

1. General Introduction

Solar technologies have played a limited role in the power sector in Africa, but are gaining attention in many countries. According to the International Energy Agency's Africa Energy Outlook 2014, electricity generated from Solar PV in sub-Saharan Africa is still very low but is expected to grow up to 7-8% of generation capacity by 2030 (equivalent to 3% of electricity generated).

2. General Principles

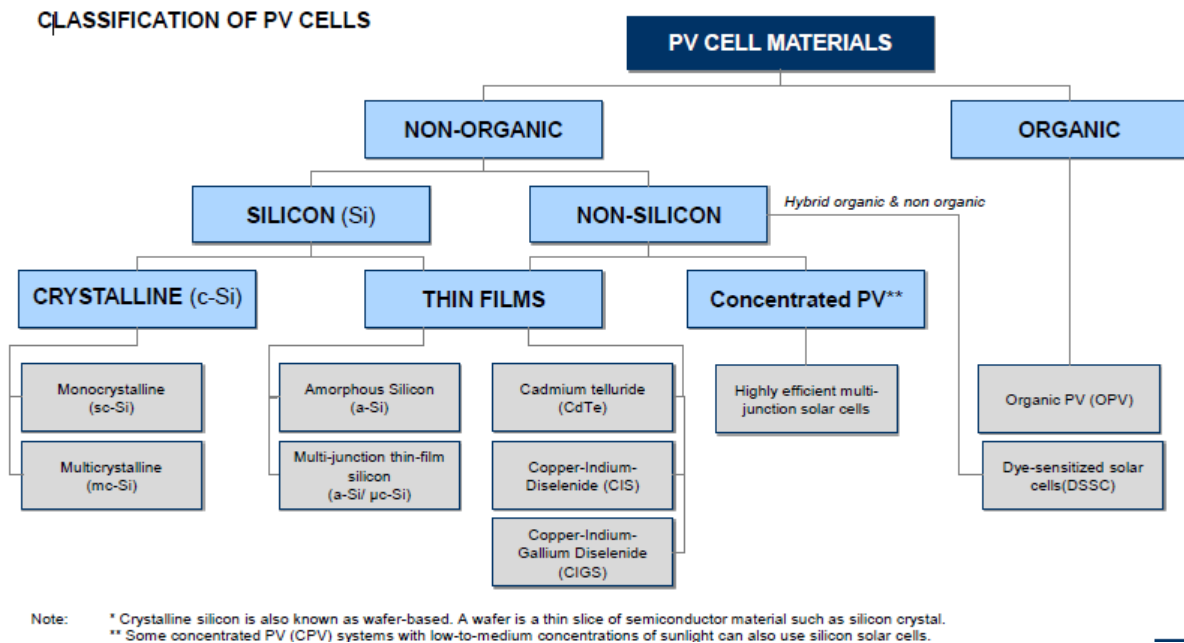
Photovoltaic systems (PV) are made of PV modules. The smallest unit in a PV module is the solar cell, which convert the light into electricity. The direct electric current (DC) produced varies constantly depending on the intensity of the incoming solar light. Also current is depended of the incoming solar energy. A PV module consists of many solar cells connected to achieve a higher voltage. A module for off-grid application normally is adapted for a voltage of 12 V or 24 V (with respectively 36 and 72 cells in serial). When modules are used for grid connected systems with higher voltage and alternating current (AC), an inverter is needed to change the DC current into AC current. Also the voltage needs to be converted to at least 230 V depending on the system it is connected to. When the cells are connected into a module, also different losses lower the module efficiency from the cell efficiency.

PV is one of the fastest growing renewable energy technologies and it is expected that it will play a significant role in the future global electricity generation mix.

PV technology can be used on a variety of scales, from an integrated solar cell in a solar lantern, to a battery operated solar system on a house or school or even a large grid connected solar power plant with a capacity of several MW.

For reference, it is important to consider that the maximum amount of energy coming from the sun at the equator is in the range of 1000 W/m² at peak hours of sunshine (see solar irradiance). In addition, the best efficiency currently available for commercial solar panels is of the order of 16%-22%. Thus one square meter of photovoltaic panel can, at best, provide an electric capacity of 220 W. Higher efficiencies can be achieved by using different layers in one cell or by concentrating the sunlight.

Classification of PV cells: Over the years several types of PV technologies have been developed and can be classified as follows:



Source: [https://energypedia.info/images/4/41/SBC Energy Institute Solar PV FactBook.pdf](https://energypedia.info/images/4/41/SBC_Energy_Institute_Solar_PV_FactBook.pdf) page 13

Crystalline silicon cells

This technology uses the wafer-based crystalline silicon (c-Si) technology, either single (mono) crystalline (sc-Si) or multi-crystalline (mc-Si). Crystalline silicon cells may be mounted into framed panels or frameless panels suitable for roof or façade integration. Highest cell efficiency for commercial mono crystalline cells are for the moment 22.5 % and the multi crystalline cells have about 18 %.

Thin-film cells

The thin-film technology reduces the amount of material required in creating the active material of solar cells. Most thin-film solar cells are sandwiched between two panes of glass to make a frameless module. Since silicon solar panels only use one pane of glass, thin-film panels are approximately twice as heavy as crystalline silicon panels. The majority of thin-film panels have 2% to 3% lower conversion efficiencies than silicon. Cadmium telluride (CdTe), copper indium gallium selenide (CIGS) and amorphous silicon (A-Si) are three thin-film technologies. The highest efficiency reach is about 20 % with Cadmium telluride (CdTe) and CIGS. The market share of thin films PV is around 11 % of all manufactured PVs.

Concentrating photovoltaic technology

Concentrating PV (CPV) systems utilise optical devices, such as lenses or mirrors, to concentrate direct solar radiation onto very small, highly efficient multi-junction solar cells.

Commercial CPV modules with silicon-based cells offer efficiency in the range of 20% to 25%. Commercial multi-junction devices have efficiencies of around 35%, significantly higher than conventional single-junction c-Si solar cells. Multi-junction solar cells consist of a stack of layered p-n junctions, each made from a distinct set of semiconductors, with different band gap and spectral absorption to absorb as much of the solar spectrum as possible. Multi-junction technology has recently been commercialized and is still in small-scale production.

