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Photovoltaic Power Stations (PVPS)

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Abstract

Qatar declared that by 2020 solar energy would produce at least 2

Index terms— Fresnel collector, and solar tower), photovoltaic (PV), and integrated solar combined cycle.

Figure **??** : Overview of Solar PV Power Plant, [1] Author ? ? ?: Qatar Environment and Energy Research Institute (QEERI) -Qatar Foundation, Doha, Qatar. e-mail: habdelrehem@qf.org.qa

The economy of PVPS is improving by time as shown Fig. **??**a, [2]; and solar cell production is increasing, Fig. **??**b, [3]. The capacity of the PVPS is on the rise worldwide, Fig. **??**a, [3] due to the decrease of PV cells' cost, Fig. **??**b, [4]. By the end of 2013, the installed capacity of PVPS reached 136 GW, see Fig. **??**a. The PVPS was rated the third in terms of capacity of the renewable energy power plants after hydro and wind in 2011, [3]. This capacity is almost doubled between 2011 to 2013 due to PV cells continuous falling costs and increasing cost of fossil fuel used in conventional power plants. It is estimated that solar module prices used in utility-scale sector (2.5 MW and above) would fall from 1.22 ?/W in 2012 to 0.92 ?/W in 2022, [5]. Module prices cost, are contineously deccreasing as shown in Fig. **??**b. A list of the countries having the highest PVPS capacity is given in Table **??**, **??**4].

Figure **??**a : Future PV Systems Evolution in Euro/W, [2]

1 J

Table **??** : Top 15 markets 2012 worldwide, [5] In Qatar, the advantages of using PVPS are clear. The primary solar energy (sunlight) is free and abundant, no moving parts and thus the needed maintenance is low, and low operating cost as no fuel is used. No water is required for operation except that needed for cleaning the panels. The decreasing cost of the PV modules lowers the capital cost and drives for installing more PVPS. The main factors hindering the spread of PVPS are still high capital cost, large needed site area, and the fact that the PVPS are not dispatchable plants. The site area of a PVPS having 15% efficiency and fixed tilt modules is about 10,000 m 2 /MW in tropic regions (23.5 degrees to the North and South of the Equator respectively); and up to 20,000 m 2 /MW in Northern Europe. One square kilometer site can be used for 50 MW. This area increased about 10% for a single axis tracker, and 20% for a 2-axis tracker to avoid shadow.

The largest cost of PVPS is still that for the modules, (accounts for about 50% of total cost), followed by costs of installation materials, labor, and the inverters. The inverters replacement cost can be significant. The PV modules warranty is generally about 20-25 years long; while, the inverters warranty is typically 10-15 years long. Improvements are rapidly achieved in many subsectors, [6].

Ratings of PVPS are usually given in terms of the solar arrays DC peak capacity in MWP, or nominal maximum AC output in MW or mega volt-amperes (MVA). Solar parks usually have medium capacity (1-20 MW), although there are large capacity operating PVPS in operation, and large plants capacity (up to one GW) are planned. The Agua Caliente solar project is now the largest operating PVPS with 290 MW in Yuma County, Arizona. Figure **??** The cost breakdown for a fixed-tilt utility-scale PV system utilizing crystalline-silicon (c-Si) modules is shown in Figs. **??**a-6c. Lower efficiency thin-film modules generally cost less but can have higher balance of plant (or non-module) expenses. This includes costs for supporting structures, DC cabling, and inverters.

The PVPS high cost and low load factorin comparison with conventional EP generation plants options are the main obstacles against the widespread of the PVPS. Factors that can improve the competitiveness of PVPS with other EP generating systems are:(a) cost reductions of solar cell modules, (b) growing concerns about energy security and climate change, and (c) continuous increase of the fossil fuels cost. Solar panel cost per watt have been falling steadily from $70/W in 1970 to $4/W in 2011, (this cost does not reflect the total system cost, which will vary widely based on the application.). However, the PVPS cost is still J e XIV Issue V Version I expensive compared to other power generation systems, [8]. The cost of the Gas Turbine Combined Cycle (GTCC) power plants that are commonly used in Qatar is low, in the range of $1.5/W compared with $5/W for the PVPS.

The National Renewable Energy Laboratory (NREL) in US, [9], conducted an analysis showed that the 2010 prices of PV systems in the US (cash purchase, before subsidy and considering reported target installer operating overhead and profit margins) are: The US showed great growth in solar power plants. Solar parks capable of delivering a total capacity of up to 750 MW are being planned or are already under construction in California, Arizona, New Mexico and Nevada.? $5.

In the hot summer in the GCC, the highest demands of EP occur in the afternoon when air conditioning machines in homes and public building are working at their highest capacity and solar power produces its maximum yields.

2 II.

Photovoltaic (pv) Power Plant Systemcomponent

The structure of a PV cell, as shown in Fig. 7a, has two semiconductor materials, the n-type that has extra electrons in a conduction band, and the p-type that has extra holes in a valence band. When photons of greater energy than the semiconductor band gap energy, Eg, see Fig. **??**b, are absorbed by the cell, the photons excite the electrons of the composite material into a higher state of energy. This allows the electrons separation from their atoms, drive electrons from the valence band to the conduction band. The movement of electrons is allowed in single direction by the nature of solar cell composition. Due to the electrons separation, positive charges are created (called holes) that flow in direction opposite of the released electrons, and this creates holes-electron pairs flowing in opposite directions across the junction, and act as charge carriers for a direct electric current. This process is called photovoltaic (PV) effect. The generated electron/hole pairs by the energy of the incident photons overcoming the energy band gap of the PV material to make a current flow according to the built-in potential slope, typically with a p-n junction of semiconductor, in the material. The freed electrons carried away by metal electrodes, and power is produced by connecting the electrodes to an external load. So, the operation of solar cells is based on the binding energy of electrons of a crystal. Two bands, called conduction and valence, can be totally or partially occupied by electrons, Fig. **??**b. Therefore, the PV cells consist of layered of semiconductors in contact with metal electrodes and covered by a protective transparent glazing. The semiconductor material used in cells is predominantly silicon because the band gap energy of silicon results in theoretical efficiency very near to the maximum for solar radiation. The maximum efficiency of a PV cell can be increased further if multiple semiconductor layers, or junctions, are stacked. In this case, the band gap of each layer is optimized for a different range of photon energies, thereby taking advantage of a greater range of the solar spectrum and improving the overall cell efficiency. A solar module consists of assembled and connected solar cells, and an array consists of assembled and connected solar modules. The array converts solar energy into a usable amount of direct current (DC) electricity.

