



Solar PV Installation Guidelines



IMPRINT

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Solar PV Installation Guidelines



Foreword

In 2014, the Department of Energy through the IRP 2010-30 update estimated that small scale embedded generation (SSEG) could reach 22.5 GW by 2030. The potential for SSEG through Rooftop Solar PV is extremely important when aligned with the Government objective to provide access to a reliable, affordable and environmentally friendly energy supply.

South Africa's PV market is quickly growing with more than 300 MWp of rooftop systems installed at the end of 2016. Addressing the quality and safety challenges in the space will not only improve the business case for Solar PV but will further promote the its uptake.

Solar PV is no longer considered an expensive luxury lifestyle product for idealists but an affordable and attractive alternative for all South Africans. It is a feasible proposition for all private and commercial users looking to protect themselves from the rising price of grid electricity. It is expected that the long term position for solar PV is bright.

The South African Photovoltaic Industry Association (SAPVIA) has developed a quality mechanism, the PV GreenCard, to ensure that Rooftop Solar PV installations are done responsibly and sustainably. It is in industry's best interest to establish good installation standards in anticipation of the SSEG revolution.

The PV GreenCard Programme is based on education, skills-development, and training as well as compliance to national standards, guidelines and international best practise. This gives the user access to qualified Solar PV installers providing quality and safe solar PV installations.

Although, several policies, regulations, standards, grid codes and guidelines assist with the implementation of SSEG, there is no dedicated national standard intended to standardise the installation of SSEG through Rooftop Solar PV. The SANS 10142-3 currently under development will address this need. In the meanwhile, it is recommended that the Solar PV Installation Guidelines be used to conform to standardised practices.

The guidelines explain the basics of electricity generation, Solar PV components, planning and sizing of the Solar PV installation. Other general guidelines are presented on working from heights, recurring duties and appropriate example installations. This therefore presents a detailed overview for everyone who is involved in the planning, installation, operation and maintenance of PV systems. The Solar PV Installation Guidelines are aligned with the National Solar PV Service Technician Qualification and assists the Solar PV installer to use international best practices when installing and maintaining grid-tied Solar PV systems. As the planning of off-grid (stand-alone) systems are different in many aspects, a separate guideline will cover these types of installations.

It should be noted that Solar PV installers are advised to use the Solar PV Installation Guidelines in conjunction with all relevant national electrical codes, building codes and regulations. Furthermore, metering and exporting of solar-generated electricity must be done in compliance with the actual legal requirements.

In order to gain a more comprehensive overview of all kinds of PV installations, we recommend to study the DGS *Manual Planning and Installing Photovoltaic Systems – A Guide for Installers, Architects and Engineers* (as published by the German Solar Energy Society, DGS). Due to the ongoing development process of technical and legal requirements for PV installations, these cannot be covered in detail in this document.

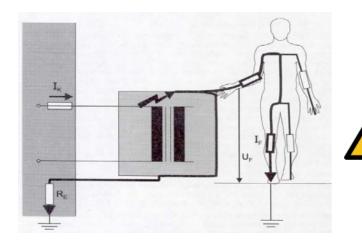
As the industry develops, we will learn how to do many things better through experience. The aim is to update the Solar PV Installation Guidelines from time to time to capture these findings. We hope you welcome those improvements in future versions.

We would like to acknowledge and thank our partners Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), The German Solar Association (BSW Solar), GreenCape and most especially Mr. **Udo Siegfriedt** from the German Solar Energy Society (DGS Berlin) who compiled the Solar PV Installation Guidelines. A further appreciation to Daniel Goldstuck, Clemens Brandt and Christopher Gross for the review and finalisation of this document that you see presented.

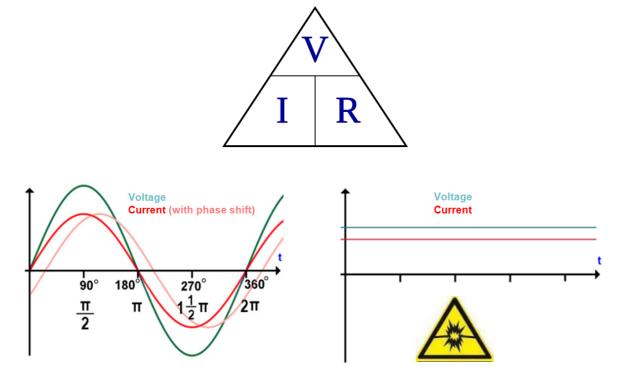
Davin ChownSAPVIA Chairperson







Base Unit	Symbol	Unit	Name
Voltage	V	V	Volt
Current	I	А	Ampere
Resistance	R	Ω	Ohm
Power	Р	W	Watt
Energy	E	Wh	Watt-hour
Frequency	f	Hz	Hertz



Electricity: Some basics

Electricity for technical use comes from various primary energy sources. Usually, a chemical source like coal is used to produce heat which then drives a turbine. A generator attached to the turbine transforms the mechanical rotational energy into electricity.

Electricity can easily be distributed and is used for many purposes – such as heating, cooling, providing light, running electronic devices, and transportation.

Although electricity is taken for granted in most households today, it still comes with certain risks. Installers who are working with electrical circuits must especially be aware that the human body is affected by contact to live components. Therefore, all necessary and possible safety precautions must be adhered to – such as disconnection from any energy source before starting work or the shielding of live components.



The installer must follow the national safety requirements in the Occupational Health and Safety Act or other regulations, standards or guidelines

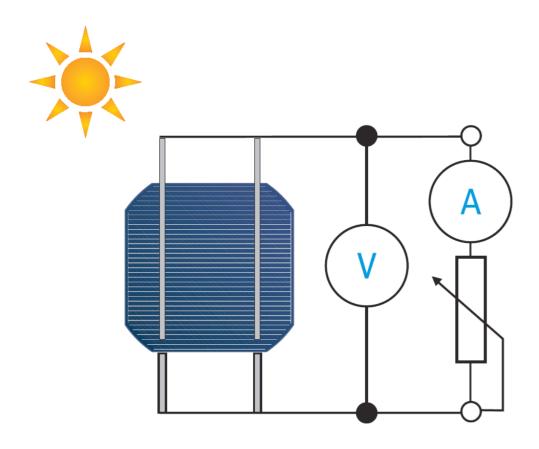
The electrical behaviour of an energy source connected to a load is described by Ohm's Law. If a voltage 'V' from a battery or solar cell is connected to a load with a resistance 'R' – a current 'l' will flow. The power that can be used by the load is calculated as the product of voltage and current. The electrical energy used by the load is calculated as the product of power and time and is transformed into another form of energy (e.g. mechanical rotation, heat).

Electrical energy is used as alternating current (AC) or direct current (DC). The voltage of an AC source shows a periodic behaviour. It oscillates from zero to a positive peak voltage, back to zero and to a negative peak voltage, and then back to zero again. The reciprocal value of the time for one total wave is the frequency 'f' given in 'Hz'.

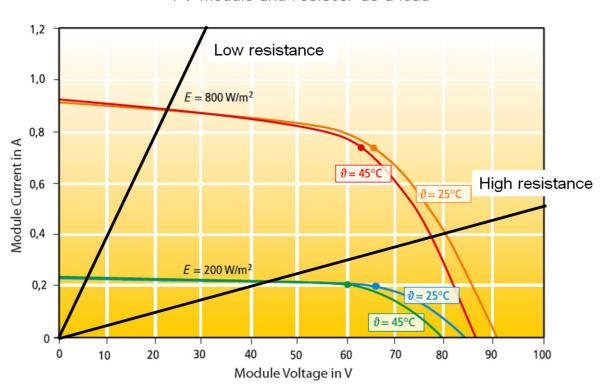
A phase shift occurs when the voltage and current do not cross the origin at the same time. The public grid is set up as a three-phase system, where the phase shifts between the voltages of the single phases are 120°.

In a DC system, voltage and current have a constant value and a certain polarity. There is no crossing of the origin, and the frequency is zero. A DC system has an increased risk of arcing in the event of switching or short circuits.





PV-module and resistor as a load



How to read characteristic curves

Electrical components can be described as active (e.g. batteries) or passive (e.g. resistors), and the electrical behaviour of any component can be described through characteristic curves. An IV curve, for example, shows the values of the current as a function of the voltage. The current for a resistance has a linear behaviour, depending on the external voltage. Most components show a non-linear characteristic. An irradiated solar cell has an almost constant current for low voltages, and a limited maximum voltage.

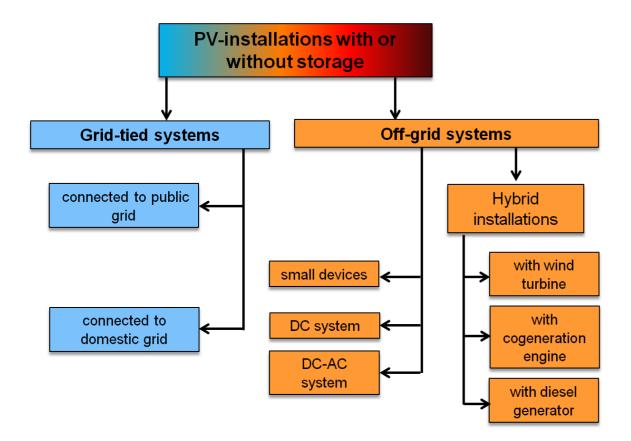
The characteristic curve shows all operating points of a particular electrical component. For a resistance of 1 Ω the IV curve shows a current of 0 A for an external voltage of 0 V and a current of 1 A for an external voltage of 1 V. It also shows that a current of 0.5 A is not possible for an external voltage of 1 V, because this point is not on the characteristic curve.

For a parallel combination of an active and a passive component, both characteristic curves can be overlaid in one diagram. Possible operating points for this combination are only the intersection points where both characteristic curves have the same value. For a PV module the characteristic curve depends on irradiation and temperature. Subsequently, the operating point will vary depending on these input factors. The operating point also depends on the value of the resistor. To change to a certain operating point on the characteristic curve of the module, the value of the resistor must be changed.

Theoretically, a characteristic curve is unlimited. However, there are permitted areas and borderlines which must not be exceeded. If the operating point for a combination of two electrical components is within a non-permitted area for one component – this particular component will be damaged. If, for example, the current for a resistor is too high, it will overheat and burn out after a while.







Field of activity of the PV installer

For a safe and reliable PV installation, proper planning, installation, operation and service are necessary. A PV installer must obtain sufficient knowledge and skill in all these areas.

For a high-quality PV installation the use of certified components such as inverters and modules, is necessary. The PV installer has to choose these components and combine them in a proper manner. For the correct sizing he needs to know the behaviour of the component under real conditions.

To ensure high yield of the PV system, an onsite survey is necessary in order to observe external conditions such as shading. All important information has to be regarded in a yield assessment for the proposed PV system.

To ensure the safe operation over the whole life time of the PV system, good craftsmanship is essential. The PV installer must know how to install the mechanical substructure and perform the electrical interconnections. Additionally, depending on the mounting situation, he must also have sufficient knowledge about roofing and other technical subjects affected by the PV system.

Once an installation is completed the PV installer has to prepare the system documentation, including the results of commissioning tests. All legal requirements must be considered and are to be documented accordingly.

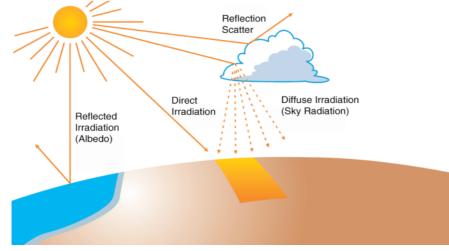
Operation and maintenance is an important subject for the safe operation of a PV system and to ensure the highest possible yield. The PV installer should be able to read data coming from a monitoring system and be able to determine errors and risks in order to avoid yield losses and damage. Once problems are detected, he should be able to perform necessary repairs and rework.

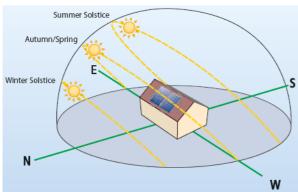
Overview of PV systems

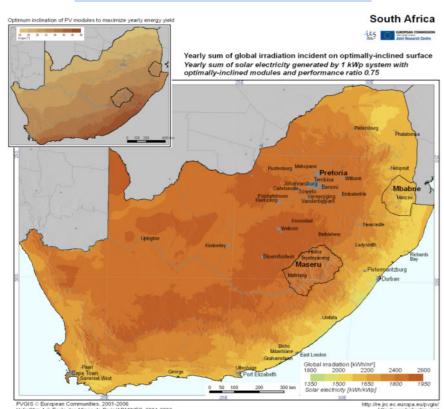
A PV system can be grid tied, off-grid or a combination of both - i.e. a backup system. In all systems a storage device can be added. For grid tied PV (also referred to as an embedded generator system), certain legal requirements such as adherence to the grid code must be fulfilled.

Off-grid systems are most often combined with other energy sources such as wind turbines and diesel generators. These hybrid systems provide a secure energy supply – even if there is insufficient irradiation. The sizing of off-grid systems is highly dependent on the load behaviour of the site.









The Sun: Energy for the next billion years

The Sun provides almost all the energy we use for our daily life. Also, all fossil energy like coal and oil are based on energy that came from the sun – albeit billions of years ago. Even wind energy is driven by the power of the Sun. Only nuclear power and geothermal power are driven by nuclear reactions. The solar energy reaching the Earth's surface would, in theory, be sufficient to solve all the energy problems on Earth.