Organic Photovoltaic (OPV)

An organic solar cell or plastic solar cell is a type of polymer solar cell that uses organic semiconductors. The plastic used in organic solar cells has low production costs in high volumes. Combined with the flexibility of organic molecules, organic solar cells are potentially cost-effective for photovoltaic applications. The main disadvantages associated with organic photovoltaic cells are low efficiency, low stability and low strength compared to inorganic photovoltaic cells. Currently, the market only has a few manufacturers. At the moment, organic photovoltaic uses three key technologies: 1. OPV oligomers 2. OPV polymers 3. OPV DSSC (dye-sensitized solar cells; hybrid technology).

The specifics of the most common applications for solar PV are as follows:

Large-scale utility PV plants are designed for the supply of power into the electricity grid. Most solar power plants today are owned by independent power producers (IPP's) though some are held by electric utilities. These plants are usually built in sizes from 10 to 100MW and occupy vast areas of land. In order to have a backup generation facility, the plant is sometimes coupled with fast-starting and sufficiently flexible diesel engines or open cycle gas turbines. Depending on the size of the system, solar resources, financing cost and project risks, the feed-in-tariffs for the electricity generated have to be around 0.10-0.15 USD/kWh in order to reach financial viability. The owner of a large scale PV system also need to have a power purchase agreement (PPA), when the energy is to be fed into the grid.



Roof-top solar PV systems are often associated with buildings: either integrated into them, mounted on top of the roof or nearby on auxiliary structures. Building-integrated photovoltaic systems are increasingly incorporated into new domestic and industrial buildings as a principal or ancillary source of electrical power. This is a market that exists in many developing countries with high electricity prices, but is still to open up in Africa. If the building itself cannot use all energy produced by PV, the owner need an agreement or PPA if he wants to sell excess energy to the grid.



Pico-PV and solar home systems have experienced significant development in recent years (especially in rural areas far from the grid), combining the use of very efficient lights (mostly LEDs) with charge controllers and efficient batteries. With a small PV module of only a few watts essential services can be provided, such as lighting, phone charging and powering a radio. Expandable solar pico-systems have entered the market. Households in rural areas can start by buying a small kit, later adding a supplement, allowing for extra lights and services to be connected and even a small TV to be considered.

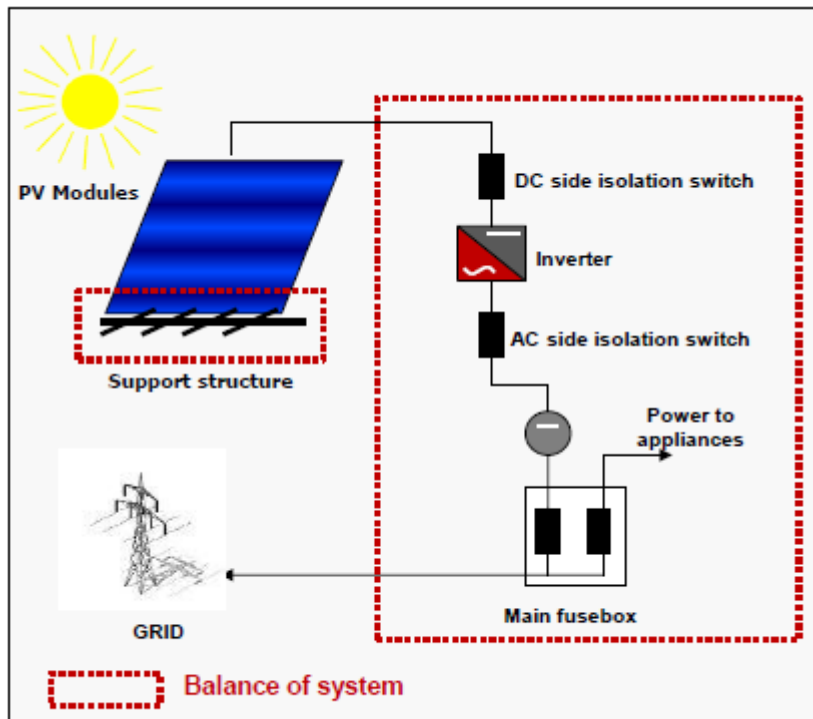


3. Technology overview

The main components of a solar PV system are

- The PV module which is semiconductor converting sunlight directly into electricity
- The solar cables that interconnect solar modules and other electrical components in the photovoltaic system
- Mounting system - required to mount or install the PV modules and other component
- Batteries to store electricity and provide energy on demand at night or on overcast days; usually only for stand-alone systems.
- Inverters required to convert the DC power produced by the PV module into AC power, if grid-connected or used as 230 V system
- Controllers that manage the energy storage to the battery and deliver power to the load

Example of a grid connected solar system



Source: https://energypedia.info/images/4/41/SBC_Energy_Institute_Solar_PV_FactBook.pdf page 12

PV Solar modules

The output of the solar module depends on many factors: its size (installed capacity), efficiency of the technology, irradiation at the site, cleanliness of the surface, the power electronics (for instance whether a Maximum Power Point Tracking device –MPPT- is engaged), and eventually on a tracking system (untypical for rural electrification).

Since sunny conditions are the norm for most developing countries, an installed capacity of 1kWp (typically 4-6 individual modules with a total surface of approximately 8m²) can generate more than 2.000 kWh annually. In moderate, cloudy climates, the modules may reach only 50% or less of this output.

Most commercially available solar modules are capable of producing electricity for at least twenty years. The typical warranty given by panel manufacturers is over 90% of rated output for the first 10 years, and over 80% for the second 10 years. Good quality panels are expected to function for a period of 30 – 35 years.

Maintenance of PV modules is relatively easy as the most common technical problems occur due to misplaced or dirty modules and can be identified visually. In these situations, the energy harvested decreases and the energy balance might be disrupted. Hence, the observation of the surrounding area is essential not only to avoid shadowing, but also to decrease the risk of hot spots that damage the generator.