3 a) Main Components

The main components in the PV power systems include:

i. Solar PV modules As given before, a PV module is combination of PV cells that produce direct electric current (DC) from sunlight with no moving parts.

Typical cells of 3W, 0.5 volts can be connected in series to produce summation of the 0.5 volts and power. When cell are connected in parallel, the output current will be the summation of current produced by the cells, but the voltage would be that of the cell. [10] When modules are connecting in series, high voltage can be obtained; and when connected in parallel, high current can be obtained. Figure **??**f : Modules forming a panel connected in series-parallel with center grounded to provide + and -supplies (fuses and diodes not shown), [10] Figure **??**a shows the current (I)-voltage (V) for a module at specific irradiance. It shows the short circuit current (I sc), open-circuit voltage (V oc) and the maximum power point (Imp; V mP), at which maximum power is attained. These three points are usually given by the PV cell manufacturers as shown for a typical PV module (KC200GT).

The I-V curves of modules are affected by the irradiance and temperatures as shown in Fig. **??**a and 8b, [11]. [11] Figure **??**c : The effect of irradiance on the I-V characteristics for typical module, [11] Global Journal of Researches in Engineering Figure **??**d : The effect of temperature on the I-V characteristics for typical module at 800 W/m irradiance, [11] Table **??** : Datasheet Parameters for KC200GT, [12] Irradiance 1000 W/m 2 800 W/m 2 ii. Inverters (or converters) Inverters convert the generated DC to alternative current (AC) in order to be connected to the utility grid. The modules are connected to the inverters through series strings and parallel strings. The PV systems connected to the grid normally do not have any real influence on the grid voltage. Their voltage operation range are therefore more of a protection function that is used for detecting abnormal utility, rather than regulators iii.

Step-up transformers Further step-up of the inverters voltage output to that required by the AC grid voltage (e.g. 25kV, 33kV, 38kV, 110kV depending on the grid connection point) is conducted by further step-up transformers; see Figure 9, [1].

4 iv. Module mounting (or tracking) systems

The modules should be attached to the ground. They can face the sun at fixed tilt angle, or they can be fixed to frames that track the sun. The substation and metering points are usually located outside the PVPS and typically located on the network operator's property. Connections to the grid network are of major concern when building PVPS in terms of the availability, locality, and capacity. This network should be able to absorb the maximum capacity of the PVSP. The PVPS may be sited at a distance (few kilo-meters) of a suitable grid connection point.

5 b) Photovoltaic Cell Materials

Most PV cells are manufactured from silicon (Si) that doped with negatively and positively charged semiconductors of phosphorous and boron. When sunlight is received by the PV cell, electrons become free to flow from the negative phosphorus to the positive boron. The produced DC is obtained through a metal grid covering the cell and external circuit. Besides crystalline silicon (c-Si), and amorphous silicon (a-Si) thin-film technologies, only cadmium telluride (CdTe) has had significant success in utility-scale solar development.

Silicon (Si) material can be mono-crystalline, poly-crystalline and amorphous silicon. Ribbon cast polycrystalline cells are also produced by drawing, through ribbons, flat thin films from molten silicon to reduce the silicon waste by sawing from ingots and thus reduces its cost. Other than silicon materials, gallium arsenide (GaAs), cadmium telluride (CdTe), copper indium diselenide (CIS) and copper indium gallium selenide (CIGS) are used in PV cells manufacturing.

Figure **??**0a : PV cells material Technology [13] Among the utility scale PV plants in the US, about 24.5% use CdTe, and 74.5% use c-Si, see Fig. 10b.An overview of the different main PV cells materials is given in Fig. **??**0. The mono-crystalline cells are made of pure silicon, have grey or black color, more efficient (16-24%) than the polycrystalline silicon (14-18%), see Table 3. Solar panel efficiency is the ratio of electric power produced by a PV module to the power of the sunlight striking the module.

The polycrystalline silicon cells are easier to be manufactured (to be sawed from ingots) and thus cheaper but less efficient than the mono-crystalline cells, and have shiny blue color. Amorphous silicon (so called thin-film) cells consist of non-crystallized very thin layers deposited onto a substrate, has brown or redbrown color, reddish brown, and typical efficiency of 4% to 10%, see Table 3.The power per unit area is typically 75-155 Wp/m for mono -crystalline and poly-crystalline modules, and 40-65 Wp/m2 for thin-film modules [13].

The other thin-film cells, other than the amorphous silicon, are Cadmium telluride (CdTe The characteristics of the cell material affect the cell performance, cost, and methods of manufacture, [3].

In 2010, 78% of the cells used PVPS were wafer-based crystalline silicon modules; and the percentage of amorphous silicon and cadmium telluride thin film modules was 22%. The solar cell materials are classified in Figure **??**, [1], and their main characteristics are given in Table 3, Table 3 shows that the cell efficiencies are in the range of 5-7% for amorphous, and 12-19% for the thick layers c-Si. The efficiency can reach up to 44.0% with multiple-junction concentrated photovoltaic, [3]. The performance of PV modules is degraded over time. High degradation occurs in the first year upon initial exposure to light and then it stabilizes. Degradation is mainly affected by used module characteristics. Irreversible light-induced degradation is suffered by c-Si modules due to the presence of boron, oxygen or other chemicals left after cells production. The so called Staebler-Wronski Effect, [15], degrades the amorphous silicon cells, and can cause 10-30% power output reductions in the first six months of exposure to light before stabilization with much less degradation rates. The performance of amorphous silicon cells after stabilization is usually given by the manufacturers. The performance of amorphous silicon is affected by temperature. The modules perform better in hot summer, and drop in cold winter.