Outside the Earth's atmosphere solar energy has an almost constant value of 1367 W/m². While passing through the atmosphere, the energy and the spectral behaviour of the sunlight changes. Due to reflections on particles in the air, clouds, as well as ground reflection, the direct irradiation is reduced and a diffuse irradiation is added. The sum of both irradiation types is usually below the value found outside the atmosphere. For a sunny day and optimised orientation towards the sun, the global irradiation is about 1000 W/m². On cloudy days there is almost no direct irradiation left, the diffuse irradiation depends on the cloud type, and can be less than 100 W/m².

The irradiation on a tilted surface also depends on the position of the Sun. This position depends on the way the Earth moves around the Sun, and also the tilt of the Earth's axis in relation to this orbit. In winter the sun-path is lower than in summer. Also, the sunshine duration in winter is shorter than in summer.

The Air Mass is the path length which light takes through the atmosphere normalized to the shortest possible path length (that is, when the sun is directly overhead). The Air Mass quantifies the reduction in the power of light as it passes through the atmosphere and is absorbed by air and dust.¹

Typical values for Air Mass are:

AM 0: Radiation outside the atmosphere

AM 1: Vertical incidence on the Earth's surface (only at the equator)

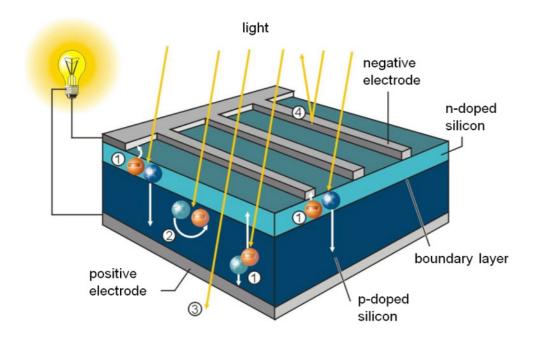
AM 1.5: Incidence angle of 48° with respect to the vertical

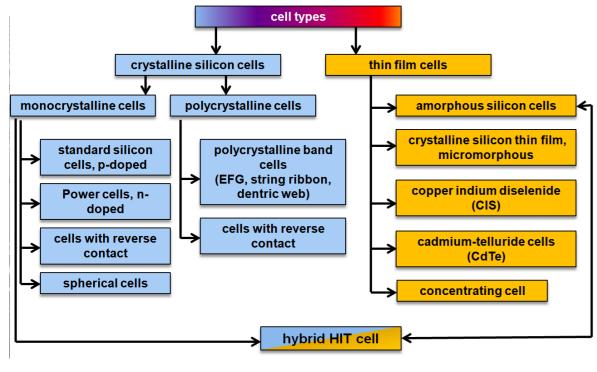
The Air Mass describes the attenuation of the irradiation and also spectral changes.

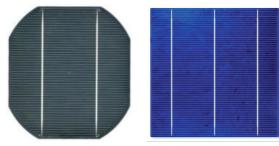
For a certain location, the annual solar energy depends on all the effects mentioned above. In South Africa, the sunshine duration, the sun path and the climate conditions such as clouds differ depending on the actual location. Nevertheless, for all geographic regions of South Africa there is sufficient irradiation to enable a PV system to provide high yield – in summer and winter.

¹ Source: http://www.pveducation.org/pvcdrom/2-properties-sunlight/air-mass









The solar cell: A diode that generates a current

The crystalline solar cell can be regarded as a large-dimension diode. In crystalline silicon cell one layer is doped as n-layer, and the remaining silicon is doped as p-layer. A negative electrode is applied to the upper side as a grid structure, and the positive electrode is applied to the rear side as a metal layer. To obtain current flow, a photon must separate a negative electron from the silicon atom leaving a positive hole behind. The freed electron can be used outside the cell as a current to power an external load. Losses occur if a photon is reflected off the surface or off the crystalline grid, passes the whole cell without separating an electron, or if an already separated electron recombines with a hole.

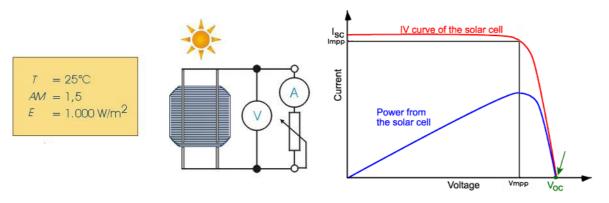
Today's market offers a wide variety of cell types. Crystalline cells comprise monocrystalline and polycrystalline cells – with each one subdivided into different types depending on the internal structure and manufacturing process. Especially for thin-film cells, there are many different materials in use. Silicon cells can be amorphous or crystalline, and other materials such as cadmium telluride are in use. Combinations of different materials are available in order to obtain higher cell efficiencies.

The global market share of crystalline cells is above 90%. Thin-film material is still less common in the market – mainly because of lower efficiency and un-proven long-term stability. With technical improvements, the market share may increase in future.

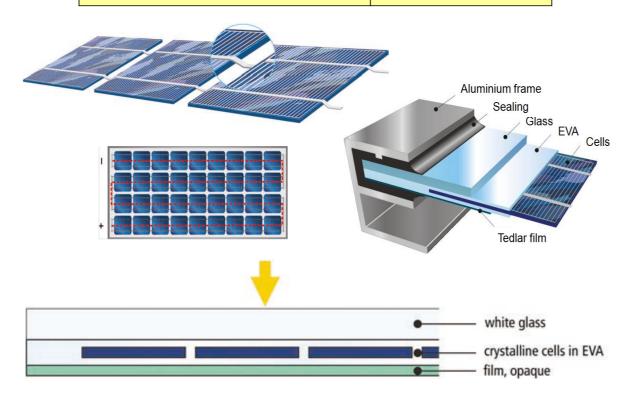
In the crystalline market, polycrystalline cells have a higher market share than monocrystalline cells. The efficiency of monocrystalline cells can be higher than for polycrystalline cells but they are generally more expensive. The shape of monocrystalline cells is not square as the cell is sliced out of a round crystal.

Polycrystalline cells can use almost the whole module area because of their perfect square shape. Therefore, the efficiency of polycrystalline modules can be higher, even with lower cell efficiency, because there are no missing areas at the cell corners. Also, the efficiency of polycrystalline cells has improved significantly in recent years. The anti-reflective coating on the cell surface is almost as effective as for monocrystalline cells. Both materials are almost black today – with only a light blue shimmer for polycrystalline cells.





Material	Module efficiency (Standard modules)	Area for 1 kW _p	
Monocrystalline rear side contacts	20.4 %	5 m²	
Monocrystalline	17%	6 to 7 m ²	
Polycrystalline rear side contacts	16,6 %	6 to 7 m²	
Polycrystalline	16 %	6 to 7 m ²	
CIS	14,5%	7 to 8 m²	
CdTe	13,5 %	8 to 9 m²	
Amorphous	7,5 %	13 to 15 m ²	
High efficiency means low area demand		Rule of thumb: 1 kW _p = approx. 1	0 m²



From solar cells to PV modules

The electrical parameters of a solar cell are measured under defined conditions: the so called Standard Test Conditions (STC). Standard testing conditions require irradiation of 1000 W/m², a cell temperature of 25° C and an air mass (AM) of 1.5. The characteristic curves for the power output show a maximum for a certain voltage and current. Measured at STC, the maximum power of the characteristic curve is the nominal power of the cell. It is also called the Maximum Power Point (MPP). Therefore, the power measured at STC is usually called P_{MPP} or P_{Peak} at the voltage V_{MPP} and current IMPP. The open-circuit voltage V_{OC} and short-circuit current I_{SC} are other characteristic values for the description of the cell behaviour.

The efficiency of a solar cell can be calculated as P_{MPP} divided by the irradiation on the cell. As the STC irradiation is 1000 W/m², the irradiation on the cell is STC irradiation multiplied by the cell area. For a module, multiple PV cells are combined. The typical value for the efficiency of crystalline modules is around 17%.

For other cell types the efficiency may differ. There are high power modules on the market, where the efficiency is slightly above 20%. At writing the current efficiency of thin-film modules is below 15%, and below 10% for amorphous cells.

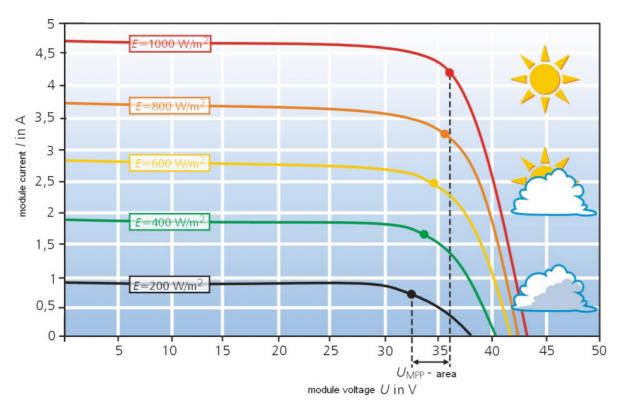
For a defined PV system power rating, the required array area depends on the efficiency of the PV modules to be used. For roof-top systems the viable installation area is smaller than the total roof area. When considering the geometry of the roof and the modules, the gap left between the modules, other roof structures, and nearby objects which may cause shading – the suitable roof area is reduced. As a rule of thumb – when using crystalline PV modules – the roof area needed for 1 kW_{Peak} is approximately 10 m². For larger roofs, with fewer roof structures or when using modules with a high efficiency, the power that can be installed will be significantly higher, but for other cell types it might be lower.

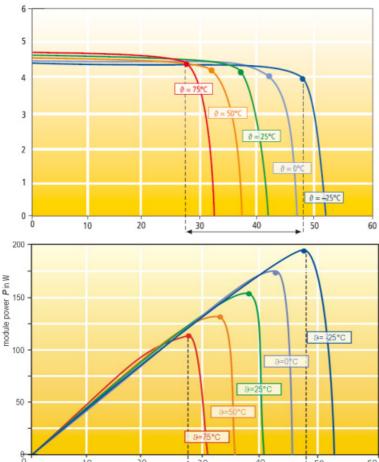
The cells inside a module are usually interconnected in series. A bus-bar twice as long as the length of a cell is soldered to the negative electrode on the face of the first cell. Current manufacturing standards provide for multiple bus-bars for the interconnection of cells in a module.

Nine to twelve cells are interconnected in a sub-string. Four to six sub-strings are interconnected for one module, and are also soldered in series with bus-bars which terminate in a junction box for interconnection to other modules.

To protect the cells from mechanical stress, weathering and humidity, they are embedded in a transparent bonding material (EVA or other material) that also isolates the cells electrically. For structural stabilisation, a pane of glass is added. The modules are sealed by a sheeting on the rear side. Most modules are framed using aluminium profiles.







Electrical behaviour

The series connection of the cells in a module lead to an output voltage in open circuit, which can be calculated as cell voltage with a typical value of 0.6 V, multiplied by the number of cells. For a module with 72 cells, the STC voltage is approximately 43 V.

Because all cells are connected in series the output current of the module equals the current of one cell. The nominal power P_{MPP} or P_{Peak} for a module is the nominal power of one cell multiplied by the number of cells.

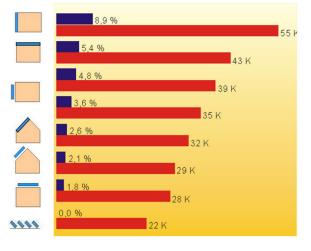
The nominal values only describe voltage, current and power of the modules for irradiation, temperature and spectrum at STC. However, all these values differ if the input parameters change. The current is almost proportional to the irradiation. For an irradiation of 500 W/m², the current will be half of the STC current. The voltage strongly depends on the cell temperature. The behaviour of voltage and current also depends on the cell type and is described in the respective temperature coefficients (ΔV , β). For most data sheets, the coefficient for the open circuit voltage is given as a negative percentage value. If the temperature goes up and the voltage will go down. A typical value for crystalline modules is β oc= 0.34 %/°K (the coefficient is usually given per °Kelvin, not per °Celsius. However, as there is a linear relationship between the Kelvin and Celsius scales, the use of either will lead to the same result. If the temperature goes up to 35°C, the difference to STC is 10°K. With the given coefficient the open-circuit voltage will go down 3.4%. For a roof-top installation, a module temperature of more than 50°C can be expected. As a rule of thumb, the open-circuit voltage of an irradiated module can be calculated as VsTC -10%.

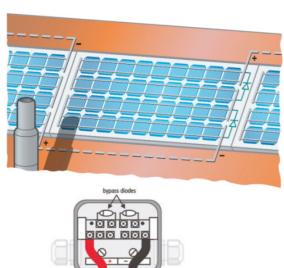
The current and power are also affected by the temperature. The coefficient of the short-circuit current $(\Delta I, \alpha)$ is positive and usually is also given in the data sheet. A typical value for crystalline modules is $\alpha OC=0.06$ %/°K. This value is significantly smaller than the coefficient for voltage. In most cases the temperature behaviour of the current may be assumed to be insignificant.

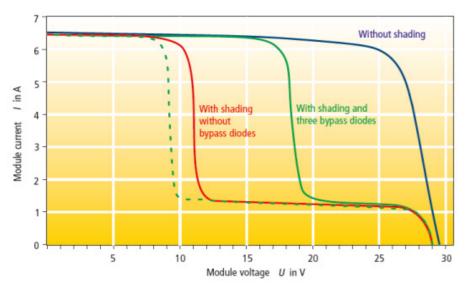
Unfortunately, the coefficients for the MPP voltage and current are not given on most data sheets. The behaviour at MPP is only given for power (ΔP , γ). It is also a negative value. Typical for crystalline modules, is γ = 0.42 %/°K.