Maintenance and sustainable operation is less a problem where market-based approaches to PV systems have been introduced and private companies are responsible for operating the PV facilities and systems. However, community or governmental based management is still the reality in many countries. To assure a sustainable operation of governmental /community managed PV system, the existence of a maintenance service provider and funding needs to be guaranteed.

Solar modules can be easily cleaned with water and a sponge, but ongoing maintenance is also necessary. This should include check-up of cables and fixation, the opening and control of the junction box and the strain relief of electric cables. Visual control of the cables should be done regularly by the user to prevent eventual damage caused by animals. Finally, PV systems located near the coast bear the risk of "blooming" effects on the aluminium frame due to salty air, which can lead to corrosion if not controlled.

Solar Cables

Solar cable is the interconnection cable used in photovoltaic power generation. A solar cable interconnects solar modules and other electrical components in the photovoltaic system. One common factor for most of the photovoltaic power systems is outdoor use, characterized by high temperatures and high UV radiation. Single-core cables (2.5/4.0/6.0 up to 35 mm²) with a maximum permissible DC voltage of 1.8 kV and a temperature range from -40°C to +90°C are generally used. A three-core AC cable is used for connection to the grid if a single-phase inverter is used, and a five-core cable is used for three-phase feed-in.

Mounting systems

Ground Mounted solar power systems consist of solar panels held in place by racks or frames which are attached to ground based mounting supports. Ground based mounting supports include:

- Pole mounts which are driven directly into the ground or embedded in concrete;
- Foundation mounts such as concrete slabs or poured footings;
- Ballasted footing mounts such as concrete or steel bases that use weight to secure the solar panel system in position and do not require ground penetration. This type of mounting system allows for decommission or relocation of solar panel systems with no ground excavation.

Roof Mounted solar power systems consist of solar panels held in place by racks or frames which are attached to roof based mounting supports. Roof based mounting supports include:

- Pole mounts which are attached directly to the roof structure and may use additional rails for attaching the panel racking or frames;

- Ballasted footing mounts such as concrete or steel bases that use weight to secure the panel system in position and do not require through penetration. This mounting method allows for decommission or relocation of solar panel systems with no impact on the roof structure.

Fixed racks hold panels in a single location as the sun moves across the sky. The fixed rack sets the angle at which the panel is held. Tilt angles equivalent to installation's latitude is common. In equatorial regions, a minimum tilt angle is required for rain water drainage.

Solar Trackers increase the amount of energy produced per panel at a cost of mechanical complexity and need for maintenance. Single-axis systems track the sun east to west as it moves across the sky, allowing them to increase system performance by 20 percent or more over fixed systems in areas of high insolation. Dual-axis trackers angle through both the x and y axes, typically generating about 8 percent-10 percent more energy than single-axis types, depending on location.

Solar Charge controller

A charge controller is needed to power DC equipment with solar modules. The charge controller provides a regulated DC output and stores excess energy in a battery as well as monitoring the battery voltage to prevent under or over charging. An inverter can be connected to the output of a charge controller to drive Alternative current (AC) loads.

A shunt charge controller or shunt regulator diverts excess electricity to an auxiliary or "shunt" load, such as an electric water heater, when batteries are full.

Inverter

Inverters may be classified into three broad types:

- **Stand-alone inverters**, used in isolated systems where the inverter draws its DC energy from batteries charged by photovoltaic arrays. Many stand-alone inverters also incorporate integral battery chargers to replenish the battery from an AC source, when available. Normally these do not interface in any way with the utility grid, and as such, are not required to have anti-islanding¹ protection.
- **Grid tie inverters**, which match phase with a utility-supplied sine wave. Grid-tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages.
- **Battery backup inverters**, are special inverters which are designed to draw energy from a battery, manage the battery charge via a charge controller, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding² protection.

Single phase inverters are used in low and medium size facilities ranging from 300 Wp to 90 kWp. To achieve this level of power capacity, several inverters are necessary. The output of each inverter and the protections of the facility are centralized in a "Main Low Voltage Board". Some installers design three-phase 400 Vac applications, using single-phase inverters; this type of installation

¹ [Islanding refers to the condition of a distributed generator that continues to feed the circuit with power, even after power from the electric utility grid has been cut off. Islanding can pose a dangerous threat to utility workers, who may not realize that a circuit is still "live" while attempting to work on the line. Distributed generators must detect islanding and immediately stop feeding the utility lines with power. This is known as anti-islanding. A grid-tied solar power system is required by law to have a gridtie inverter with an anti-islanding function, which senses when a power outage occurs and shuts itself off. Unless there is a battery back-up system, the gridtie solar system will not produce power when the grid is down.](#)

² [ibid](#)

requires a careful balancing of phases. Price is the main driver for choosing single phase inverters versus three phase inverters. This short term approach does not account for (i) the extra costs of wiring and checking the balance of the AC system, (ii) possible ground current through the neutral, etc. In case of failure of one inverter or of one of the chains connected to inverters, a phase imbalance occurs; this leads to disturbances on the grid and causes a fault with a security trip out of the whole system.

3 Phase inverters are used in medium to large size facilities ranging from 5 kWp to several MWp. To achieve this level of power capacity, several configurations of inverters are possible

- Three-phase inverters designed for systems ranging from 10 kWp up to 1 Megawatt. Outputs and protections are centralized at the main low voltage board in the case of a connection to the grid at LV level. Connection to the MV grid will require a transformer.
- For installations above 100 kWp up to several Megawatt such as photovoltaic power plant, it will be implemented a central inverter which injects current directly on a medium voltage transformer.

Batteries

The **Lead Acid battery** is made up of plates, lead, and lead oxide (various other elements are used to change density, hardness, porosity, etc.) with a 35% sulphuric acid and 65% water solution. This solution is called electrolyte, which causes a chemical reaction that produce electrons. When the battery is discharged, the sulphur rests on the battery plates and when the battery is recharged the sulphur returns to the electrolyte.

Battery Maintenance. The lead battery should be cleaned using a baking soda and water solution. Cable connections need to be cleaned and tightened as battery problems are often caused by dirty and loose connections.