Degradation can be caused also by environment effects such as air pollution, dis-coloring or haze of the lamination defects, humidity, and wiring degradation. Degradation can be reduced by regular maintenance and cleaning.

In general, long term of power output degradation rate ranges between 0.3 and 1% per year. Banks often assume a flat rate of degradation rate of 0.5% per annum, [15].In general, good quality PV modules may be expected to have a useful life of 25-30 years.

6 III.

7 Pv System Performance a) PV Cell and Module Ratings

The solar modules are compared with each other based on standard test conditions at normal irradiance rate of 1000 W/m 2 , cell temperature 25°C and Air Mass (AM)=1.5. The AM is corresponding of receiving surface at 37° tilt angle towards the equator facing the sun.

Solar insolation is the integration of irradiance over a specified time, usually day, year or an hour.

Therefore, the insolation has a unit of Watt-hours per square meter. The insolation is usually denoted by H is used for insolation for one day; I is used for insolation for an hour or year. The symbols H and I can represent beam, diffuse or global and can be on surfaces of any orientation. Solar radiation consists of beam (direct) radiation received from the sun without having been scattered by the atmosphere, and diffuse radiation received from the sun after its direction has been changed by scattering in the atmosphere. The sum of the beam and the diffuse solar radiation on a surface, global radiation, is often referred to as total solar radiation. The most common measurements of solar radiation are global radiation on a horizontal surface, referred to as global horizontal radiation.

Peak sun hour is the total number of hours of a day that can receive radiation; it is an equivalent form of insolation and most radiation data is represented using either of these units expressed as kWh/m 2 /day. The figure below shows the annual insolation map of the United States.

The performance ratio (PR) of the PVPS is defined as percentage ratio of the AC yield to the installed capacity in kWp multiplied by plane array irradiation in kWh/m 2 ,[1] It gives the yield to the maximum nominal output. The PR does not take in consideration the size or the solar resource. A PVPS of high PR converts solar energy to electric power efficiently, and can be achieved by well-designed solar PVPS and not operated in high temperature conditions. The PR of varies between 77% in summer to 82% in winter. Amorphous silicon modules in some PVPS show the opposite effect with high PR in hot summer and low PR in cold winter. Electrical losses decrease the PR, [10], see Table2.

Throughout the components of the system there are electrical losses, which de-rate the conversion from nameplate DC power rating to AC power rating (as explained in Table 4), [16]. Table 4 gives the losses due to the several system components.

. Table 4 notes that the overall DC-to-AC de-rate factor varies for different PV systems and applications. NREL's PVWatts tool incorporates a standard de-rate factor of 0.77 (or a 23% loss in output from nameplate DC rating to actual AC energy produced).

The load (or capacity) factor of a PVPS power plant (usually expressed in percentage) is the ratio of the actual output over a period of one year and the target yield (output if it had operated at nominal power the entire year), and is defined as:( ) CF 8760(/) ( ) = = ×

8 Annual Energy Generated kWh Actual yield E Target yield hours annum Installed Capacity kWp

Note that the target yield (dominator) is different from the annual sum of global irradiation, h, that hits the module, and it depends on the specific location. The value of h is to be obtained from measurements, or from an irradiance map, and its units is kWh/m 2 . The relation between the target a out and h is given by:

9 Target yield = ? norm h A

This gives = = ? ? ? ? pre rel sys norm

10 Actual yield E E Target yield h A

Where, ? ?????? = Nominal efficiency ? ?????? = Conversion efficiency ? ?????? = Relative efficiency ? ?????? = system efficiency The performance ratio is independent from the irradiation h and therefore it is useful to be used to compare systems. The specific final yield, Y f , (kWh/kWp) is the total annual energygenerated E in kWh divided by the nameplate DC power P0 of the installed modules capacity (kWp), i.e., Y f =E/Po. Another useful expression is the specific yield to the standard conditions of 1 kW/m 2 irradiance Y r . The reference yield Y r is the total in-plane irradiance H divided by the PV's reference irradiance G, i.e., Y r = H/G (hours). Therefore, Y r is the number of peak sun-hours or the solar radiation in units of kWh/m 2 . The performance ratio PR is the Y f divided by the Y r , i.e., PR= Y f /Y r (dimensionless).

Qatar annual global horizontal irradiation GHI are given as: 2055 kWh/m 2 (minimum), 2160 kWh/m 2 (maximum), 105 kWh/m 2 (range) and 2134 kWh/m 2 (mean), [17]. The fixed tilt PVPS capacity factor plant in sunny areas is about 16%. This means that a PVPS of 100 MWp plant would generate the equivalent energy of 17.7 MW by combined cycle (CC) having 90% CF.

11 b) Photovoltaic Power Station

The largest solar PVPS as of March 2014 are given in Table **??**.

Table **??** : Large-Scale Photovoltaic Power Plants, Ranking 1-50, [18] Power The PVPS can be divided based on its capacity, to mid-capacity station of less than50 MW, and large capacity plants of 50 MW or more. A NREL report issued in 2012 accounted for 56 PVPS of mid-size ranging from 5-48 MW each, and total capacity 589. V.

12 Power Conversion

Inverters are required to convert the DC power produced by the modules into AC, which can then be connected to the electrical grid. DC rating to actual AC energy produced. Inverters are solid-state electronic devices. Inverters can also perform a variety of functions to maximize the output of the plant. These range from optimizing the voltage across the strings and monitoring string performance to logging data, and providing protection and isolation in case of irregularities in the grid or with the PV modules.