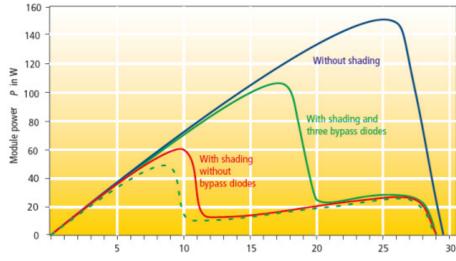
The cell temperature strongly depends on the irradiation. Ambient temperature and wind speed also need to be taken into account. Most important is the air-flow along the lower side of the modules. For a free-standing system, the air-flow is deemed to be ideal. For building integration the airflow is almost negligible. For South Africa, the ambient temperature is 0°C to 32°C for Cape Town and Johannesburg. In other regions like the Karoo the temperature can be much higher. Depending on the mounting situation, the maximum module temperature can rise up to 90°C or even higher. For a typical roof-top PV system, a temperature rise of 29°K and therefore a maximum module temperature of more than 60°C can be expected. The temperature can be approximated using the normal operating cell temperature (NOCT). This temperature is measured at 800 W/m², an ambient temperature of 20°C, and a wind velocity of 1 m/s for a free-standing installation. The sum of ambient temperature and NOCT is often regarded as the expected module temperature. Because a typical NOCT value of 45°C is much higher than the expected temperature rise of a roof-top installation, this can be regarded as a worst case scenario.











Shading effects

In a module, all cells are interconnected in series and will therefore operate at the same current. If the current of one cell is reduced due to shading or other effects, this will affect all other cells which are connected in series. Without protection, the unshaded cells would try to inject a higher current into the shaded cell. The shaded cell would stop operating as a generator – and become a load. Bypass diodes are implemented in the module junction box to avoid damage of the shaded cell. For every 18 to 24 cells, a diode will bypass the higher current of the unshaded cells. Only the cells connected to the same diode will operate with the lower current. The shaded cell is therefore protected from damage.

The characteristic power curve of a shaded module has two maximum points. While one maximum is the MPP, the other maximum can still be an operating point. Both points are lower than the unshaded MPP. Inactive cell areas caused by cracked cells will also reduce the current and act like a shaded cell. Other degradation effects might also show a similar characteristic curve.

For a PV system, the actual operating point depends on the number of modules interconnected in series in a string, and the number of strings interconnected in parallel to the MPP input of an inverter. For this interconnection a composite characteristic power curve exists. The MPP tracking algorithm of the inverter will operate all strings connected in parallel at one operating point. Depending on the voltage range of the inverter (the tracking algorithm or the time response of the whole system), both maxima are possible. The resulting operating point of the inverter string can be the real MPP or another maximum with reduced output power.

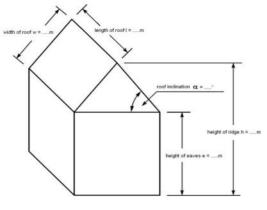
For a maximum with a voltage below the normal MPP Voltage, the bypass diode in parallel to the sub-string with the affected cell will bypass the difference of the unshaded current and the shaded current. For a maximum at a higher voltage, the current in all cells will be the same as for the shaded cell. The unshaded cells are then not operating at their MPP – but closer to the open-circuit voltage. In both cases the shaded cell is protected from damage.

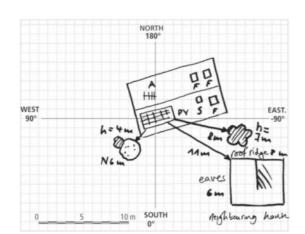
To assess potential shading of an installation, a site survey is required. A sketch of the building and surroundings can help to make the right decisions about where to install the PV system and how to interconnect the modules. Usually, satellite data such as Google Maps, Google Earth or Bing maps are helpful.

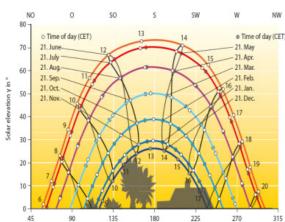
The orientation of elevated objects should be clearly marked, and the heights must be added. The information can be used in simulation tools. It is also possible to overlay a diagram of the sun path and the position of the relevant object.

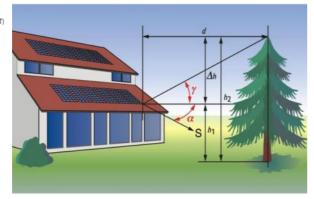
Especially when there are only a few elevated objects, e.g. an industrial smoke stack, the elevation angle can easily be calculated. First, the distance between the generator and the object must be observed. An adequate way is to step out the distance or use Google Earth. Then the height of the object must be observed, and also the height of the generator. Either one can use the worst case for the survey by choosing the lowest point of the generator or the most affected corner (see picture on the left), or an average point in the middle of the generator.

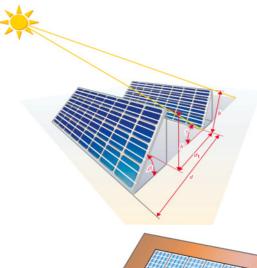


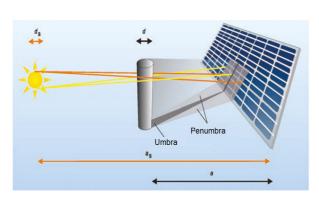
















The difference between both heights and the distance to the shading object is used to calculate the elevation angle of the object. Now it is possible to add elevation and orientation of the object to the sun path, which provides the initial information on how often the object will shade the specific area and whether a detailed shading analysis might be necessary.

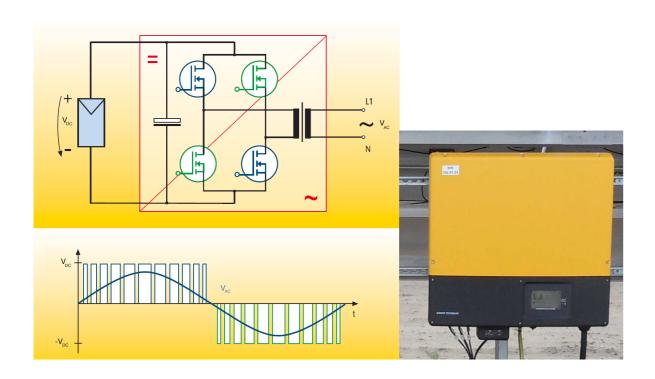
To calculate annual shading losses, the meteorological data are also important. Shading losses are mainly caused by the direct irradiation being blocked by an object. Only large objects nearby will block an essential amount of diffuse irradiation. Therefore, the share of direct irradiation in winter becomes most important. Compared to Germany, this share remains relatively high in South Africa. Therefore, many rules of thumb developed in Germany cannot be applied in South Africa.

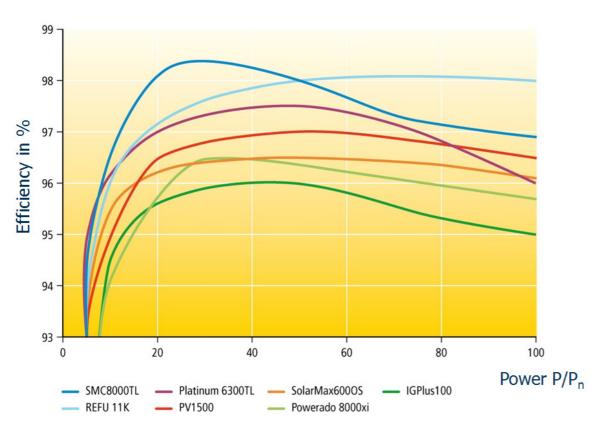
For inclined installations on flat roof tops and free-standing systems, inter-row shading cannot be avoided. The unshaded annual irradiation is optimised in South Africa for an orientation to the North and a slope of roughly 30°. For an elevated system, a certain distance between the rows is necessary to reduce shading effects. If the distance is reduced, the losses and the total installed power will increase and vice versa. For Germany, a rule of thumb allows a distance where the lowest sun altitude at noon (in Germany 21 December, in South Africa 21 June) is the geometrically calculated shading angle. A row distance sized that way would lead to unacceptable annual losses because of the higher share of direct sunlight in the South African winter.

To minimise shading losses, an umbra must be avoided. It can be calculated that the minimum distance must be 106 times the diameter of the shading object; this is most important for lightning rods and other roof structures.

If only small areas of the PV system are shaded in winter, the module orientation can be used to reduce the losses. The example shows the same shading situation for a vertical and horizontal installation. If the modules are orientated horizontally only two bypass diodes are affected, but for a vertical orientation the shading will affect seven bypass diodes. To optimise the annual behaviour a detailed shadow path must be observed. Usually, however, the effect is negligible and the required effort too high.







Inverter

Like the PV modules the inverter is a key component of a PV system. Installed between the PV generator and the public grid, it has to convert DC to AC electricity. To obtain a high yield the inverter has to operate at the maximum power point (MPP) as the optimised operating point. Integrated safety checks, like DC insulation measurement, are important functions performed by the inverter. On the AC side the behaviour of the inverter depends on standards and regulations as defined in national grid codes.

Important technical parameters of an inverter are the MPP voltage range, maximum input voltage, maximum input current and nominal AC power. These values are used for system sizing. Certain input parameters are limited to a safe value by the inverter itself. If, for example, the generator current exceeds the maximum input current most inverters will limit the current to prevent damage. Other parameters however, like the input voltage, may not exceed the given maximum as the inverter will be damaged.



The installer must observe the data sheet and the inverter manual. He has to ensure that the inverter fulfils the given standards and other regulations as defined in the grid codes.

Not only is the safe operation of the PV system important, we also need to minimise system losses. The inverter efficiency is one of the most important parameters to consider when choosing an inverter. As input power depends on irradiation and temperature we have to consider operation at extreme values. A weighted efficiency, as defined for the European Efficiency value, are given for most inverters. This value takes into account seasonal variation.

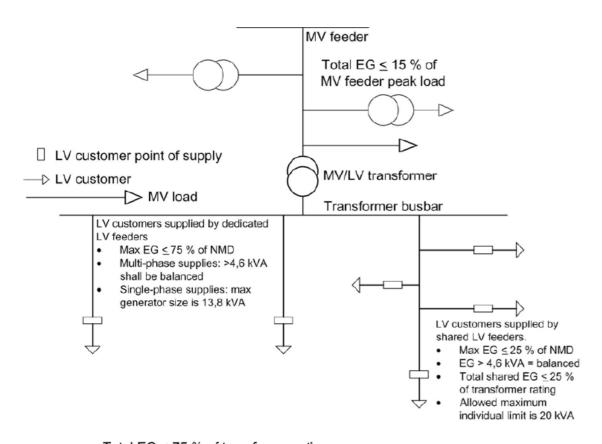
Another important feature of the inverter is the monitoring system and required components. Some inverter manufacturer include this as a standard feature. Other inverters require a third-party monitoring solution.

It is important to consider the mounting location when selecting an inverter. For installation outdoors the minimum requirement for the housing is an IP 54 rating.

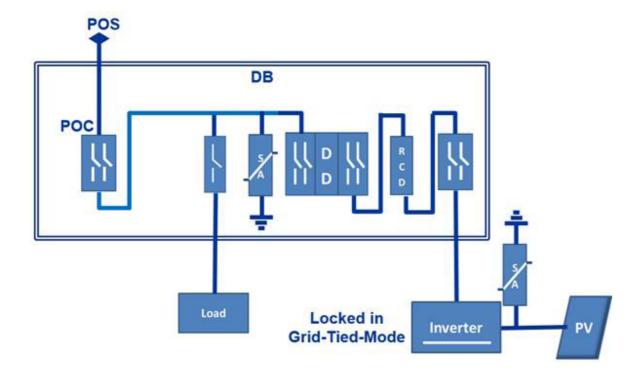
Other inverter features may include an internal DC isolator, overvoltage protection, optimised behaviour for certain shading situations and so on. These may be important considerations for inverter selection when designing a PV systems.

When selecting an inverter also take note of the warranty conditions and terms of service.





Total EG ≤ 75 % of transformer rating



Legal requirements in South Africa

Before installing a PV system in parallel to the public grid, the PV installer must ensure that its installation is legal. In any case, the PV installation must be registered with the local grid authority. Embedded generation on its low voltage (LV) network is currently not allowed by Eskom – but an increasing number of municipalities are providing for this.

South Africa still has a lack of regulations and standards regarding PV installations. Nevertheless, existing regulations must be adhered to.

In the NRS 097-03, the maximum size of a PV installation connected to a certain feeder is stipulated. If a planned installation does not conform to the minimum requirements, a detailed grid study may become necessary.

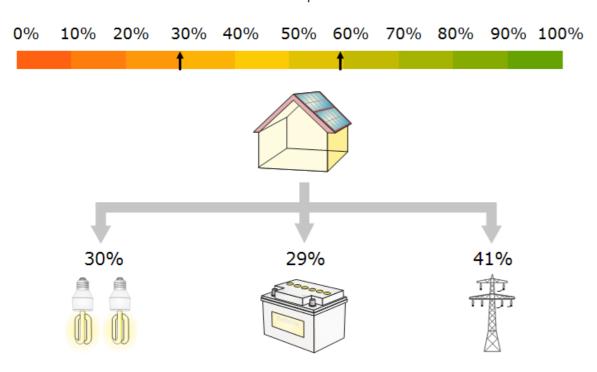
Other important issues of the NRS 097 are a balanced interconnection to the three-phase grid if the nominal power of the inverter exceeds a power of 4.6 kVA in a single-phase feeder. For shared and dedicated feeders the acceptable maximum power differs.