Battery warranties are usually prorated to the month used versus the warranty life. Only 30% of batteries sold today reach the 48-month battery life mark. 80% of all battery failure is related to sulphate build-up. This build up occurs when the sulphur molecules in the electrolyte (battery acid) become so deeply discharged that they begin to coat the battery's lead plates.

Nickel-metal hydride battery (NiMH): These are now a common consumer and industrial type. The battery has a hydrogen-absorbing alloy for the negative electrode instead of cadmium. Following the ban of Cadmium as toxic element, NiMH batteries have completely superseded Nickel-cadmium (NiCd) batteries.

Lithium-ion battery: The technology behind lithium-ion battery is used in electric and hybrid cars and is gaining production capacity at lower prices (e.g., 3000 Euros for 10 kWh and 10 year warranty). The batteries have one of the best energy-to-mass ratios and a very slow loss of charge when not in use.

Lithium-ion polymer battery: These batteries are light in weight and can be made in any shape desired.

Type	Voltage V	Energy density			Power W/kg	Eff. %	discharge %/month	cycles #	Life year
		MJ/kg	Wh/kg	Wh/l					
Lead-acid	2.1	0.11-0.14	30-40	60-75	180	70-92	3-4	500-800	20
NiMH	1.2	0.11-0.29	30-80	140-300	250-1000	66	30	500-1000	
Li ion	3.6	0.58	150-250	250-360	1800	80-90%	5-10	1200	10
Li-Polymer	3.7	0.47-0.72	130-200	300	3000+	99.8%	2.8-5.05	500-1000	2-3

4. Key elements of design

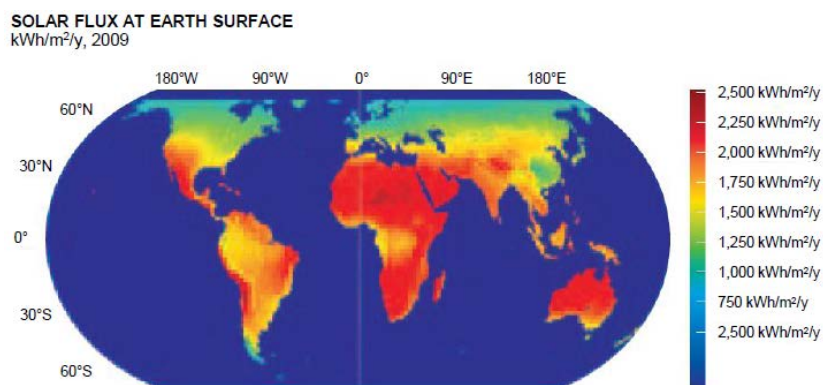
The performance of a PV plant is a function of the climatic conditions, the equipment used and the system configuration. The primary energy input is the **solar irradiance** and global irradiation in the plane of the solar modules, and this in turn is a combination of the direct and the diffuse radiation. A key determinant of the output of the system is the **conversion efficiency** of the solar modules, which will depend in particular on the type of solar cells used and ranges from 14% to 19% for commercially available crystalline solar cells.

4.1 Solar irradiance

Solar irradiance is the radiation emitted by the sun that has been transmitted through the atmosphere of the earth. The irradiance is measured by satellite near the outer surface of Earth's atmosphere and is called the solar constant, which is 1361 W/m². Solar radiation emanating from the sun is attenuated, before reaching the ground, by the earth's atmosphere, which can be classified in two broad types, without and with clouds. Depending on scattering and absorption in the atmosphere the final irradiance value reaching the ground and what PV modules can utilize, is about 1000 W/m². This is the power of the sun.

Direct normal irradiation (DNI) is the amount of solar radiation received per unit area by a surface that is always held perpendicular to the rays that come in a straight line from the direction of the sun at its current position in the sky. The total daily sum of solar irradiation per square meter is the total energy received per day (kWh/m²). Normally also the monthly or annual sums can be measured or simulated by different programs. The total sum of the power during a certain time is also the total energy. Energy is power x time.

The PV modules are sub-systems which convert incoming light into electricity. Africa is particularly rich in solar energy potential, with most of the continent enjoying an average of more than 320 days per year of bright sunlight and experiencing annual global irradiation levels of almost 2 000 kWh per square metre (kWh/m²) (twice the average level in Germany). The best solar resources stretch across the Sahara, North Africa and parts of Southern Africa, with irradiation levels close to 2 500 kWh/m². Central and West Africa generally have lower irradiance levels, particularly near the Gulf of Guinea.

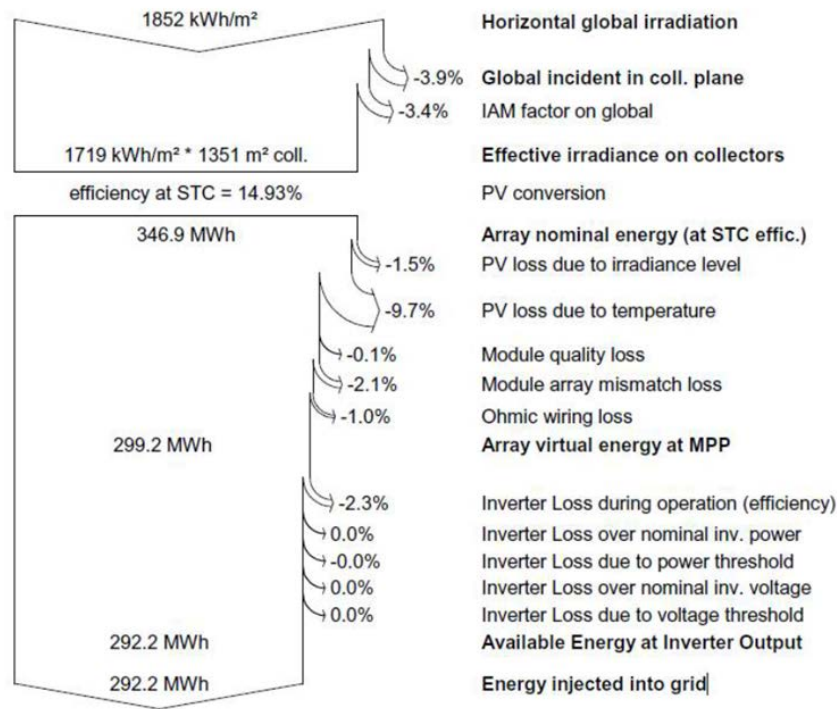


Source: Breyer and Schmidt (2010); IEA (2011), "Solar Energy Perspectives"
©2013 SBC Energy Institute. Permission is hereby granted to reproduce and distribute copies of this work for personal or nonprofit educational purposes. Any copy or extract has to refer to the copyright of SBC Energy Institute.