Technological improvements are rapidly occurring in many subsectors. For example, microinverters can be paired with each PV module, in contrast to centralized inverters, which are paired with a bank of modules. Therefore, if a single micro-inverter fails, only the module paired to the failed inverter is affected, [6] There are two primary alternatives for configuring this conversion equipment; centralized inverter and string inverter, see Figure 11. Notes: Power is specified in MWp if DC array power is known. If DC array power is unknown then output power is specified. In some cases, it is unclear if the power is the output or DC array power. Sarnia power plant has AC power of 80 This power was also disclosed in press release. DC array peak power (97 MWp) is unofficial information and is based on personal communication. SolarparkSenftenberg I (18 MWp) was put into service in 2010 and constructed by Phoenix Solar and is a separated project not related to Senftenberg II and III. Last modified: 3/15/2014.

In central inverters,large numbers of modules are connected in series to form a high voltage string. Strings are then connected in parallel to the inverter, Figure **??**. Central inverter configuration is the first choice for many medium and large-scale solar PV plants. Central inverters offer high reliability and simplicity of installation. However, their disadvantages are: increased J e XIV Issue V Version I Photovoltaic Power Stations (PVPS) mismatch losses and absence of maximum power point tracking for each string. This may cause problems for arrays that have multiple tilt and orientation angles, suffer from shading, or use different module types.

Central inverters are usually three-phase and can include grid frequency transformers. The transformer's location in the Waldpolenz Solar Park, shown in Figure 12 is divided into blocks each with a centralized inverter.

String inverters are substantially lower in capacity, of the order of 10kW, and condition the output of a single array string. This is normally a whole, or part of, a row of solar arrays within the overall plant. String inverters can enhance the efficiency of solar parks, where different parts of the array are experiencing different levels of insolation, for example where arranged at different orientations, or closely packed to minimize site area. While numerous string inverters are required for a large plant, individual inverters are smaller and more easily maintained than a central inverter.

13 VI Ground Mounting

PV modules must be mounted on a structure to keep them correctly oriented and provides them with structural support and protection. The mounting structures may be either fixed or tracking. The fixed tilt mounting system is simpler, cheaper and has lower maintenance compared to than tracking systems. The tracking systems are more expensive and more complex, but can be cost-effective in locations with a high proportion of direct irradiation.

Most solar parks use ground mounted (sometimes called free-field or stand-alone) arrays. Land area required for solar parks varies depending on the location, and on the solar modules' efficiency, the slope of the site and the type of mounting used. Fixed tilt solar arrays using typical modules of about 15% efficiency on horizontal sites, need about 10,000 m 2 /MW.

14 a) Fixed Tilt

The solar panels in many PV stations are mounted on fixed structures, and thus have fixed inclination calculated to provide the optimum annual output profile, and is generally optimized for each PV power plant according to its location. This helps to maximize the total annual energy yield. These are normally oriented towards the Equator, at a tilt angle slightly less than the latitude of the site. Note that the tilt angle or "inclination angle" is the angle of the PV modules from the horizontal plane. The orientation angle or "azimuth" is the angle of the PV modules relative to south; East is -90° south is 0° and west is 90°.

Fixed tilt mounting systems are simpler, cheaper and have lower maintenance requirements than tracking systems. Frames to carry the PV panels are built first, and then the PV panels are fixed on the frame as shown in Figures 10a-10c, [

15 b) Seasonally Adjusted Tilt

As the majority of the solar energy is in the direct beam, maximizing collection requires the sun to be visible to the panels as long as possible. The tilt angle can be mechanically adjusted seasonally to optimize output in summer and winter. The angle is usually adjusted twice or four times per year. These require more land area to reduce internal shading at the steeper winter tilt angle. Because the increased output is typically only a few percent, it seldom justifies the increased cost and complexity of this design. Figure 11 shows the arrangement of seasonally adjusted PV panels in photovoltaic power plant near Alamosa, Colorado. In this plant, the 82-acre tract site is one of the largest PV in the US. The Alamosa Photovoltaic Plant, which went on-line in December 2007, and generates about 8.2 megawatts of power. Having the direct (beam) radiation, main part of the global radiation, perpendicular on the PV panel surface as much as possible maximizes the energy collected and thus the yield. The main factor affected the energy contributed by the direct beam is the cosine angle between the incoming light and the panel (angle i). The power lost due to deviation of this angle is given in Table 6, and Fig. 15. Trackers with accuracies of $\pm$ 5° can deliver greater than 99.6% of the energy delivered by the direct beam plus 100% of the diffuse light. Thus, high accuracy tracking is not usually used in nonconcentrating PV applications. Tracking will always result in a higher energy yield. The amount of the boost however is very much dependent on the location. Generally, locations with a higher proportion of direct sunlight will benefit more from tracking than locations with a high proportion of diffuse light such as Germany, see Table 4. Tracking increases the performance ratio of a system. It also results in higher yields for the inverter. Dual-axis tracking systems increase the average total annual irradiation in locations with a high proportion of direct irradiation. Tracking systems follow the sun as it moves. Orienting the solar panels to be normal to the sun's rays maximizes the intensity of incoming direct radiation. The two axis tracking system enables tracking the sun in its daily orbit across the sky, and as its elevation changes throughout the year. The arrays have to be spaced out to reduce inter-shading as the sun moves and the array orientations change. So, it needs more land area. The maximum increased output can be of the order of 30% in locations with high levels of direct radiation, but the increase is lower in temperate climates or when diffuse radiation is significant, due to overcast conditions. Schematic increase of power output due to the use of dual axis tracking is shown in Figure 12.

