 standards rich in business-critical content covering a broad range of disciplines for all industry sectors
www.yoursunyourenergy.com/	Portal that aims to gather and promote the best that the Web has to offer in relation to solar PV energy in a global and complements information already available elsewhere
www.pv-tech.org/	Information on production equipment, solar components and PV market in general
http://www.irena.org/home/index.aspx?PriMenuID=12&mnu=Pri	IRENA targets to Foster all types of RES and to consider various RE policies at the local, regional, and national levels
eur the Eur	Information and services provided by the EU Energy

		Strategy for Europe (roadmaps, markets, statistics etc)
	http://europa.eu/pol/env/index_en.htm	All EU environment law – summaries (waste, noise, air pollution etc)
	http://europa.eu/epso/index_en.htm	European Personnel Selection Office (EPSO) target is to deliver a staff selection service to the highest professional standards on behalf of the EU Institutions.
	http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/	Statistics at European level that enable comparisons between countries and regions.
www.buildup.eu		European portal for energy efficiency in building, valuable knowledge on how to reduce energy consumption in buildings
www.epia.org		**World's largest industry association devoted to the solar PV electricity market (information on** latest legislative developments, advising key decision-makers on the most adequate policies to develop a sustainable PV market, technical and economic issues etc)
http://re.jrc.ec.europa.eu/pvgis		The model algorithm estimates beam, diffuse and reflected components of the clear-sky and real-sky global irradiance/irradiation on horizontal or inclined surfaces The total daily irradiation [Wh/m^2] is computed by the integration of the irradiance values [W/m^2] calculated at regular time intervals over the day
www.meteonorm.com		Climatological database for solar energy applications: a meteorological database containing comprehensive climatological data for solar engineering applications at all points of the globe

FURTHER READING

1. M. Drifa, P.J. Pereza, J. Aguilera, J.D. Aguilar, A new estimation method of irradiance on a partially shaded PV generator in grid-connected photovoltaic systems, Renewable Energy vol 33, pp 2048–2056, 2008 (relevant §2.1.3)

PV installers can study a new method for estimating irradiance on a partially shaded PV system. The principles of the proposed method and the algorithm used for calculating the irradiance on shaded planes is presented in the aricle.

2. H. Haeberlin, Optimum DC operating Voltage for grid connected PV plants, 20th European PV Solar Energy Conference, Barcelona, Spain, June 2005 (relevant §222).

The technician may find answers to such questions as: at which VMPP should an inverter be tested and at which interval should the STC array voltages of a PV plant be chosen. The design procedure is also presented in the conference paper with some numerical examples.

3. IEA PVPS, International Energy Agency Implementing Agreement on PV Power Systems, Use of PV Power Systems in Stand-Alone and Island Applications, 2003

PV installers can deepen their knowledge of common practices and practical techniques to set up lightning protection (relevant §228).

4. J.P. Dunlop, Batteries and Charge Control in Stand-Alone Photovoltaic Systems. Fundamentals and Application. Sandia National Laboratories USA, 1997 (relevant §2210)

The PV technician can gain specialized knowledge on battery technology and charge control strategies commonly used in stand-alone PV systems. Details are provided on the common types of flooded lead-acid, valve regulated lead-acid, and nickel-cadmium cells. Comparisons are provided for various battery technologies, and considerations for battery subsystem design, auxiliary systems, maintenance and safety are discussed.

5. Danish Energy Agency, Optimisation of the Design of Grid-Connected PV Systems under Danish Conditions" (PV-OPT), 2009 (relevant §231)

The trainee can study the design of several case studies, in order to comprehend the theory presented in chapter 2. Three examples are provided on designing a PV plant on a roof of a single house, using commercially available products. In the examples, the expected annual yield is calculated using 3 different methods: a manual calculation based on data sheets for modules and inverter; the web-based PVGIS software program; and, the PVSYST software system. Trainees can study practical examples.

6. P. Arun, R. Banerjee, S. Bandyopadhyay, Optimum sizing of photovoltaic battery *systems incorporating uncertainty through design space approach, Solar Energy*

vol 83, pp 1013-1025, 2009 (relevant §2210)

The trainee can study a methodology for the optimum sizing of PV battery system for remote electrification. The proposed methodology is based on the design space approach involving a time series simulation of the entire system.

7. L. Lu, H.X. Yang, Environmental payback time analysis of a roof-mounted BIPV system in Hong Kong, Applied Energy vol 87, 3625-3631, 2010 (relevant §2.4.1)

The energy payback time and greenhouse-gas payback time of a rooftop BIPV system (grid-connected) in Hong Kong is investigated in order to measure its sustainability.

8. EPIA, Solar generation 6; Solar Photovoltaic Electricity Empowering the World, 2011 (relevant §2.4.2)

The PV technician can collect valuable market information from the current status of PVs worldwide and will also be informed of environmental issues, potentials and growth prospects over coming years. This information will be valuable in discussions with potential clients.