Source: https://energypedia.info/images/4/41/SBC_Energy_Institute_Solar_PV_FactBook.pdf page 9

4.2 Conversion efficiency – loss diagram

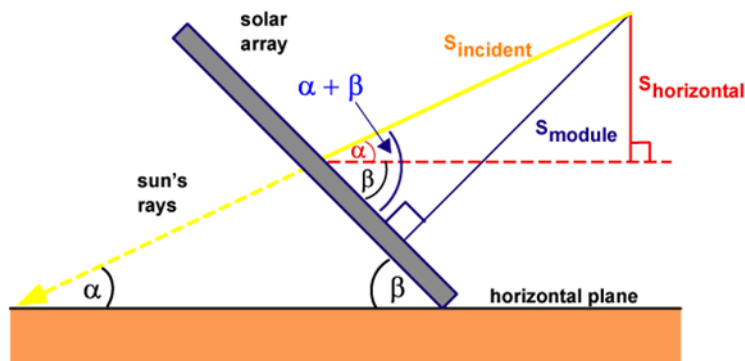
Due to a wide range of factors such as light absorption losses, mismatch, cable voltage drop, conversion efficiencies, temperature influences and other parasitic losses, there are losses between the Direct Normal Irradiance (DNI) and the actual AC power delivered to the grid. The loss diagram provides a quick and insight look on the quality of a PV system design, by identifying the main sources of losses as illustrated in the diagram below.



Loss diagram by PV-SYST software

Each loss is defined as percentage of the previous energy quantity. Therefore the percent values are of course not additive: when grouping the losses, the overall percentage is not the sum of the detailed values.

Global incident in collector plane is the result of the transposition of the irradiance from horizontal ("S horizontal" indicated in the solar irradiance atlas) to the plane of the array ("S module" with an angle β over the horizontal).

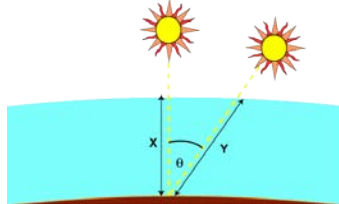


Source: <http://www.pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-on-tilted-surface>

The **incidence effect** (or **IAM**, for "Incidence Angle Modifier") corresponds to the decrease of the irradiance really reaching the PV cells surface below the protective layer (usually glass + antireflective coating), with respect to irradiance under normal incidence, due to reflexions increasing with the incidence angle.

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. The Air Mass is defined as:

$$AM=1/\cos(\theta)$$



where θ is the angle from the vertical (zenith angle). When the sun is directly overhead, the Air Mass is 1.

Source: <http://www.pveducation.org/pvcdrom/properties-of-sunlight/air-mass>

PV cell conversion efficiency

A key determinant of the output of the system is the conversion efficiency of the solar modules, which will depend in particular on the type of solar cells used.

At commissioning, normalised solar cell efficiencies at Nominal Operating Cell Temperature (NOCT) 46°C are as follows:

- Mono or Polycrystalline silicon cells 12.5%-15%
- Thin film cells 9.5%-10%
- Multi-junction cells 33%-35%

PV conversion loss due to temperature

The standard test conditions are specified for a cell temperature of 25°C, but the modules are usually working at much higher temperatures. For crystalline Si solar modules only, the DC power generated decreases by 0.7-0.9% per °C above 25°C.

PV conversion loss due to module mismatch

The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules. This is mainly due to the fact that in a string of modules (or cells), the lowest current drives the current of the whole string. This difference called "Mismatch loss" is a result of slight inconsistencies (statistical distribution of cells parameters) in performance from one module to the next and amounts to at least a 2% loss in system power.

PV conversion loss due to wires resistance

Power is also lost to resistance in the system wiring. These losses should be kept to a minimum but it is difficult to keep these losses below 1% for the system. A reasonable reduction factor for these losses is 99% or minus 1%.

PV conversion loss due to inverter

The DC power generated by the solar module must be converted into AC power using an inverter. Some power is lost in the conversion process. Modern inverters have peak efficiencies of 96-98% indicated by manufacturers.