Tracking systems are generally the only moving parts employed in a PV power plant. Single-axis trackers either alter the orientation or tilt angle only, while dualaxis tracking systems alter both orientation and tilt angle. Dual-axis tracking systems are able to track the sun more precisely than single-axis systems. Depending on the site and precise characteristics of the solar irradiation, trackers may increase the annual energy yield by up to 27% for single-axis and 37% for dual-axis trackers. Tracking also produces a smoother power output plateau, as shown in Figure 15. This helps meet peak demand in afternoons, which is common in hot climates due to the use of air conditioning units. Tracking the sun in one dimension can achieves some of the output benefits of tracking, with a less penalty in terms of land area, capital, and operating cost. A single axis tracker with roughly 20 degree tilt at Nellis Air Force Base in Nevada, USA is shown in Figure 14.

16 Economy of pvps a) Levelized Cost of Energy (LEC) of Solar PV Systems

The levelized cost of energy (LEC) of solar PV systems reflects the price at which energy must be sold to break even over the assumed economic life of the system. In other words, it is the cost incurred to install and maintain an energy-producing system divided by the energy the system will produce over its lifetime of operation: LEC = Life time energy cost/ Life time energy generation This equation yields a net present value in the familiar cents per kilowatt-hour (kWh) of electricity generated. This is an assessment of the economic lifetime energy cost and energy production and can be applied to essentially any energy technology. It is frequently used to evaluate a technology or energy system against electricity purchased from the grid. The LEC equation takes into account system costs, as well as factors including financing, insurance, operations and maintenance (O&M), depreciation and any applicable incentives. Installed costs are a primary driver for solar PV systems as they lack fuel costs and require minimal O&M.

By knowing that the EP produced by PVPS is higher than the EP retail price, it is required to identify if and when the declining LEC of solar PV intersects with the increasing retail electricity prices. The term frequently used to describe this intersection is ”grid parity”. The installed cost of solar PV systems is the largest component of the LEC.

The installed price of utility-scale systems varies significantly across projects. In the US, among 49 projects completed in 2011, for example, installed prices ranged from$2.4/W to $6.3/W, reflecting the wide variation in project size (from 2 MW to 35 MW), differences in system configurations (e.g., fixed-tilt vs. tracking and thin-film vs. crystalline modules), and the unique characteristics of individual projects, **??**20]. It is noticed that for very large PVPS plant of 187.5 MWP DC one-axis utility-scale ground mount, the estimated cost was $4.40/WP DC, or $ 5.9/W (by considering 0.75 De-rate Factor from DC to AC). So, for Qatar and 50 MW plant in Qatar if 20% increase is assumed the price would be $7.04, and the plant will cost 352 million (M). In another study for India, 169 Indian Rupee ($3)/W were reported. Again, if this for peak DC, and by considering 0.75 De-rate Factor from DC to AC it would be $4/W, **??**1].

A study to calculate the LEC by North Carolina State University indicated that for 10 MW plant made the following assumptions: the installed cost is $3.75 -$5/W, economic life of system is 20 years, fixed operation and maintenance is $50-65 kW/year, capacity factor 15-28%, the LEC is $0.24-0.46/kWh, [21]. The cost breakdown was given in Fig. 18. The utility in Qatar is acting as contractual intermediary agent between the power producer and the customers. The owner of the power plant sells power output from the plant (it is solar PV system here) to the utility, which, in turn, sells the power back to the site host/end-user. This arrangement protect consumers (rates and reliability) and to ensure a highly functioning electric grid. By having a single entity control the system, a utility can balance constantly changing supply and demand to ensure reliability and keep the electricity flow on the grid optimized and safe. The string wiring is shown as follows:

The tracking and orientation are given as:

17 Conclusions

The technology and economics of the PV power station is presented in this paper. The main components of the PV power plants including the solar PV modules, module mounting and tracking systems, inverters (or converters), and step-up transformers was outlined. It reviews the materials of the PV cells, the PV cells

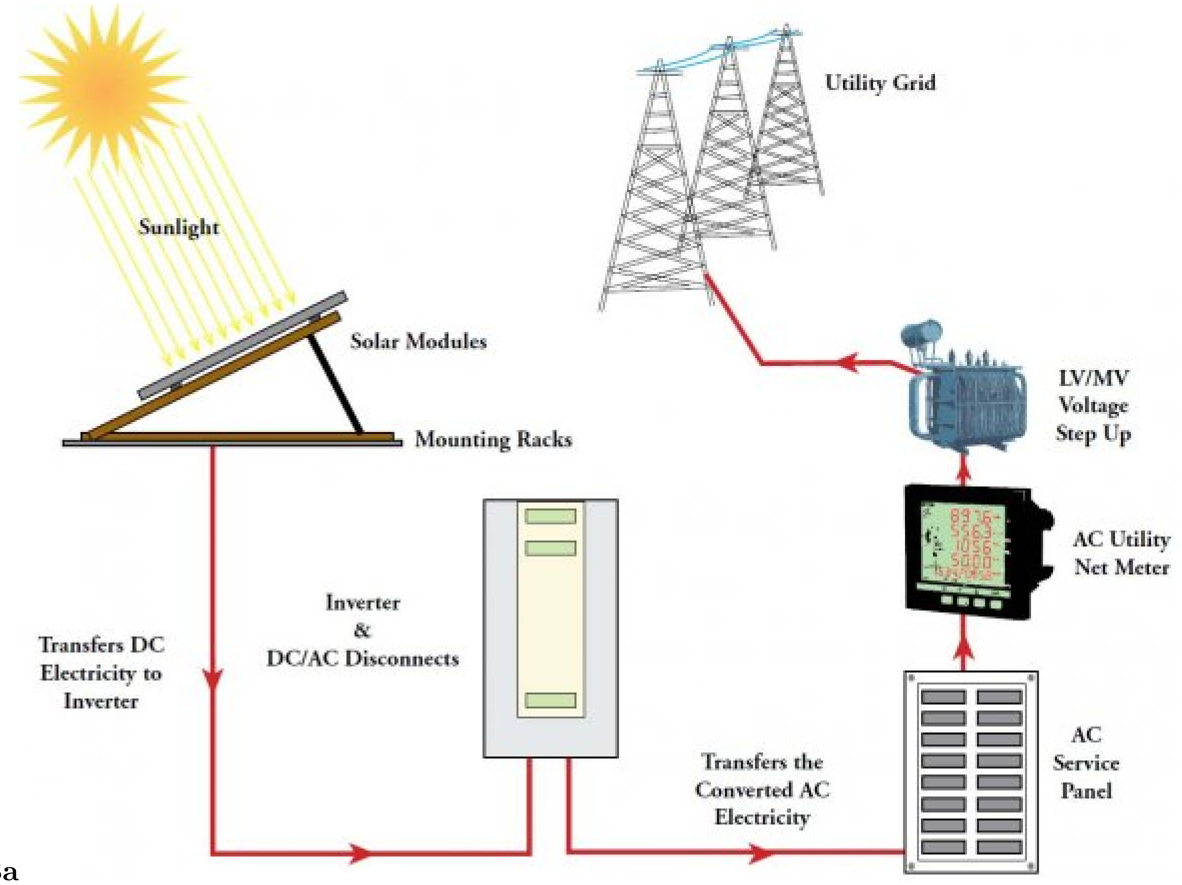
The itemized capital cost is given as: [1] [2] [3]