9. M. A. Eltawil, Z. Zhao, Grid-connected photovoltaic power systems: Technical and potential problems—A review, Renewable and Sustainable Energy Reviews vol14, pp 112-129, 2010

The paper reviews the literature on expected potential problems associated with high penetration levels and islanding prevention methods of grid tied PV. According to the survey, PV grid connection inverters have fairly good performance.

10. B. Yu, M. Matsui, G. Yu, A review of current anti-islanding methods for photovoltaic power system, Solar Energy vol 84, pp 745-754, 2010

The technician can learn about different anti-islanding method developments for grid-connected PV power generation based on single phase systems. Active and passive anti-islanding methods are evaluated and compared through experimental results.

11. X. Gong, M. Kulkarni, Design optimization of a large scale rooftop PV system, Solar Energy, vol 78, pp 362-374, 2005 (relevant §2.7.1)

Optimization of PV systems is an essential issue when designing a system. The article presents the technician with the optimization process of a grid-connected PV system, on the rooftop of a Federal office building and a PV energy conversion model. Based on this model, array surface tilt angle and array size are optimized. The optimization method is based on maximizing the utilization of the array output energy, and, at the same time, minimizing the electricity power sold to the grid.

12. A. Salaymeh, Z. Hamamre, F. Sharaf, M.R. Abdelkader, Technical and economical assessment of the utilization of photovoltaic systems in residential buildings: The case of Jordan, Energy Conversion and Management, vol 51, pp 1719-1726, 2010 (relevant §271)

The trainee can study a case study that examines the cost of a PV system and the payback period. The feasibility of utilizing PV systems in a standard residential apartment in Jordan is presented. An apartment is chosen as a case study to conduct energy and economic calculations. The electrical power needs and cost are calculated for the apartment.

13. SEAI, Sustainable Energy Authority of Ireland, Best Practice Guide– PVs, Ireland, 2010 (relevant §2.7.1)

The PV technician can study the preliminary design of a BIPV system. The case study describes the design and planning of a PV installation, including the integration of PV into the building.

14. NABCEP, North American Board of Certified Energy Practitioners, NABCEP study guide for photovoltaic system installers, USA 2009 (relevant §272)

Different questions and answers are presented in this article that tests the knowledge of trainees on different PV issues. The answers are also presented in the same study guide.

15. Photovoltaics in Buildings Guide to the Installation of PV Systems 2nd edition 2006 (DTI publication DTI/pub URN 06/1972). (3rd edition to be published shortly). Available from www.bre.co.uk/filelibrary/pdf/rpts/Guide_to_the_installation_of_PV_systems_2nd_Edition.pdf

16. BRE Digest 489 'Wind loads on roof-based photovoltaic systems.' Available from www.brebookshop.com

17. BRE Digest 495 'Mechanical installation of roof-mounted photovoltaic systems.' Available from www.brebookshop.com

18. 'Photovoltaics in Buildings – Safety and the CDM Regulations', (BSRIA/DTI February 2000, ISBN 086022 548 8

Further Reading, in Greek

1 Οδηγίες για την εγκατάσταση Φ/Β συστημάτων σε κτιριακές εγκαταστάσεις, ΚΑΠΕ, 2009

The manual is available from the CRES website and summarizes information for professionals on PV installation in buildings.

2 Μηχανική των Φωτοβολταϊκών Συστημάτων, Τεχνολογία, Μελέτες, Εφαρμογές, ΣΝ Καπλάνης, Εκδόσεις ΙΟΝ 2004

Plenty of PV exercises and examples for the trainee to comprehend the theory and the design issues presented in chapter 2.

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A great deal of additional information on the PVTRIN project is available on the web at: www.pvtrin.eu.
We would welcome feedback on this publication, if you have comments or questions please contact the project coordinator.

PHOTOVOLTAICS CERTIFIED INSTALLER

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PVTRIN PARTNERS

Partner	Country	Website
Technical University of Crete *Environmental Engineering Dpt.* *Renewable and Sustainable Energy Systems Lab* *PROJECT COORDINATOR*	*Greece*	www.resel.tuc.gr
Agency of Brasov for the Management of Energy and Environment	*Romania*	www.abmee.ro
Building Research Establishment Ltd	*UK*	www.bre.co.uk
Energy Institute Hrvoje Požar	*Croatia*	www.eihp.hr
European Photovoltaic Industry Association	*EU/ Belgium*	www.epia.org
Scientific and Technical Chamber of Cyprus	*Cyprus*	www.etek.org.cy
Sofia Energy Centre	*Bulgaria*	www.sec.bg
Tecnalia	*Spain*	www.tecnalia.com
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