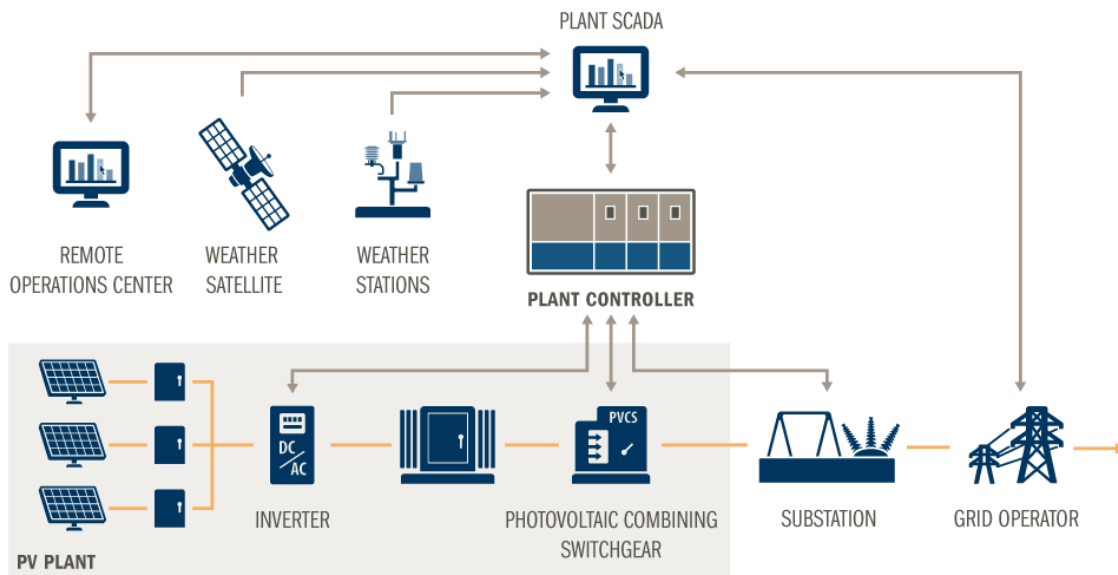
PV loss due to module ageing

The median degradation rate is around 0.5%/year, with modules made after 2000 having a significantly lower degradation rate, so that a system will lose only 12% of its output performance in 25 years. A system using modules which degrade 4%/year will lose 64% of its output during the same period. Many panel manufacturers offer a performance guarantee, typically 90% in ten years and 80% over 25 years. The output of all panels is typically guaranteed at plus/minus 3% during the first year of operation.

Performance ratio PR

The performance ratio (PR) quantifies all the losses between the nominal DC output of the solar modules under specified test conditions and the actual AC power delivered to the grid. This covers a wide range of factors such as light absorption losses, mismatch, cable, inverter. In modern solar plants the performance ratio should typically be in the range of 80%.

4.3 Large scale utility PV



Source: <http://www.firstsolar.com/en/technologies-and-capabilities/grid-integration>

A large-scale PV power plant consists of:

- PV array made of individual modules
- DC side bus
- DC to AC power inverters
- AC voltage electrical systems
- Communication and plant monitoring system

PV modules are mounted on support structures and interconnected to deliver a power output to the electronic power conditioning sub-system.

Solar modules produce direct current (DC) electricity, so solar power plants need conversion equipment to convert this to alternating current (AC) which is the form of electricity transmitted by the electricity grid. This conversion is done by grid-connected inverters, designed to shut down automatically upon loss of electricity supply, for safety reasons.

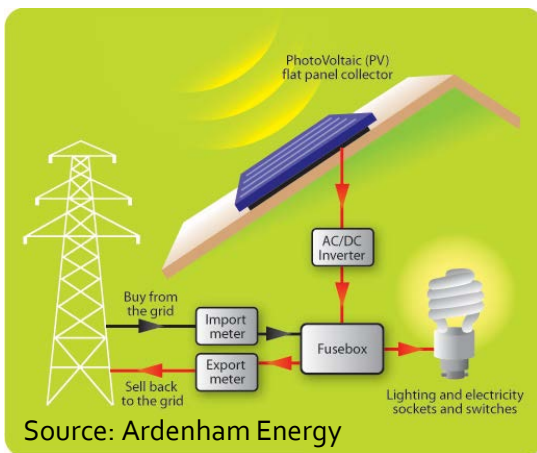
The performance of a PV plant is a function of the climatic conditions, the equipment used and the system configuration. The primary energy input is the global solar irradiance in the plane of the solar panels, and this in turn is a combination of the direct and the diffuse radiation.

The development of large scale utility PV is linked to the electricity sector policy and regulation in relation with **electricity generation from renewable energy** (both central and distributed generation) of which the **Feed-in-Tariff policy** is an approach adopted by a few countries. For all large scale PV plants a Power Purchase Agreement (PPA) is always needed.

For large scale PV power plants, **grid stability and reliability of power flows** must be checked as part of a grid connection study. The power plant may complicate the regulation of voltage along the feeders. Advanced power electronics may help the power plant in playing an active role in voltage regulation. The power plant may also disrupt the operation of the system protection schemes by making it harder to detect a fault and to coordinate protection devices. New sensors, communication equipment and management systems will permit to restore the system reliability.

4.4 Roof top solar PV

A rooftop photovoltaic power station, or rooftop PV system, is a photovoltaic system that has its electricity generating solar modules mounted on the rooftop of a residential or commercial building.



The various components of such a system include, photovoltaic modules, mounting systems, cables, solar inverters and other electrical accessories.

Rooftop mounted systems are small compared to ground-mounted photovoltaic power stations with capacities in the megawatt range. Rooftop PV systems on residential buildings typically feature a capacity of about 5 to 20 kilowatts (kW), while those mounted on commercial buildings often reach 100 kilowatts or more.

The development of roof top PV is linked to the **net metering** policy and regulation. Net metering allows grid-connected electricity consumers who also generate their own power to “bank” or “store” their electricity in times of over-production (i.e. for solar energy, during peak production in the day), and to offset their grid consumption with this banked or stored electricity during other times (i.e. during night, morning and evening hours). Net metering is usually but not exclusively applied to small-scale generators using renewable energy sources.

5. Typical Benchmarks

Trend of PV systems costs

The cost of a PV system depends of its market, despite the trends are universal. For example, the total cost for a PV system has decreased in Germany from \$5.43/Wp in 2009 to \$2.40/Wp in 2015. This reflects a cost reduction of nearly 60% in six years.

Trend cost progression of a c-Si solar system 2009-2015, US\$/W germany							
Year (jan)	2009	2010	2011	2012	2013	2014	2015
Module 1/	3,51	2,23	1,88	1,18	0,86	0,76	0,66
Balance of system 2/	1,92	1,90	1,87	1,84	1,80	1,77	1,74
Total Cost	5,43	4,13	3,75	3,02	2,66	2,53	2,40
Note 1: Source	http://www.solarserver.com/service/pvx-spot-market-price-index-solar-pv-modules.html						
Note 2: Source	http://www.diva-portal.org/smash/get/diva2:474164/FULLTEXT01.pdf						

6. Economic and environmental aspects

Economic aspects

Solar PV Plants are infrastructures of capital intensive nature with low operating and maintenance costs when batteries are not used. The overall cost breakdown is as follows:

- Capital cost comprising:
 - PV modules and support structure supply and installation,
 - Inverter equipment supply and installation,
 - Battery banks (optional),
 - Genset (optional),
 - Electrical instrumentation and controls ("I&C") supply and installation,
 - Project indirect costs, fees and contingency, and
 - Owner's costs (excluding project financing costs).
- Operation and Maintenance costs (O&M) including:
 - Fixed O&M costs (are those that do not vary significantly with generation)³
 - Variable O&M costs (are production-related costs which vary with electrical generation)
 - Major Maintenance costs⁴

The following table provides the typical breakdown of the capital cost (of main components) for a large scale Solar PV plant. The biggest part of the cost is attributable to the PV modules evidencing the high sensitivity to this item of cost.