Figure 1:

[1] © 2014 Global Journals Inc. (US)

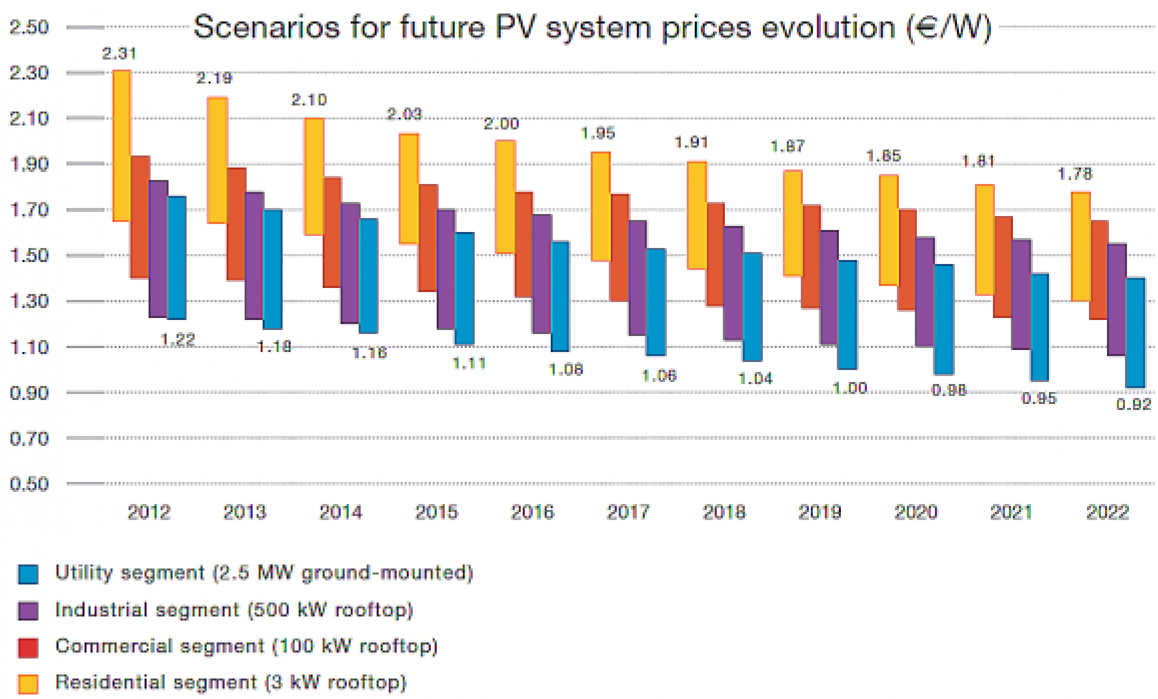
[2] Photovoltaic Power Stations (PVPS)

[3] © 2014 Global Journals Inc. (US)Global Journal of Researches in Engineering



2b3a

Figure 2: Figure 2b :Figure 3a :