The feed-in meter must be approved by the grid company. For net metering, a bidirectional meter is used. If the household is connected via a prepaid meter, a feed-in must be blocked. For stand-alone systems the grid company may demand a Certificate of Compliance issued by a registered electrician – verifying that the installation is not connected to the public grid.

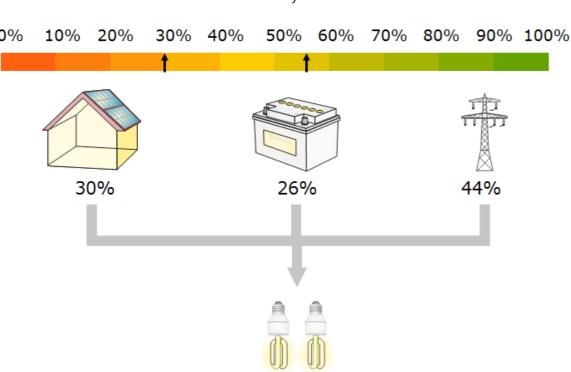
The requirements of additional safety devices are still under discussion. At this time, it is still unclear if, in future, an automatic disconnecting device must be installed at the house connection point. In the end, the installer is liable for his workmanship and the planning and implementation of a PV system that fulfils all legal requirements. Therefore, he must be aware of all upcoming changes to national standards and regulations.







Autonomy Ratio



Own consumption ratio vs autonomy ratio

The energy produced by a PV system can be consumed in the same household or fed to the public grid and then consumed by another user. Because of the lack of or low feed-in tariffs, the most economical way to operate a PV system in South Africa is to use most of the PV energy in the same household. If a prepaid meter is installed, it is not allowed to feed to the public grid. In that case, all energy must be consumed in the same household or the inverter must reduce the energy production or even stop operating if no internal consumption is available.

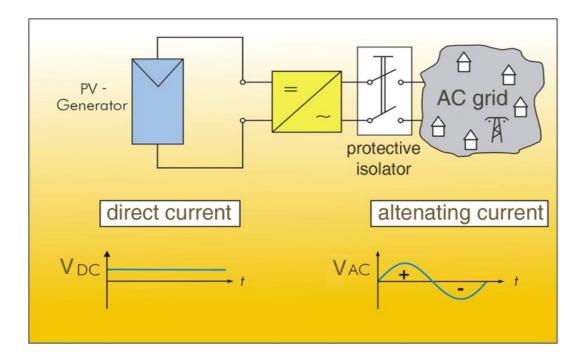
The direct or own consumption ratio refers to the energy produced by the PV system that is consumed in the same household (concurrent or indirectly using batteries) – and which is not fed into the grid. A high own consumption ratio is achieved with a small PV system, additional storage, or a matched consumption. Typical values are 30% or 60% if storage is added to the system.

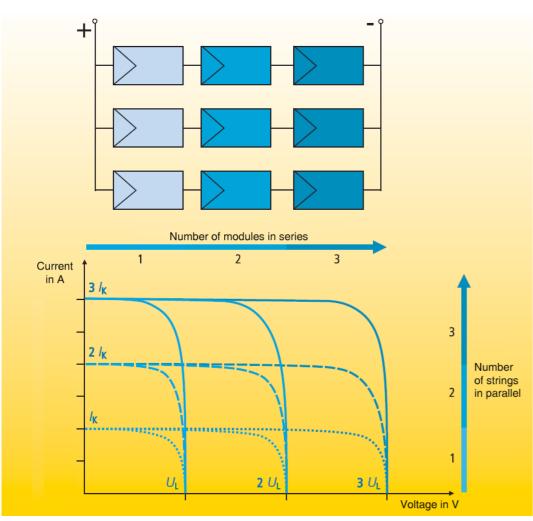
The autonomy ratio refers to the energy demand covered by the PV system (concurrent or indirectly using batteries). For a high autonomy ratio, the PV system and storage must be enlarged.

To achieve a high own consumption ratio and a high autonomy ratio, an enlargement of the storage is necessary. The impact of the PV system size on the own consumption ratio, is contrary to the impact on the autonomy ratio. An increased PV system will increase the autonomy ratio. Because of over production on sunny days, the own consumption ratio will be reduced.

If security of supply is required, a backup system in combination with grid connection and a standalone system is necessary. The sizing of these systems depends on the expected shut-down period or necessary stand-alone period. For a secure supply, a hybrid system using a combustion generator might be necessary.







Design of PV systems

A grid tied PV system has a DC supply before the inverter, and an AC supply after the inverter. The inverter converts the DC current coming from the PV generator with a certain voltage – to an AC current that is fed into the existing grid. The grid demands a specific behaviour with regard to voltage, current, frequency and active and reactive power. National grid codes and other regulations and standards must always be adhered to. There are also safety checks, e.g. an insulation test, which must be performed on the DC side prior to final commissioning.

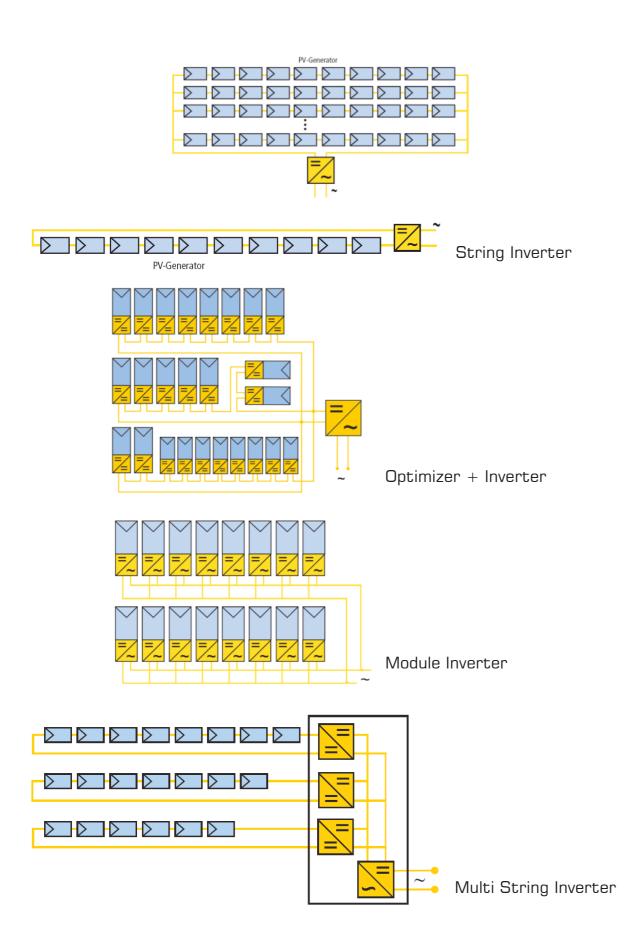
The input voltage range of an inverter is limited. The inverter starts to operate at a minimum voltage, and will be damaged if a maximum voltage threshold is exceeded. Similarly, the MPP tracker has a specific voltage range. Most inverters are equipped with active current limitation. Maximum input power is limited to avoid overheating of the inverter while the output can be regulated to limit maximum feed in, as per international grid codes.

To achieve safe operation and high yield, the correct power, voltage and current sizing of the PV system are necessary. The number of modules interconnected in a string defines the system voltage. Similarly, strings containing the same number of modules can be interconnected in parallel. The PV system current is defined by the number of strings in parallel and the module current. The PV system power is defined by the total number of modules and the module power.

For voltage adjustment, the number of modules in each string must be changed. To obtain a higher voltage, the number of additional modules depends on the required voltage step and the module voltage. For a generator with two strings, a minimal step to a higher voltage can only be achieved by adding one module to each string. The generator current would remain the same – but the power would also increase to twice the module power.

Power adjustment can be done by adding or removing the same number of modules in each string or by adding or removing complete strings. Therefore, a precise adjustment is not possible.





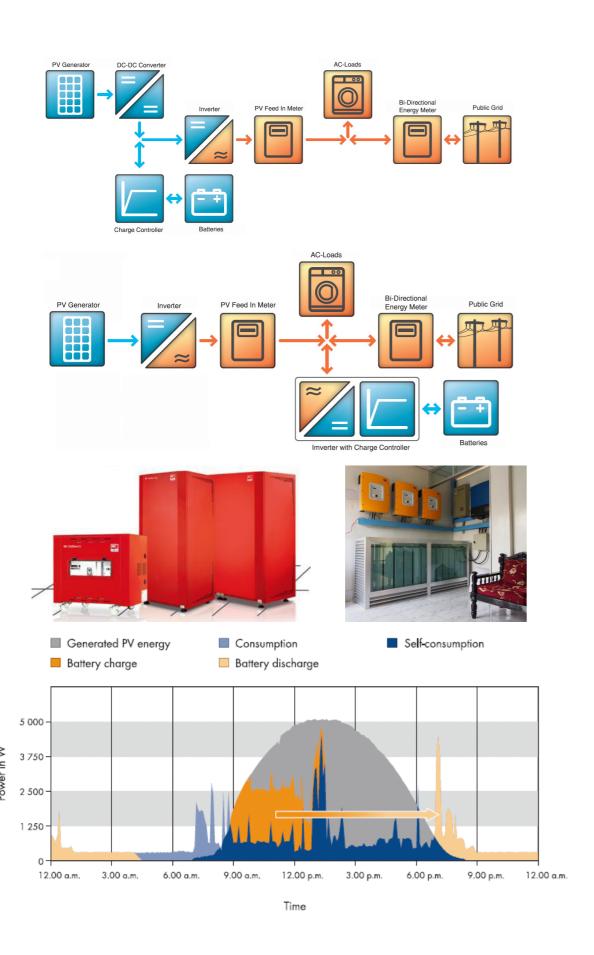
The input voltage range and the power of the inverter define the topology of the PV system. The number of modules connected in series determines the input voltage at the inverter. For example, connecting 10 modules in series will result in an input voltage of approximately 500 V. For roof-top systems on small residential buildings the PV system size is typically around 5 kW. For this reason, many generators consist of only one or two strings. Changes in sizing are therefore easier than for PV systems with multiple strings.

To avoid sizing problems for larger PV systems and to ensure a good design regarding shading and other borderline conditions, it is often recommended to split the generator into sub-arrays. For complex shading situations, or other reasons, micro-inverters or DC module optimisers may be an alternative design solution instead of using strings. For some situations the higher cost for module-level solutions are compensated by the higher yield. The micro inverter is a small inverter connected to each module on the DC side and is directly connected to the grid on the AC side. Therefore, the modules are not interconnected in series. The so-called DC optimisers are also connected directly to the modules. Their output is still DC and a certain number of optimisers are interconnected in series as a string. One or more strings are connected to an inverter. Due to their behaviour, the number of optimisers in each string can differ.

If it is necessary to split the PV system, the use of a multi string inverter instead of several smaller inverters, may be advantageous. These inverters not only have several pairs of input sockets but also more than one MPP tracker. If, for example, a smaller area of the PV system is shaded, it is possible to connect the unshaded modules to one MPP input in order to achieve high yield and to connect the remaining modules to the second MPP input. This split avoids unnecessary yield losses caused by the shaded areas.

Another benefit of multi-string inverters is the option to have strings of different lengths. This can also be done at a later stage if shading is only found during installation or if a module cannot be put in place due to previously unnoticed roof structures or for other reasons. Furthermore, deviations in orientation or slope can be addressed more easily.





Batteries in grid tied, stand-alone, hybrid, and backup systems

Batteries can store energy for later use. They are used in grid-connected systems to increase the own consumption ratio and autonomy ratio. For stand-alone (off-grid) systems, batteries are a requirement in order to operate loads when there is insufficient irradiation and therefore no energy production directly from the PV system. The same principle applies to the grid tied system with battery backup – the batteries will continue to supply energy even when the grid fails. In a hybrid system the use of batteries can reduce fuel costs.

The battery systems are DC or AC coupled; there are pros and cons for each system. In a DC system it is the reduction to only one inverter. However, retrofit is easier for AC systems. The behaviour of both systems – with regard to own consumption ratio and autonomy ratio – is very similar.

For most batteries the basic materials are lead and lithium. The efficiency and long-term behaviour of a battery depends on the charging and discharging behaviour, the depth of discharge (DOD), ambient temperature, and many other operating parameters. For the customer the total life-time costs per discharged kWh would be very interesting, but this value is not easy to calculate as some important parameters such as the cycle life time are not clearly defined.

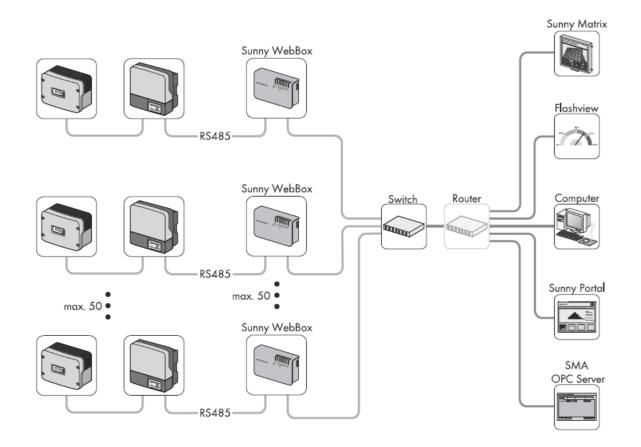
The necessary safety measures depend on the battery type. Consider all risks like fire caused by short circuit, incorrect fuse sizing, and explosive gases emitted during charging.



Read the manual carefully and ensure that all safety measures mentioned are adhered to. You need to participate in dedicated training courses by the manufacturer.

Always choose the highest possible safety level.