³ Operating labour cost is usually low, as plants are automated and have few personnel on site during normal operation

⁴ Maintenance repair and replacement of large electro-mechanical equipment requires skilled staff and import of very specific equipment and spare parts that are often not available on the African market

Components	Life duration in years	% total cost of the installation (without battery banks)	% of the total cost of the installation (with battery banks)
PV module	20-25	35%	19%
Inverters	5-10	15%	7%
Battery bank	2-5	0%	50%
Structure	30-50	45%	24%
Total cost per kWp installed in US\$		1900-2600	3000-3600

The major advantage of solar PV is the near elimination of all variable costs especially fuel costs. As solar modules are designed and mass-produced in standard sizes, their manufacturing cost can be kept at reasonable levels.

Most commercially available solar modules are designed to generate electricity for at least twenty years. The typical quality guarantee given by panel manufacturers is over 90% of rated output for the first 10 years, and over 80% for the second 10 years. However, modules can be expected to have a life period of up to 30 years under moderate climate conditions.

Energy payback time (EPBT) for PV modules is the time it takes to produce all the energy used in their life cycles. Currently EPBT is between six months to two years, depending on the location/solar irradiation and the technology.

Solar PV produces the least amount of greenhouse gases during operation. Furthermore, a solar PV power plant will displace fossil fuel used for power generation in conventional power plants, therefore reducing import dependence or releasing fossil fuels for other purposes. Under climate change regulation, this abatement effect on greenhouse gas emission can be monetized through carbon credit thereby providing an upside revenue.

Solar PV power is usually considered a “**must-run**” source of power. A solar PV plant has no capacity for energy storage by itself and hence cannot co-ordinate the output of electricity generation to match consumer demand.

Solar PV power is often considered a “**non-firm**” source of power. It is impossible to commit over a firm power generation output over a long period of time. In the power purchase agreement (PPA), it is accepted that the generation is lower than expected during a period of time provided that the plant may catch-up the generation deficit later. This is a typical “non-firm” deal, which is the standard deal for solar PV power plants. Solar PV plants usually generate more power during the dry season than in the rainy season. The solar radiation pattern and associated power generation is predictable to some extent on short term basis (day-ahead scheduling).

Environmental impact

Once a PV facility is constructed, the project produces no direct waste, and has a considerably lower output level of carbon dioxide emissions (CO₂) than fossil fuel power plants. The only carbon footprint is associated with the manufacturing of the equipment and the plant construction.

Total land area requirement for ground-mounted systems varies depending on the technology, the topography of the site, technical maintenance choices and location (latitude). Large-scale PV systems requirements range from about 1.7 to 5 hectares per MW.

Certain thin-film PV cells, such as Cadmium telluride (CdTe), contain toxic materials. If not handled and disposed of properly, these materials could trigger serious environmental or public health hazards. However, manufacturers have a strong financial incentive to ensure that these highly valuable and often rare materials are recycled rather than thrown away.

Pico-PV systems such as solar lanterns and solar home systems often use batteries that contain toxic materials. Most developing countries do not have adequate battery collection and recycling programs. This is a problem that needs to be addressed, as it could hamper the benefits that such systems bring.

For large-scale PV plants in arid zones, water is also needed to clean the panels from the dust.

Social impact

Solar PV systems have a significant positive impact especially in rural areas that are remote from the grid. The electricity helps improving people’s life style and if the capacity is sufficient for lighting and electrifying schools, hospitals and public utilities, the social services are also considerably improved.

Solar PV systems increase energy security and individual solar systems make people immune to (fuel) price hikes, fuel shortages, power cuts or inflation.

For large-scale PV plants, land management issues (especially ownership) need to be considered.

7. Organisational models

The different organisational models currently used in the world can be summarised in the table below (by generation from Go.0 to G2.3⁵):

Model	ownership	Control	Operation maintenance	Finance	Utility’s role
Go.0	End-user	End-user	End-user	End-user	Passive
G1.0	Third-party	End-user	Third-party	Third-party	Facilitator
G2.1	Third-party or end-user	Third-party or end-user	Third-party	Third-party	Facilitator and passive PV services buyer
G2.2	Third-party or end-user	Utility	Third-party	Third-party	Facilitator and active PV services buyer
G2.3	Utility	Utility	Utility	Utility	System integrator and services seller

8. Studies and time frames

Studies and investigations

The technical studies to be undertaken when developing a solar power plant project include:

Solar irradiation studies: collection from satellite data, local meteorological administration if existing, on site measurement and analysis of solar irradiation, rain falls, wind speed, temperature.

Assessment of the legal framework: what legal structure would be most appropriate and what are the local laws governing contracts, land titles, electricity sales, guarantees, etc. and how contracts can be upheld.

Geological investigation: soil properties under main civil works.

Geographic review: topographical survey, location plan with contour lines, project layout with contour lines, review of infrastructure facilities.

⁵ GX.Y = X for the level of generation of the model and Y of the option in the generation

Solar photovoltaic system design: PV modules arrangement, parallel, series, PV array angle, photovoltaic array spacing and calculation of grid connected PV system efficiency.

Power study: calculation of power generation and impact of the plant on the existing grid system.

Design of civil works: power house (plan, section), service roads.

Design of electrical equipment and specification data sheet: inverters, electrical control and SCADA (Supervisory Control and Data Acquisition), lightning protection and grounding, relay protection and metering, electric single line diagram (including protection and metering), 33 kV switch yard (plan and section), MV and LV cubicles, generator transformer and protection, station transformer, medium voltage line, metering system, station auxiliaries.

Operation tools: list of critical spare parts, list of tools.

Environmental and social impact assessment (EIA)

Economic analysis: costs estimates (bill of materials and costs data sheet), operating and maintenance costs, feed-in-tariff applicable and expected income, cost-benefit analysis.