3b3

Figure 3: Figure 3b : 3

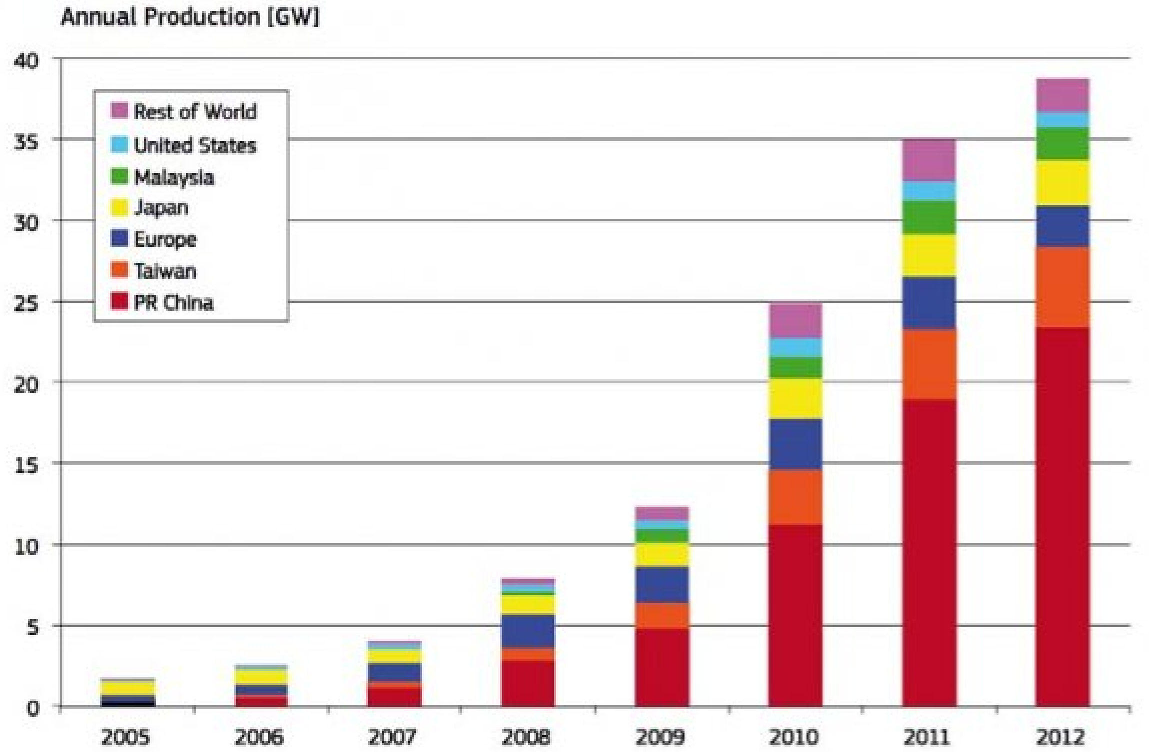


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Figure 4: Figure 5 : 5 2014 J

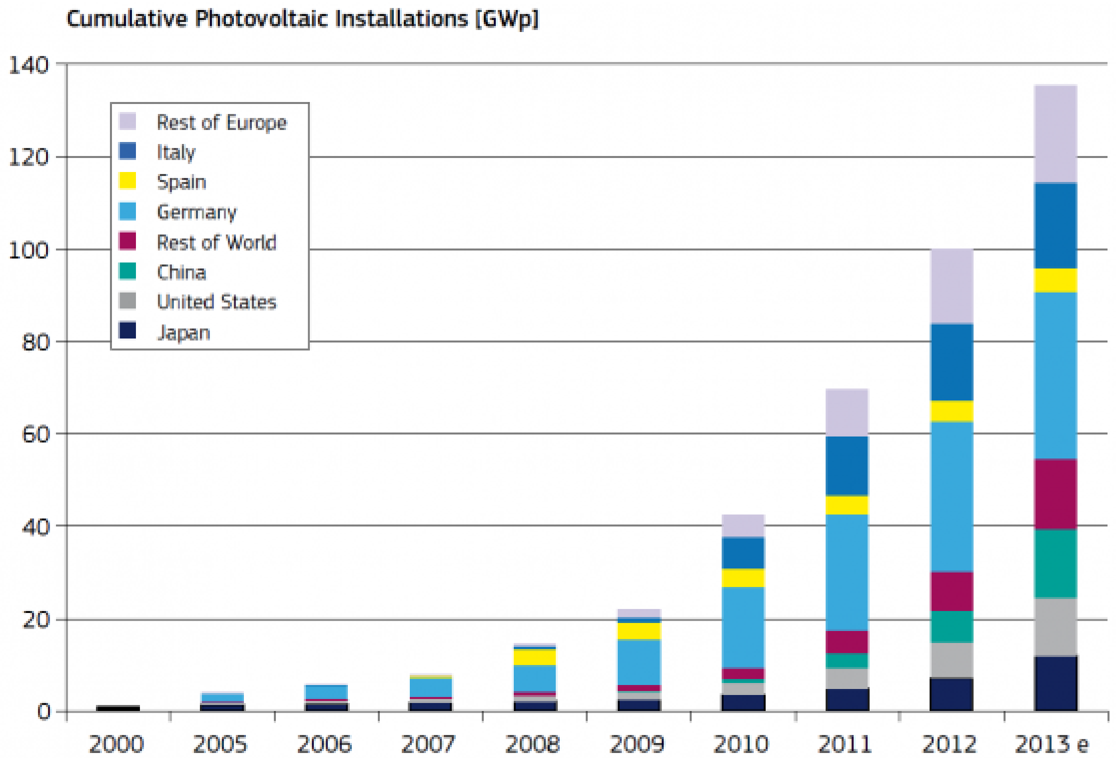
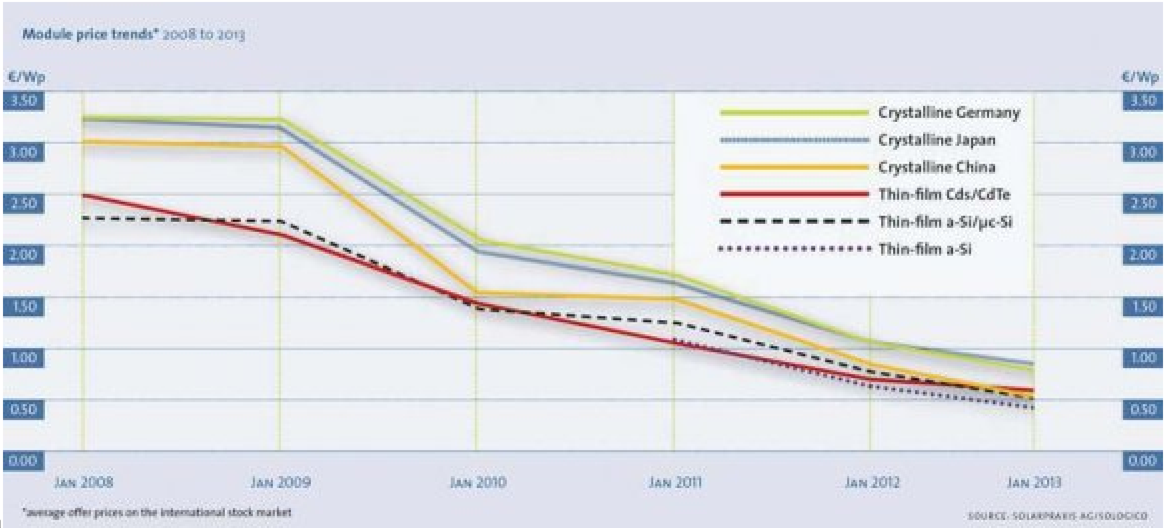