Monitoring system

The inverter has to measure the input voltage and current for the internal MPP tracker. Most inverters provide an interface to display the measured information or send it to a data logger. A bus structure is used to interconnect all components like the inverter, logger, and additional devices such as irradiation sensors. Most manufacturers use an internet-based portal for data storage and visualisation.

There is no communication standard for PV components. Problems occur while interconnecting components of different manufacturers. Also, the manufacturer portals are only for their respective components. Most of these portals are free or are only charged at a minimal fee. Third-party vendors also offer this type of service for a fee.

The user interface is also an important feature. The end customer needs an easy-to-understand overview of the most important information. For the installer, detailed information on all measurements are required for remote monitoring.

Data storage for the whole life time of the PV system is as important as an email or SMS alert in case of warnings or malfunctions. Automatic monthly and annual reports can help to recognise yield losses caused by slow (creeping) processes like degradation or soiling.



Sample Module SolarWorld SW 250

PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

		SW 250
Maximum power	P _{max}	250 Wp
Open circuit voltage	V _{oc}	37.8 V
Maximum power point voltage	V_{mpp}	31.1 V
Short circuit current	I _{sc}	8.28 A
Maximum power point current	Impp	8.05 A
*CTC 1000W/m2 35°C AAA 1 5		

THERMAL CHARACTERISTICS

NOCT	46 °C
TC I _{sc}	0.004 %/K
TC voc	-0.30 %/K
TC P _{mpp}	-0.45 %/K
Operating temperature	-40°C to 85°C

PERFORMANCE AT 800 W/m², NOCT, AM 1.5

		SW 250
Maximum power	P _{max}	183.3 Wp
Open circuit voltage	V _{oc}	34.6 V
Maximum power point voltage	V _{mpp}	28.5 V
Short circuit current	I _{sc}	6.68 A
Maximum power point current	Impp	6.44 A
Minor reduction in efficiency under partial (+/-3%) of the STC efficiency (1000 W/m²) is		:: at 200W/m², 95%

COMPONENT MATERIALS

Cells per module	60
Cell type	Mono crystalline
Cell dimensions	6.14 in x 6.14 in (156 mm x 156 mm)
Front	tempered glass (EN 12150)
Frame	Clear anodized aluminum
Weight	46.7 lbs (21.2 kg)

Sample Module Hanwa QCells Q. Peak-G4. 1 295-305

OWER CLASS		295	300	30
NINIMUM PERFORMANCE	AT STANDARD TEST CONDITIONS, STC1 (POWER T	OLERANCE +5W / -OW)		
Power at MPP ²	P _{MPP}	295	300	30
Short Circuit Curren	t* I _{sc}	9.70	9.77	9.8
Open Circuit Voltage Current at MPP*	o* V _{oc}	39.48	39.76	40.0
Current at MPP*	I _{MPP}	9.17	9.26	9.3
Voltage at MPP*	V _{MPP}	32.19	32.41	32.6
Efficiency ²	η	≥17.7	≥18.0	≥18.
NINIMUM PERFORMANCE	AT NORMAL OPERATING CONDITIONS, NOC ³			
Power at MPP ²	P _{MPP}	218.1	221.8	225
Short Circuit Curren	t* I _{sc}	7.82	7.88	7.9
Open Circuit Voltage	o* V _{oc}	36.92	37.19	37.4
Current at MPP*	I _{MPP}	7.20	7.27	7.3
Voltage at MPP*	V _{MPP}	30.30	30.49	30.6

Sample Inverter SMA Sunny Boy 1.5 and 2.5

Technical Data	Sunny Boy 1.5	Sunny Boy 2.5
Input (DC)		
Max. DC power (at cos φ = 1)	1600 W	2650 W
Max. input voltage	600 V	600 V
MPP voltage range	160 V to 500 V	260 V to 500 V
Rated input voltage	360 V	360 V
Min. input voltage / initial input voltage	50 V / 80 V	50 V / 80 V
Max. input current	10 A	10 A
Max. input current per string	10 A	10 A
Number of independent MPP inputs / strings per MPP input	1/1	1/1
Output (AC)		
Rated power (at 230 V, 50 Hz)	1500 W	2500 W
Max. apparent AC power	1500 VA	2500 VA
Nominal AC voltage	220 V / 230 V / 240 V	220 V / 230 V / 240 V
Nominal AC voltage range	180 V to 280 V	180 V to 280 V
AC power frequency/range	50 Hz, 60 Hz / -5 Hz to +5 Hz	50 Hz, 60 Hz / -5 Hz to +5 H
Rated power frequency/rated grid voltage	50 Hz / 230 V	50 Hz / 230 V
Max. output current	7 A	11 A
Power factor at rated power	1	1
Adjustable displacement power factor	stable displacement power factor 0.8 overexcited to	
Feed-in phases/connection phases	1/1	1/1
Efficiency		
Max. efficiency / European weighted efficiency	97.2 % / 96.1 %	97.2 % / 96.7 %

Information on data sheets

On most data sheets for PV modules the values given are at STC and NOCT. Some manufacturers also provide the efficiency reduction for an irradiation of 200 W/m² as a percentage value. The information on the data sheet (below) is required for sizing a PV system. Always read the correct value. Errors in sizing usually happen when NOCT instead of STC values, or nominal instead of open circuit values, or vice versa, are used for the calculations.

Value	Symbol	Unit
Open Circuit Voltage	Voc	V
Short Circuit Current	Isc	A
Nominal Power	P _{MPP}	W
MPP Voltage	V _{MPP}	V
MPP Current	Імрр	I
Temperature Coefficient Open Circuit Voltage	β or Δ Voc	mV/°C or %/°C often °K (Kelvin) instead of °C (Celsius)
Temperature Coefficient Power	γorΔP _{MPP}	W/°C or %/°C often °K (Kelvin) instead of °C (Celsius)

Most modules are sorted into classes according the power measured by the manufacturer during production. A 250 W module type, for example, may have classes from 230 W to 270 W. Quite often, however, the wholesaler cannot offer all classes permanently. After the first planning process a redesign may be necessary. The PV system power, current and voltage, must be checked or even re-calculated.

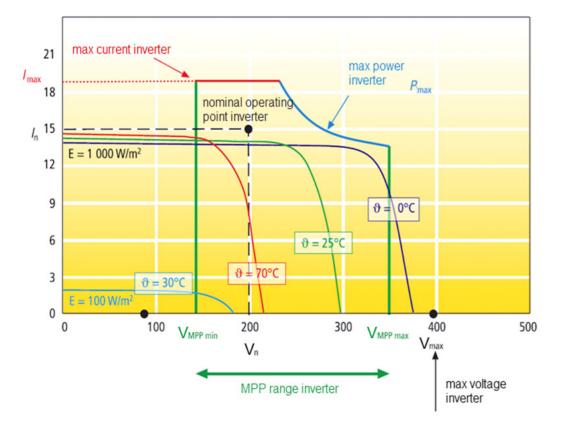
For each power class the temperature coefficients would differ if given in mV/°C or W/°C. The percentage value is valid for all classes – and therefore most common on the data sheets. If a certain power class is installed, ensure that the correct data from the respective class are used.

For an inverter, most information is given for nominal conditions as defined in the respective standards. Therefore, most values are valid for an ambient temperature of 25°C. For higher temperatures, some manufacturers supply information on the power reduction behaviour.

The amount of data provided in inverter data sheets can easily lead to confusion. The most important parameters are the nominal and maximum values for the DC and AC power and a maximum PV system size is specified. For inverter power sizing the nominal AC power should be used instead of any other power value given on the data sheet.

For the efficiency, a maximum and the European efficiency as a weighted value are mentioned. The European efficiency will however not adequately describe the annual behaviour in South Africa. Nevertheless, it is reasonable to compare this weighted efficiency – rather than the maximum value of two inverters. If the Californian efficiency is given, this might be the best value to compare in South African conditions.

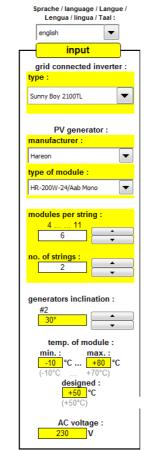




PV generator design for string inverters ("String": serially connected PV modules) PV plant design grid connected inverter PV generator Hareon HR-200W-24/Aab Mono 2 x 6 = 12 modules max. AC power: 2,2 kW string nominal power: 1,2 kWp max. DC power GCI / nominal power PV) nominal power ratio: 92%

Sunny Boy 2100TL		HR-200W-24/Aab Mono		
		2 x 6 = 12 modules		
max. AC power :	2,1 kW	string nominal power :	1,2 kWp	
max. DC power:	2,2 kW	total PV power :	2,4 kWp	o.k.
(max. DC power GCI / nom	inal power PV)	nominal power ratio :	92%	
min. DC voltage :	125,0 V	string-MPP voltage at +80°C :	180,8 V	o.k.
		string-MPP voltage at +50°C :	206,3 V	o.k.
		string-MPP voltage at +25°C :	227,6 V	o.k.
max. MPP voltage :	480,0 V	string-MPP voltage at +15°C :	236,1 V	o.k.
		string-open circuit voltage at +25°C	274,1 V	o.k.
max. DC voltage :	600,0 V	string-open circuit voltage at -10°C	303,8 V	o.k.
max. DC current :	11,0 A			
max. DC current (206 V):	10,7 A	max. possible PV current :	10,5 A	o.k.
		part of utilized energy :	99,87%	o.k.

module datasheet				
0	(MPP: maximum pow	er point)		
nominal power :	200 Wp	cells :	72, mono	
MPP voltage :	37,9 V	MPP voltage at +50°C :	34,4 V	
MPP current :	5,3 A	MPP voltage at +80°C :	30,1 V	
ppen circuit voltage :	45,7 V	MPP voltage at +15°C :	39,3 V	
short circuit current :	6,0 A	open circuit voltage at -10°C	50,6 V	
emp. coefficient of open circuit voltage :		-0,31 % / °C		
emp. coefficient of MPP voltage :		-141,61 mV / °C	estimated	
allowed system voltage of the module :		1000 V		



Power, voltage and current sizing

When selecting an inverter the ratio of DC to AC power is an important consideration. Typically the DC power will range between 80% and 120% of the nominal AC power of the inverter, depending on the site-specific considerations. A DC:AC ratio greater than 1 will be the most cost effective.

The operating temperature of the inverter depends on its mounting situation; the ambient temperature will differ for outdoor or indoor mounting. If the inverter is exposed to direct sunlight the internal temperature will increase. In addition, insufficient ventilation will heat up the inverter. If a high inverter temperature is expected, it is reasonable to reduce the sizing ratio in order to avoid power limitations. The string voltage and therefore the PV system voltage depend on the number of modules interconnected in a string. Due to the voltage temperature coefficient, the maximum voltage of a PV system is the open-circuit voltage at the lowest expected module temperature. For most regions of South Africa, a value of 0°C can be used for the calculation.

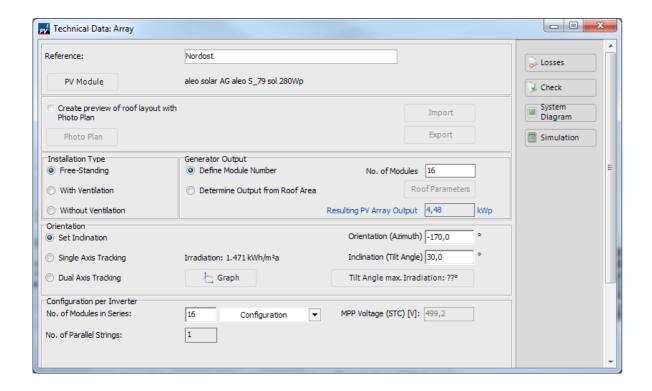
The minimum operation voltage is the MPP voltage at the highest expected module temperature. There is no temperature coefficient given for MPP voltage behaviour in most data sheets. It is common to use the open-circuit voltage temperature coefficient. The power coefficient on the other side adequately describes the MPP voltage behaviour, even if it is for another physical value. In fact it would be better to use the power coefficient for calculating the minimal MPP voltage, instead of the open-circuit voltage coefficient.

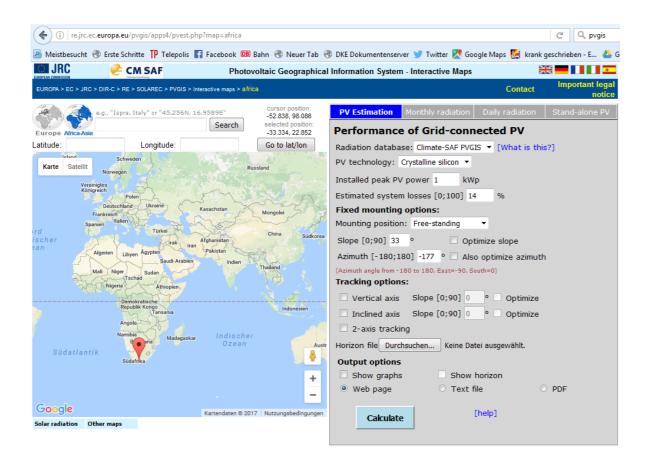
The maximum temperature depends strongly on the ambient temperature and the mounting situation. For residential buildings in cities and usual roof-top installations a maximum value of 70°C is reasonable. For other areas the maximum value should be set to 90°C in order to avoid a PV system MPP voltage below the inverter MPP range. The module temperature can roughly be estimated as the sum of ambient temperature and NOCT. For a typical NOCT of 46°C and an ambient temperature of 35°C, a module temperature of 81°C is calculated.