Risk analysis: main risks and mitigation actions.

Time Frame

The implementation (up to commissioning of operations) of a solar PV scheme project depends of course on its dimension. There is a usual sequence of steps which can be broadly summarized as follows:

Step/Phase	Duration range	Main Activities/Method
Identification	1 to 3 months	On site reconnaissance, desk studies, data analysis
Pre-feasibility study	3 to 6 months	On site surveys, preliminary design and computations
Feasibility study (Including ESIA studies)	6 to 24 months	On site surveys, in situ tests, economic analysis, cost estimates, design development
Detailed design	6 to 12 months	Computations, modeling, bills of quantities
Tender documentation	3 to 6 months	Bidding documents, contracts models
Tendering/Bidding period (till award of contract)	3 to 6 months	Contractual and administrative documentation package
Mobilization of financing	9 to 18 months	Commitments of lenders and financing agreements
Implementation	6 to 18 months	Construction, commissioning

The durations in the above table are indicative only. Broadly for a totally new project, the duration from identification to commissioning can span from 2 years to more than 5 years in the worst case when phases are not achieved in due time, thus depending also on the size and complexity of the project.

9. Key questions

Market analysis

- Is there a national policy target in term of share of solar energy in the electricity mix and associated strategy? Is it implemented?
- Does the policy encourage the hybridisation of diesel generators supplying isolated grids?

Project development

- Is the project developer reliable? (Sufficient technical expertise in PV farms, financial solvency, experience in the country of intervention, access to financing)?
- Will the national regulation for this type of investment be applied?

Financial analysis

- Is the feed-in tariff acceptable for both parts (project developer and national utility) in term of price, duration, conditions (take or pay on committed energy production, pay per committed available capacity)?
- Is there any reduced tariff for seller's delivery below short term commitment (under generation) and buyer's acceptance below deemed generated energy (under acceptance)?
- Is the maintenance component of the tariff indexed on the price of labour and PV equipment?
- What impact will have the feed-in tariff on the national utility financial situation and the cost of electricity to the final consumers?
- What is the national grid capacity to absorb the new quantity of electricity produced?
- Is the PV project the least cost solution to electricity production?
- What will be the running costs of the PV power plant including the maintenance?

Economic analysis

- What is the impact of the project on the economic and incomes generating activities?
- What is the expected social impact on the beneficiary population (education, health)?
- What impact will have this PV power plant on the public finances?
- What will be the possibilities to use the electricity surplus (selling on the market, using it in industrial process such as desalination...)?

Organisations and business models

Is the business model chosen appropriate to the country?

Technology

- What will be the impact of new PV power plant on the grid?
- What measures will be taken to guarantee the grid stability? (Voltage and frequency)?
- Does it match with key technical benchmarks? (Expected production per kWp installed...)?
- Is the land required to build the plant available and what will be the impact on environment and agricultural products?
- How the after sale service and maintenance will be ensured?
- Is enough water available on the site to clean the PV modules?
- Is the selected site well sunned without shadow?

10. Useful references

RET Screen International's website on photovoltaic project analysis:

http://www.retscreen.net/ang/g_photo.php

Internet site on how to calculate PV module efficiency: <http://www.pveducation.org/pvcdrom/properties-of-sunlight/solar-radiation-on-tilted-surface>

http://ec.europa.eu/europeaid/what/economic-support/private-sector/documents/psd-communication-2014_en.pdf

UTE C-15-712-1 (2010): V electrical installations - Photovoltaic installations connected to the public distribution network

Draft IEC 62548 (82/646F/CDV 2011 and 82/743B/RVD 2012): Design requirements for photovoltaic (PV) arrays

Draft IEC 60364-7-712 (64/1843/CC 2012): Electrical installations of buildings – Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems

Solar radiation and photovoltaic electricity potential - country and regional maps for Africa

http://re.jrc.ec.europa.eu/pvgis/cmmaps/afr_new.htm

Solar radiation basics

<http://www.newport.com/Introduction-to-Solar-Radiation/411919/1033/content.aspx>

Šuri M., Huld T.A., Dunlop E.D. Ossenbrink H.A., 2007. Potential of solar electricity generation in the European Union member states and candidate countries. Solar Energy, 81, 1295–1305,

<http://re.jrc.ec.europa.eu/pvgis/>

SolarGis radiation maps end calculations: http://solargis.info/doc/pics/imaps_ghi1.jpg

Solar cell efficiencies: <http://www.solarplaza.com/top10-monocrystalline-cell-efficiency/>

Huld T., Müller R., Gambardella A., 2012. A new solar radiation database for estimating PV performance in Europe and Africa. Solar Energy, 86, 1803-1815

PVsys SA, Route du Bois-de-Bay 107, 1242 Satigny Switzerland, <http://www.pvsyst.com/en/>

Stuart Bowden, Christiana Honsberg, the Solar Power Labs at ASU,

Australia, <http://www.pveducation.org/pvcdrom>

<http://www.pvresources.com/>

ESTI PV laboratory <http://setis.ec.europa.eu/setis-magazine/solar-power/esti-research-facilities-help-develop-international-pv-standards>

Planning guides:

http://www.bre.co.uk/filelibrary/pdf/other_pdfs/KN5524_Planning_Guidance_reduced.pdf

Photovoltaics business models, L. Frantzis, S. Graham, R. Katofsky, and H. Sawyer, Navigant Consulting Inc. Burlington, Massachusetts, Subcontract Report NREL/SR-581-42304 February 2008

<http://www.nrel.gov/docs/fyo8osti/42304.pdf>

Price of PV solar module on the international market: <http://www.solarserver.com/service/pvx-spot-market-price-index-solar-pv-modules.html>

https://energypedia.info/images/4/41/SBC_Energy_Institute_Solar_PV_FactBook.pdf

Etude sur le montage de projets photovoltaïques en Afrique Sub-saharienne – AFD – RECP – Nodalix – Axenne – Mai

2013 <http://www.afd.fr/webdav/site/afd/shared/PORTAILS/SECTEURS/ENERGIE/pdf/RECP-synthese-solaire-PV-2013.pdf>