The number of strings is limited by the maximum input current of the inverter and the maximum operation current from the PV system. The PV system current is calculated as string current multiplied by the number of strings. To achieve the maximum number of strings the maximum input current of the inverter must be divided by the maximum string current. The nominal MPP current is measured at 1000 W/m². Because of cloud enhancement effects the actual irradiation might be even higher. It is reasonable to calculate the maximum string current for an irradiation of 1250 W/m². If, for any reason, a higher current occurs most inverters have a current limitation for protection.

Most inverter manufacturers provide a free proprietary sizing app or calculation program. To archive a proper calculation, the input values must be correct. The default values for the temperature range are usually set for European installations. Cloud enhancement effects and the more complex MPP behaviour are usually not taken into account. Thus, reconsideration might be necessary if the system operates close to certain borderline conditions.







Yield assessment

To obtain an economically beneficial PV system – the costs and the income must be taken into account. One important issue for the income is the annual energy produced. For a detailed yield study, a simulation program, correct climate data, the shading situation, detailed information on the inverter and the modules, cable losses, and assumptions for other losses such as soiling are all required.

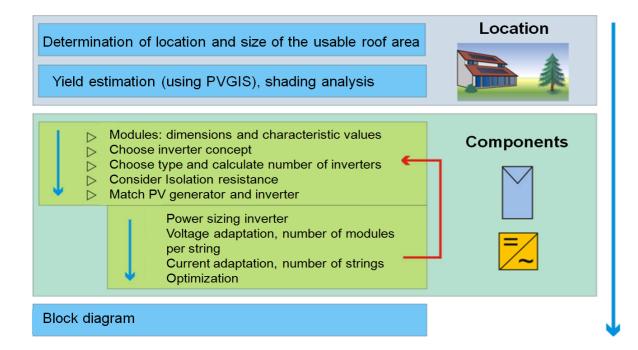
When starting to plan a PV system, not all information may be available. An in-depth yield study may be expensive. For a first estimation PVGIS offers an easy-to-use internet-based portal which is free of charge. The estimation is based on historical meteorological data. All of South Africa is covered, so estimations can be done simply by entering the coordinates of the prospective site. Other information to be entered includes the nominal PV system power, module orientation, and slope and mounting type. In addition, thin film modules or crystalline modules can be selected.

The calculation is not based on hourly or minute-by-minute time steps, but only uses estimated system losses. A default of 14% can be changed to a different value.

PVGIS also offers a calculation of the optimised orientation and slope.

As in South Africa, the own consumption is most important, but a detailed economic assessment also must consider the load profile of the respective building. If a prepaid meter is installed by the grid company, no export of energy is allowed and power reduction in the case of PV-overproduction must be taken into account.

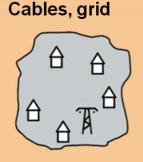




 Structural analysis, choose and size mounting system, note building law requirements
 Create a plan where to mount modules and hooks, cable routing



- Cross section DC cables, DC safety technique
- Junction box and DC main switch
 Lightning and overvoltage protection
- AC safety technique, Cross section AC cables
- Grid connection
- Energy meter, protection devices, switches



Calculation, proposal

Yield assessment

Calculation of profitability under consideration of funding, taxes and interest

Step-by-step planning and sizing

The flow chart shown defines all the necessary steps for planning and sizing of a grid-connected PV system. Minor issues like the monitoring system are not considered. Despite listing a step-by-step procedure, the installer also has to keep in mind later issues when starting the process. To perform the structural analysis, for example, it is first necessary to know the number of modules. On the other hand, the structural analysis has an impact on the usable roof area which determines the maximum number of modules. There might be some step backwards, not only in the section "components". Also, legal regulations must be taken into consideration. One important point for South Africa is the maximum PV system size allowed – depending on the existing grid supply as defined in the NRS 097-2-3.

Location

An onsite assessment should be performed to determine the usable roof area and to get information on the shading situation. Also, possible ways for cable laying, the inverter location, and other necessary issues, should be observed. A determination of all important distances (e.g. from the PV array to the inverter, but also from the inverter to the feed-in point) should be performed.

Components

Ask to hear customer requirements during the onsite assessment. Are there limitations such as cost, size, and appearance? A customer, for example, may demand an all-black module or may not want the inverter to be installed in a certain location.

Size components according the information you received during the onsite assessment. Create the block/line diagram.

Roof

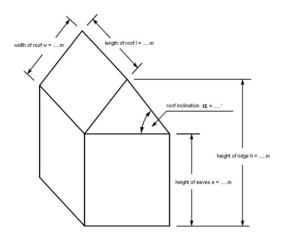
Choose the mounting system, perform a structural analysis (or request the services of a structural engineer) to verify the load bearing capacity of the roof. Prepare a module allocation plan – including hook position and cable laying. Determine inlets and the cable length.

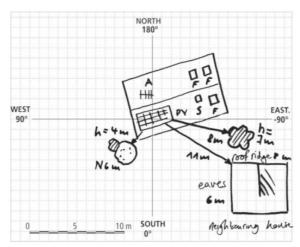
Cables, Grid

Calculate DC and AC cable cross-sections according to current carrying capacities and losses. Choose and size balance of system (BOS) components.

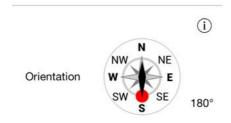
Once all the material and required labour is known a proposal can be created. A detailed yield assessment can also be performed – where shading effects and other sources of yield losses can be taken into account. The customer can receive a profitability report in consideration of costs and income.







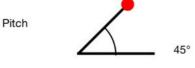




11:05 PM

PV*SOL app











Onsite assessment

To get all necessary information for a proper planning and sizing, it is reasonable to perform an onsite assessment. A rough estimate of the usable roof area can be determined by using Google Earth or similar programs. Also, photos provided by the customer can help to prepare a rough overview of a suitable system and the average costs. However, specific details like the exact cable lengths and the shading situation can only be determined correctly during a personal check while doing an onsite assessment.

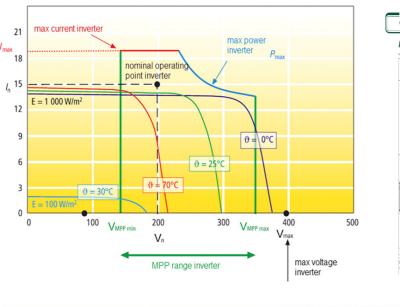
While checking the usable roof area, the installer also must check the stability of the roof. Are there any visible problems like corrosion? You need to check all important dimensions like the total roof area, position and dimensions of other roof structures, and distances from the inlet to the feed-in point.

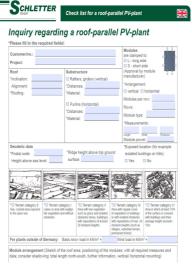
Add all necessary information to an existing building plan – or sketch a plan by yourself. Add information on nearby structures like neighbouring buildings, trees, and utility poles.

Take as many photos as you can, so you can reconsider the onsite situation when back at your office. Special apps for PV-system design are available for your smartphone which might help – e.g. PVSol. It includes an angle meter and a rough yield estimation for the current location, orientation, and slope. Also check and determine all possible wireways for DC and AC. Consider the necessary measures for a fire-safe installation. Check for possible alternative solutions which might be easier to perform or less expensive. If, for example, expensive measures like fireproof bulkheads and fire-retarding cable ducts are needed for mounting an inverter inside a building, it might be better to choose an inverter with an IP rating suitable for outdoor mounting – and keep all DC components outside the building.











PV system sizing

Before starting to size the PV system, the installer must recognise the given limitations. The maximum power can be limited by the roof area, legal limits, total costs or other reasons like particular customer demands.

Items to consider:

- Choose module type: cell type, colour, frame
- Calculate number of modules according to usable roof area or required maximum power
- Choose inverter
- Size power, voltage, current
- Sketch a block diagram

Always use the correct values from the module data sheet. Print every calculation and add it to the documentation.

Mounting system and structural analysis

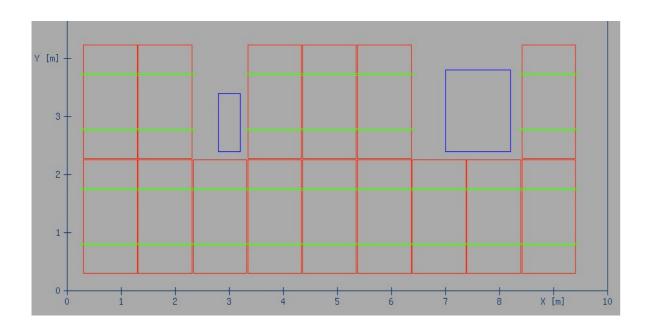
The mounting system depends on the type of roofing and the expected appearance of the system. Mounting hardware will vary depending on the type of module used (e.g. frameless, black frame). Also consider other aspects like easy dismantling.

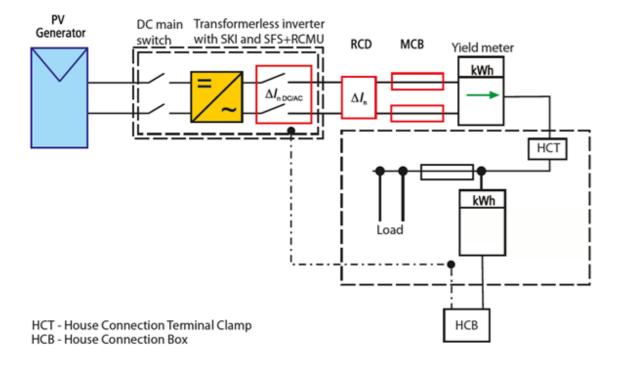
Items to consider:

- Choose a mounting system
- Fill in the inquiry and perform structural analysis for the mounting system or send information to the mounting-system manufacturer
- Perform structural analysis for the building with regard to the results from the structural analysis for the mounting system

The structural behaviour of both system and building must be considered for the whole life-time of the PV system. Don't use material combinations that provoke corrosion or other negative interaction.







DC-Balance of system (BOS) components

Create a plan which includes module position, hook position, cable laying, and inlets. Consider integration into the lightning protection (where applicable).

Determine DC cable lengths according to plan including cable from the PV array to the inverter. Choose DC cable type and determine the cross-section under consideration of current carrying capacity and maximum losses of 1% at nominal power.

Choose and size all other BOS components on the DC side, such as surge-protection devices, DC-isolators, DC-fuses, and junction boxes.

AC components

Choose and size all BOS components on the AC side, like surge-protection devices, AC isolators, AC breakers, and cabinets. Consider legal requirements and the necessary meter.

Determine AC cable lengths from the inverter to the feed-in meter and the feed-in point. Choose AC cable type and calculate cross-section under consideration of current carrying capacity and maximum losses of 1% at nominal power.

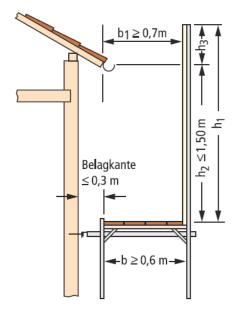
Create a single line diagram for the documentation.

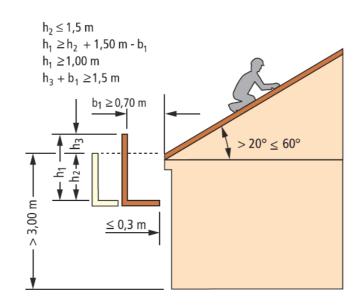
Proposal, yield assessment and financial viability calculation

Calculate the cost for components and labour. Don't forget costs for safety measures like scaffolds or fall arresters. Add or at least mention additional costs like necessary reinforcement of the roof, other rework on the roof or the building, and fees from the utility company.

Working at heights













Working at heights

During installation, and even during the first on-site assessments, the planner and the installer may have to work on the roof. Therefore all regulations of the Occupational Health and Safety Amendment Act and other regulations and guidelines must be adhered to in order to ensure a safe working environment. This includes a notification and the provision of all necessary safety measures such as fall prevention or fall arresters. An employer has a duty to designate a competent person as responsible for the preparation of a Fall Protection Plan – including the following as a minimum:

- Must be site-specific (requires a physical hazard identification on site)
- Ensure everything is documented
- Hazard Identification (must be attended by the site or in-house team)
- Risk assessment (analysis and evaluation with an in-house team)
- Management manage and control (consider changes)
- Determination of controls e.g. safe work procedures and method statements
- Written safe work procedure (WSWP) include 'who', 'when', 'why', 'what', 'where'
- Method statement to eliminate risks focus on 'how'
- Rescue plan (include how to rescue a person, after a fall from height, and within a short time?)
- Emergency plan (how to safely evacuate site)
- Implement, maintain, monitor, and review plans
- "Toolbox" talk on safety
- Site induction

The Fall Protection Plan must also address the process for evaluating the employee's physical and psychological fitness.

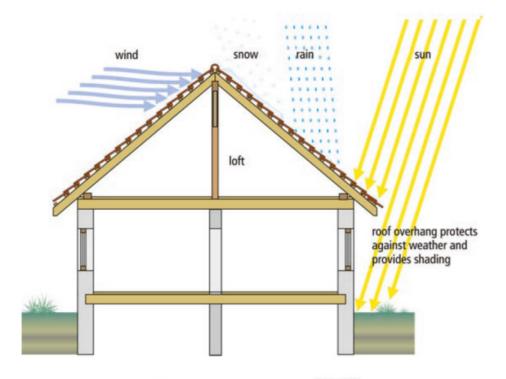
Many risks may remain unnoticed until an accident occurs. For a proper assessment – the risk of falling off or through the roof must be considered. Especially weak roofing and sky-lights bear high risks. If no other safety measures like fencing or temporary reinforcement (solid walkways) are possible, a scaffold is mandatory.

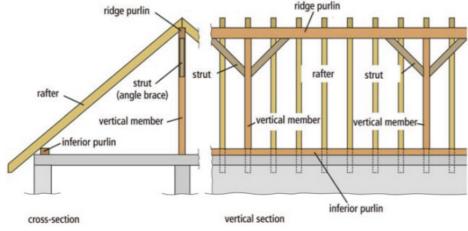
When in doubt a safety expert should be consulted.



Maintenance and repair must be performed safely. If a scaffold is not feasible due to a short work time and high costs – other measures providing a similar safety level must be chosen.









Roof-top PV system

The roof is protecting the building against wind, sun, rain and – in some regions – also snow. After the installation of a PV system, the proper behaviour of all functions mentioned above must be ensured for the whole life-time of the PV system. The planner and the installer must have the necessary knowledge to avoid damage to the roof and the building itself. In many cases the mechanical installation of the mounting structure and the modules is performed by a roofer. The mechanical installation can also be done by another person – provided it is performed professionally.

During the mechanical installation it is inevitable that some electrical installation will be done as well. Once the modules are mounted, there is no access to the module cables and connectors, because they are between module and roofing and therefore out of reach. The person who does the mechanical mounting of the modules has to interconnect the modules and attach the cables. Today, most modules are equipped with cables and connectors. Therefore the interconnection of modules can be done by a trained non-electrician under supervision of an electrically skilled person – as long as there are no exposed live parts. Additional wiring and assembly of plugs must be performed by an electrician who must also ensure correct wiring of the whole PV system.



All persons involved in the mechanical and electrical mounting of a PV system must be aware of the risks of electrical energy, and the special behaviour of PV modules. An electrically skilled person must be designated to supervise all electrical mounting.

The most common roof types for residential buildings in South Africa are cement tiles and corrugated iron. For most roofing types, a suitable mounting system is provided by one or more mounting-system manufacturers. The installer must know all information given by the manufacturer, and has to follow the given advice and requirements stipulated in the installation guidelines.

The following pages will show a typical mounting situation for a roof-top system on a tiled roof – using hooks and rails as a mounting structure.





Check list for a roof-parallel PV-plant



Inquiry regarding a roof-parallel PV-plant

Roof *Inclination: Alignment: *Roofing: *Roofing: *Material: *Purlins (horizontal) *Distances: *Material: *Purlins (horizontal) *Distances: *Material: *Material: *Material: *Modules per row: Rows: Module type: *Measurements: **Measurements: **Module power: **Measurements: **Measurements: **Measurements: **Terrain category of the isolated buildings on hills): **Terrain category of the open sea **Terrain category I Area with low vegetation and without obstacles **Terrain category I Area with low vegetation of at least 20 obstacle heights **Terrain category II Area with low vegetation of vegetation or buildings or with isolated obstacles **Terrain category II Area with low vegetation or of vegetation or buildings or with suparations of at a least 20 obstacle heights (such as villages, suburban terrain, permanent forest) **Terrain category II Area with low vegetation of wegetation or buildings or with surface is covered with buildings and their with separations of at a least 20 obstacle heights (such as villages, suburban terrain, permanent forest)	Customer/no.:			Modules are clamped □ L - long si	de		
*Ridge height above top ground isolated buildings on hills): Height above sea level: "Terrain category 0 Sea, coastal area exposed to the open sea "Terrain category I Lakes or area with negligible vegetation and without obstacles (trees, buildings) with seperations of at least 20 obstacle heights "Terrain category II Area with regular cover of vegetation or buildings or with isolated obstacles with separations of max. 20 obstacle heights (such as villages, suburban terrain, permanent forest) "Terrain category II Area with low vegetation or buildings or with isolated obstacles with separations of max. 20 obstacle heights (such as villages, suburban terrain, permanent forest)	*Inclination: Alignment:	Rai *Dista *Mate	rial: rlins (horizontal)	(Approval by manufacture *Arrangemer vertical Modules per Rows: Module type: *Measureme	(Approval by module manufacturer) *Arrangement: vertical horizontal Modules per row: Rows: Module type: *Measurements:		
Height above sea level: Surface: Yes No * Terrain category 0 Sea, coastal area exposed to the open sea * Terrain category I Lakes or area with negligible vegetation and without obstacles * Terrain category II Area with low vegetation for such as grass and isolated obstacles (trees, buildings) with seperations of at least 20 obstacle heights * Terrain category II Area with regular cover of vegetation or buildings or with isolated obstacles with separations of max. 20 obstacle heights (such as villages, suburban terrain, permanent forest) * Terrain category II Area with low vegetation or buildings or with isolated obstacles with separations of max. 20 obstacle heights (such as villages, suburban terrain, permanent forest)	Geodetic data			*Exposed loc	cation (for example		
* Terrain category 0 Sea, coastal area exposed to the open sea * Terrain category I Lakes or area with negligible vegetation and without obstacles * Terrain category II Area with low vegetation of vegetation or or buildings or with isolated obstacles with separations of max. 20 obstacle heights * Terrain category II Area with regular cover of vegetation or buildings or with isolated obstacles with separations of max. 20 obstacle heights (such as villages, suburban terrain, permanent forest) * Terrain category II Area with regular cover of vegetation or buildings or with isolated obstacles with separations of max. 20 obstacle heights (such as villages, suburban terrain, permanent forest)	*Postal code:	*Ridg	e height above top grou	and isolated buil	isolated builings on hills):		
Sea, coastal area exposed to the open sea Lakes or area with negligible vegetation and without obstacles Lakes or area with negligible vegetation and without obstacles (trees, buildings) with seperations of at least 20 obstacle heights Area with regular cover of vegetation or buildings or with isolated obstacles (trees, buildings) with seperations of at least 20 obstacle heights with separations of max. 20 obstacle heights (such as villages, suburban terrain, permanent forest) Area with regular cover of vegetation or buildings or with isolated obstacles with buildings and their average height exceeds 15m	Height above sea lev	el:surfa	ace:	☐ Yes	□ No		
For plants outside of Germany: Rasic snow load in kN/m² = Wind load in kN/m² =	Sea, coastal area exposed to the open sea	Lakes or area with negligi- ble vegetation and without	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with seperations of at least	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of max. 20 obstacle heights (such as villages, suburban terrain,	average height exceeds		
Pol plants outside of Germany. Dasic show load in kiv/iii -	For plants outside of	Germany: Basic sn	ow load in kN/m² =	Wind load in kN/m	η ² =		



Number and position of hooks and rails

The required number of hooks depends on the load, and the structural behaviour of the hooks and rails. For structural design, the inquiry form of the manufacturer must be filled in. According to SANS 10160-3, a basic fundamental wind-speed of 28m/s is stipulated for most regions in South Africa.

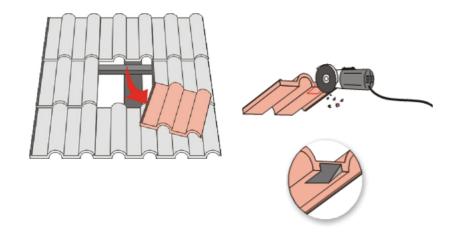
The inquiry will demand information of the location – including height above sea level and the wind load in kN/m², the terrain category, roof orientation and slope, dimensions and orientation of the modules and clamping points, and the distance between rafters and purlins/battens. If the location is prone to higher wind speeds and higher loads, this information must also be added to the inquiry.

The structural analysis based on this inquiry is usually performed by the manufacturer. The installer is responsible for providing accurate information. The resulting design will stipulate the number of hooks per square metre and the maximum span and excess length of the rails – or even a detailed roof plan including the exact position for hooks and rails. The installer must prepare a roof plan if none is provided by the mounting-system manufacturer. If the hooks are mounted on every second rafter, they should alternate in each row to avoid excessive load on specific rafters. The installer is also responsible for the structural behaviour of the building itself. If in doubt, an expert in structural analysis should perform the necessary calculations.

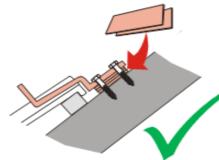
The structural behaviour of rafters can be affected by fungus or for other reasons. Before and during the installation, all abnormalities must be considered. If in doubt, consult an expert on structural analysis.

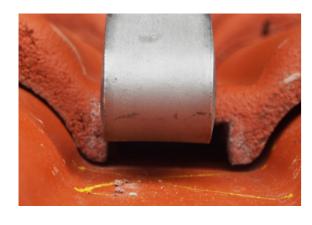
The roof plan has to be transferred onto the roof. With a chalk line and crayons, the outline of the PV array and the position of the hooks can be marked. If the PV system cannot be mounted as originally planned due to roof structures or other reasons, a redesign will be necessary.



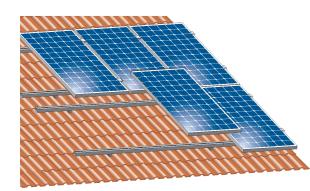














Hook and rail mounting

Remove the upper tile at a hook position, and grind it to prevent contact between the tile and the hook.

Usually, the shaped tile is replaced in its position, and pushed up to mount the hook.

The hook is mounted to the rafter using at least two screws that can hold the load. To ensure that the wood is not splintered, pre-drilling might be necessary as well as ensuring a sufficient distance to the edge of the rafter.

The hook may not touch the lower tile; it is necessary to have a gap of 5 mm. As necessary, the height must be adjusted with durable layers such as plywood.

After the hook is mounted, the upper tile is pulled back to its former position. It is important that a minimum overlap of the upper and the lower tiles is observed in order to avoid leakage from rain.

It is advisable to start with the upper hooks. To get a proper appearance, these hooks should be aligned with the roof using a chalk-line. Don't use a level, but rather align it to the roof itself to avoid a levelled PV system on a skew roof.

After mounting the hooks, the rails are bolted to the hooks. The position of the hooks depends on the position of the rafters and the tiles. Due to slotted holes in the hooks, some adjustment of the rail position is possible. The position of the rails must ensure correct clamping of the modules. A minimum gap between the module rows needs to be provided. If the hook position doesn't fit these requirements, it might be better to use a double-layer rail installation.

The cutting of rails must be performed on the ground in order to avoid metal swarf on the roof.

For sagging roofs it might be necessary to use plates (aluminium or stainless steel) as an additional layer between hook and rail in order to avoid a sagging PV array.

Some manufacturers provide adjustable hooks for easy adjustment. When in doubt about the suitability of a system always consult the manufacturer.



Observe all safety instructions while using the grinder, cutter and other tools!





Cable laying and module mounting

Because the cables and the inlet are underneath the PV modules, the wiring on the roof must be performed before or during mounting of the modules. A detailed wiring plan should be on hand during installation.

For an inlet, one tile may be replaced with a ventilation tile or a tile which is shaped in such a way that cables protected by a soft but durable layer can pass through it without lifting the upper tile. All cables from the inverter to the inlet and the string cable should be laid in place and firmly attached. Plug assemblies for all DC cables should be performed by a skilled electrician. Incorrect assembly and the use of incompatible connectors by third-party manufacturers are the main reasons for arcing and therefore fire.

A bonding of 6 mm² Cu (or comparable) of the metal substructure to potential equalisation must be performed. Because of the anodised aluminium the module frame cannot be used for equalisation. The installer must ensure that all rails are correctly bonded.

Once the wiring is completed, the modules can be put in place and clamped to the mounting structure. The string interconnection of one module to another must be performed in parallel – because the back of the modules are inaccessible once they are mounted. The installer must put the module in place, plug in the cable coming from the previous module, attach the module cable to the mounting structure, lay down the module to its final position, and fasten the clamps – in one work step.

The plugs must not touch the roofing and the cables should not lie on the roofing. The wiring must be fastened in such a way that no damage to cable and plugs will occur for the life-time of the PV installation.

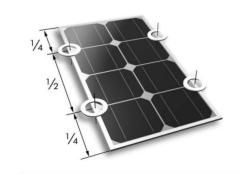
The minimum gap between the modules may depend on the clamp dimensions. Due to roof sagging or other reasons, sometimes the gap can be wider. The installer has to ensure that the clamp lies sufficiently on both module frames and the rail, in order to ensure a proper clamping.

The end clamp lies on the module frame and the rail. To ensure a proper clamping, the height of the clamp must correspond to the frame. Furthermore, a sufficient rail length is necessary to ensure that the end-clamp will not slip off the end of the rail.

Module clamps need to be tightened to the correct torque using a torque wrench. Please refer to the manufacturer's installation manual.



TYPE OF INSTALLATION	MODULE	POINT MOUNTING SYSTEM	LINEAR MOUNTING SYSTEM
INSTALLATION WITH CLAMPS	Q.PRO-G3 Q.PEAK-G3 Q.PEAK BLK-G3	245 - 445	245 - 445
	Q.PEAK S-G3	180 - 380 CL1	180 - 380 CL3 CL4













Module handling hints

Follow the module installation manual. If no manual is on hand, the clamping points shall be at the quarter points of the long side of the module.

Do not step on the module. Even if no glass breakage occurs, micro cracks or other visible or invisible damage to the modules may occur. If some work in the PV array area is inevitable, use special tools such as walkways or ladders protected with a soft layer to avoid high-static loads on the modules.

Don't drill into the module frame. This will void the manufacturer's warranty. If the back sheet is damaged, there is also a high risk of isolation faults.

Don't let any tools scratch the back sheet. Be careful at the end of a rail while mounting the module. Avoid clamps under a module during installation. If modules are stored on top of each other, always lift a module without sliding from the pile. When sliding modules across each other, the frame of the lower module might scratch the back sheet of the next module.

Don't let the modules fall down – especially on a corner. Even for framed modules, glass breakage or other damage might occur.

Module handling should always be performed by two persons in order to avoid the risks mentioned above. The best way of handling a module is using a hand-held suction lifting pad.





ON-SITE EMBEDDED GENERATION
(EG) CONNECTED! THE EG IS
FITTED WITH AN AUTOMATIC
DISCONNECTION SWITCH WHICH
DISCONNECTS THE EG IN CASE OF
UTILITY DE-ENERGISATION

ISOLATE EMBEDDED
GENERATION MODULES AT
SUPPLY END & ISOLATE MAIN
AC SUPPLY BEFORE OPENING
JUNCTION PANEL



Inverter installation and AC connection

The mounting position for the inverter depends on the ingress protection (IP) rating of the inverter. For outdoor mounting, an IP rating of at least 54 is mandatory. Even then, a sheltered installation is recommended.



The DC string or main cables must not connect to the inverter before commissioning!

The necessary components in the distribution board – such as AC isolators, circuit breakers and an energy meter – depend on the requirements of the grid company and the applicable standards.

Even though it is not mandatory in South Africa, warning signs should be attached near the inverter and at the distribution board. These signs should clearly indicate that a PV installation is mounted on the roof and that the DC cables are energised – even when the inverter is isolated from the grid.









Electrical Inspection of a PV Installation minimum requirements Report Nr.						M			
Costumer Name Street/Nr.	Feed lugrical				Installer Name Street/Nr. Town	Jo /2 27 S- Capa	1 road		
	Pre	e-Calculation			Power Check		c	ommissioning	
	Nominal Generator Power 2 100 Irradiation 806		800	Power Inverter Display 1710		Re-Examination			
		ule temperature	45	Check expected and		04			
	Generator power at modu			di	splayed values		J		
	rule of thumb: power at 900 W/m² and	45°C = power S							
Pre-Calculat		1	2	3	4	5	6	7	8
	Modules in series	/16							
Open circuit	Module Voc at 25°C	42							
voltage	String Voc at 25°C	672							
	Module temperature	45							
	String Voc at module temperature	605							
	rule of thumb: string voltage at 45°C =		tage STC -10%						
	Impp at 1000 W/m ²	9.2							
Operating	Irradiation	200							
Current	Impp at irradiation	8,28							
	rule of thumb: sunny day irradiation 90	0 W/m², cloudy	day 200 W/m"						
String Measurements		1	2	3	4	5	6	7	8
	Polarity OK								
Open circuit voltage	measured value	604							
	Check expected and measured value	04							
	measured value	81							
Operating current	Check expected and measured value	04				0.	1		
Date	2,1,2017				Signature		96		

Commissioning

Currently, municipalities require the PV system to be signed off by Professional Engineer (Pr. Eng.) or Professional Technologist (Pr. Tech.).

On sign-off certain items need to be confirmed:

- PV solar system design approved by Pr. Eng. or Pr. Tech.
- Letter of installation and commissioning approval from Eskom or municipality
- Installation was performed under the supervision of a qualified electrician according the approved design
- Electrician has to sign a certificate of compliance (CoC) for the installation
- Pr. Eng. signs off an as-built drawing, after system works as specified
- Installer or supplier provides any additional documents and reports for commissioning the PV system to client
- All requested documents must be sent to the network operator for final commissioning and operation approval

For the PV system itself, some measurements must be performed before the PV array is connected to the inverter. According to the international standard IEC 62446, for each string the measurements of V_{oc} and I_{sc} and a polarity and isolation check are mandatory.

As a minimum requirement, the measurement of V_{oc} and a polarity check must be performed before connecting the strings to the inverter. It is reasonable to compare measured and expected values. The expected value for voltage must consider Voc for the actual module temperature and the number of modules connected in series.

Once the PV system is connected to the AC grid, a string current measurement with a DC clamp can be performed.

A report of all measured values should be part of the system documentation. Always compare measured and expected values in order to find errors in the wiring or malfunctioning modules.





PV GreenCard

ROOFTOP SOLAR PV

PV GreenCard

To ensure a consistently high quality standard for PV installations, the South African Photovoltaic Industry Association SAPVIA will provide the PV GreenCard as voluntary proof that the registered installers have the requisite knowledge to plan and install a PV system, and that such a system was installed according to international best practices. To provide a GreenCard, an installer must pass an assessment in order to register. The GreenCard lists all the necessary information which needs to be handed over to the customer.



Daily	Inverter	Operating without any fault display?
Monthly	Yield check	Log the meter readings regularly (not necessary in systems with automatic recording and evaluation of operating data)
	PV array surface area	Heavy soiling? Leaves, bird droppings, air pollution or other types of soiling? Clean with copious amounts of water (use a water hose) and a gentle cleaning implement (a sponge), without using detergents Do not brush, or wipe the modules with a dry cleaning implement to avoid scratching the surface Are all modules still correctly fixed? Is the generator surface area subject to any mechanical stress? (e.g. as a result of a warped roof structure)
Every six month	ns PV combiner/junction box (if present)	Are there any insects/is there humidity in the device? (if mounted outdoors) If possible, check fuses
	Surge arresters Cables	Check after thunderstorms as well Surge voltage arrester intact (window white or red)? Look for charred spots, broken insulation and other kinds of damage (e.g. cables damaged by animals)
		Check the fixing points
Every three to four years	Repeat the measurements as during commissioning	Only to be carried out by a trained professional
	Inverters in outdoor applications	Humidity may penetrate in spite of suitability for outdoor applications Only to be controlled by a trained professional
If suspected	Modules PV combiner/junction box AC protective equipment	Peak output measurement by a trained professional Check string fuses Line circuit breakers, AC fuses and RCDs

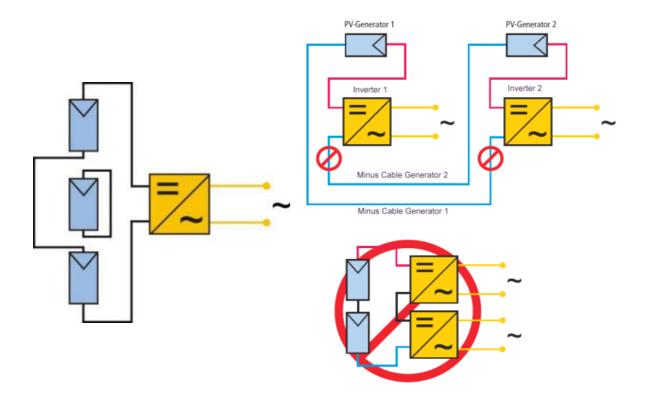
Operation and maintenance

A PV system needs little maintenance. However, for safety reasons and to obtain the highest yield and overall performance, a minimum maintenance effort is needed.

A daily check of the inverter can be done by the monitoring system. Because yield losses often remain unnoticed, a monthly yield check is recommended. An economically meaningful frequency for onsite maintenance by an installer depends on the costs and the installed PV system. For small residential installations, the necessary work can partly be done by the owner. This would include a visual check of the PV array in order to address soiling or moss growth.

For some safety issues such as ground faults, insulation checks are performed by the inverter automatically. In case of insufficient insulation resistance, a warning message is initiated by the inverter. This problem should be addressed as soon as possible – in order to avoid yield losses and potential hazards.







Typical electrical failures in PV installations

During installation some failures may already occur due to wiring faults. If plugs are assembled to a cable the polarity must be correct.

The modules are only interconnected by plugging them into the previous and next modules. Wiring errors occur when the wrong number of modules are connected as a string. Some of these modules are just not plugged into the other modules. Sometimes they are short circuited by plugging the plus and the minus of the same module into each other. In both cases the string voltage and power is reduced.

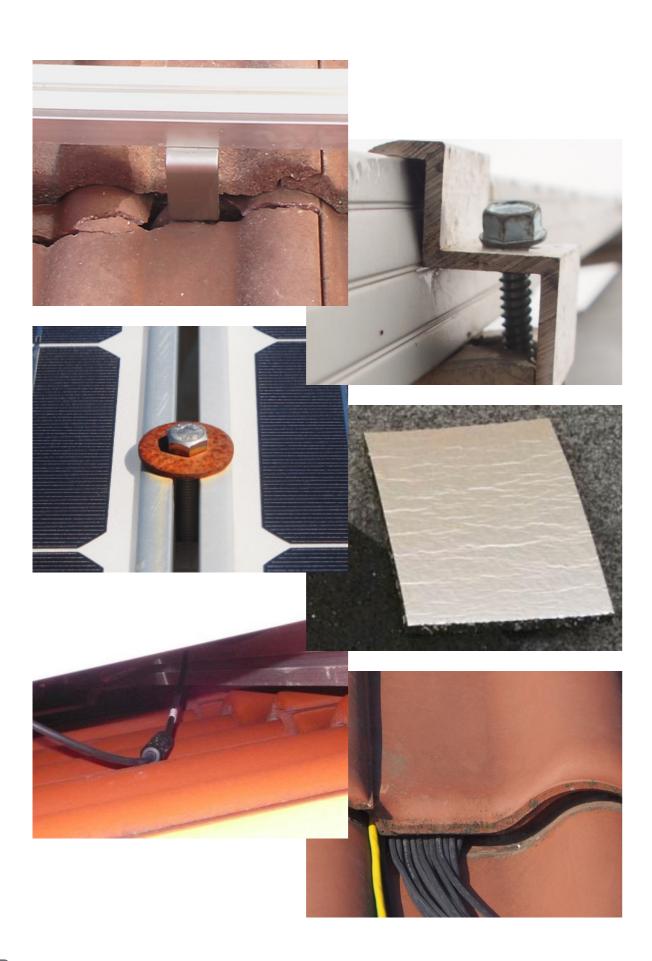
In installations with more than one inverter, a clear labelling of the string cables is very important, otherwise a cross connection of two PV arrays is possible. The plus of one sub-array is connected to the correct inverter – but the minus is connected to another inverter. The other sub-array is similarly connected. This kind of interconnection is a circuit where both PV arrays are in series and connected to both inverters which are also connected in series. If transformerless inverters are in use they will blow one of their fuses once they are connected to the public grid and might be damaged. If inverters with transformers are in use, this cross connection might work for years. However, both inverters will be operating at half the total PV system voltage. In this case the yield is reduced, because both MPP trackers will attempt to operate the PV system at different set-points.

During operation most electrical failures occur due to mechanical problems. Examples are cracked cells due to glass breakage, or cable-isolation faults caused by a too tight bending radius or laying over sharp edges. In addition, cables and especially plugs must not be in direct contact with the roofing in order to avoid isolation faults.



With earth faults or short circuits due to isolation faults arcing may occur – leading to a high risk of fire





Typical mechanical failures in PV installations

Breakage of a tile is a typical problem if hooks are not mounted properly. If a minimum gap between hook and lower tile was not observed, the tile will break due to pressure on it under load. The roof is not sealed anymore if this happens and the PV installation must be dismantled to replace the broken tiles.

Incorrect clamping is another common failure. The end clamp is not dimensioned correctly according the height of the frame, the rails are too short, the clamps slip off the rail, and the support of the clamp on the module frame is insufficient. Also, for the clamp between two modules, insufficient support on the frame due to a wider gap can loosen the module if it slips off the frame. If one module is loose and is blown away — a chain reaction is possible.

The wrong combination of two metals may lead to corrosion. Minor problems can be fixed with an anticorrosive coating – but the installer must ensure a proper structural behaviour for the life-time of the installation. Therefore, a replacement of affected components is recommended in most cases.

A waterproof lining between the mounting structure and the roof structure may be compromised if the wrong material is used. Sheeting like vinyl can crack after some years. The roof is then no longer waterproof and the PV installation must be dismantled in order to renew the whole sheeting.

Unsupported cable lying on the roof may cause isolation faults. Also, too tight a bending radius or sharp edges can damage the insulation layer of a cable. If the cable can swing around in the wind, the cables in the whole installation might be affected. In that case, due to the possible arcing in the DC installation and the high risk of fire, the cables must be replaced. For a roof parallel installation the PV modules must be dismantled in order to gain access to the module cables.









Direct Measurements: Current, Characteristic Curves, Power





Indirect Measurements: Infra Red, Electroluminescense

Measurement devices for PV

For some measurements performed on PV systems, normal measurement devices for electricians like a voltmeter or a current clamp may be used. The devices must be suitable for DC applications. In principle, there are two types of measurement:

- Direct methods are the measurement of current, voltage, power of modules, strings, or the entire PV system. The measurements are carried out during normal operation or in open or short circuit when the modules are disconnected
- Indirect methods such as electroluminescence or infrared inspections show effects of the module behaviour through other physical values. The inspections are carried out during normal operation or while an external current is supplied to the PV modules

In most cases infrared measurements and current measurements using a clamp can be performed with very few risks.

Infra-red measurements can also be used for checking the electrical installation. Overheating caused by incorrect assembly of plugs or loose screws at terminals also shows a thermal signature.



During measurement, the installer must follow the national safety requirements given in the Occupational Health and Safety Act or other regulations, standards or guidelines on working at heights and electrical safety.









Environmental maintenance

Yield losses might occur due to soiling or shading effects caused by plant growth in front of the PV modules.

The necessity of cleaning strongly depends on the environment and slope. The lower edge of framed modules with a slope less than 20° may show dirt accumulation. This soiling can be regarded as a permanent shading of the cells beneath this edge.

Shading effects caused by plants are more common in a ground-mounted installation than roof-mounted systems. Nevertheless, all systems should be inspected regularly.



During maintenance the installer must follow the national safety requirements in the Occupational Health and Safety Act or other regulations, standards or guidelines on working at heights and electrical safety