Figure 5:



7a

Figure 6: Figure 7a :

	COUNTRY	2012 NEWLY CONNECTED CAPACITY (MW)	2012 CUMULATIVE INSTALLED CAPACITY (MW)
1	Germany	7,604	32,411
2	China	5,000	8,300
3	Italy	3,438	16,361
4	USA	3,346	7,777
5	Japan	2,000	6,914
6	France	1,079	4,003
7	Australia	1,000	2,412
8	India	980	1,205
9	United Kingdom	952	1,829
10	Greece	912	1,536
11	Bulgaria	767	908
12	Belgium	599	2,650
13	Spain	276	5,166
14	Canada	268	765
15	Ukraine	182	373
	Rest of the World	2,692	9,546
	Total	31,095	102,156

7c7d

Figure 7: Figure 7c :Figure 7d :

7e92014 

Figure 8: Figure 7e : 9 2014 J

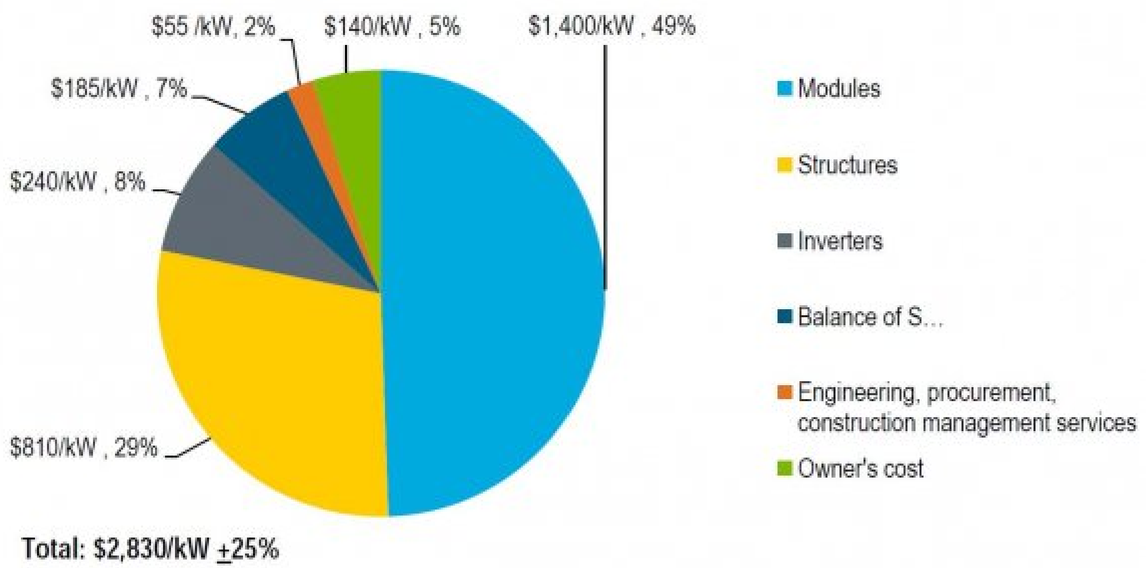
8a8b 

Figure 9: Figure 8a :Figure 8b :

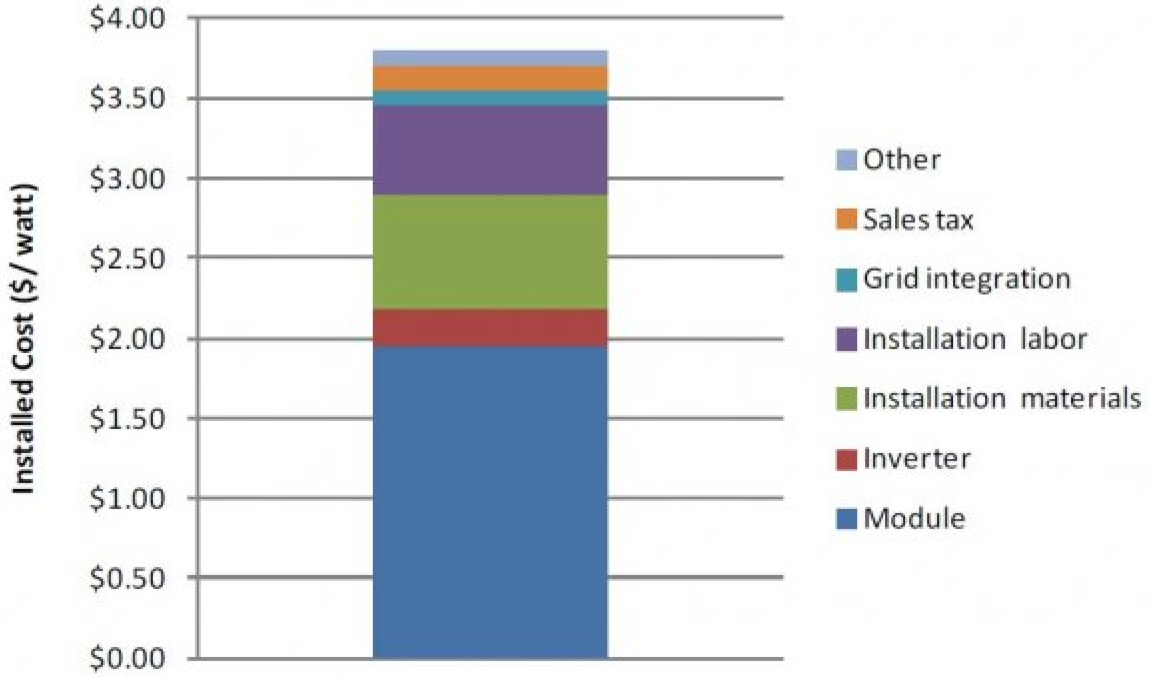


Figure 10: (

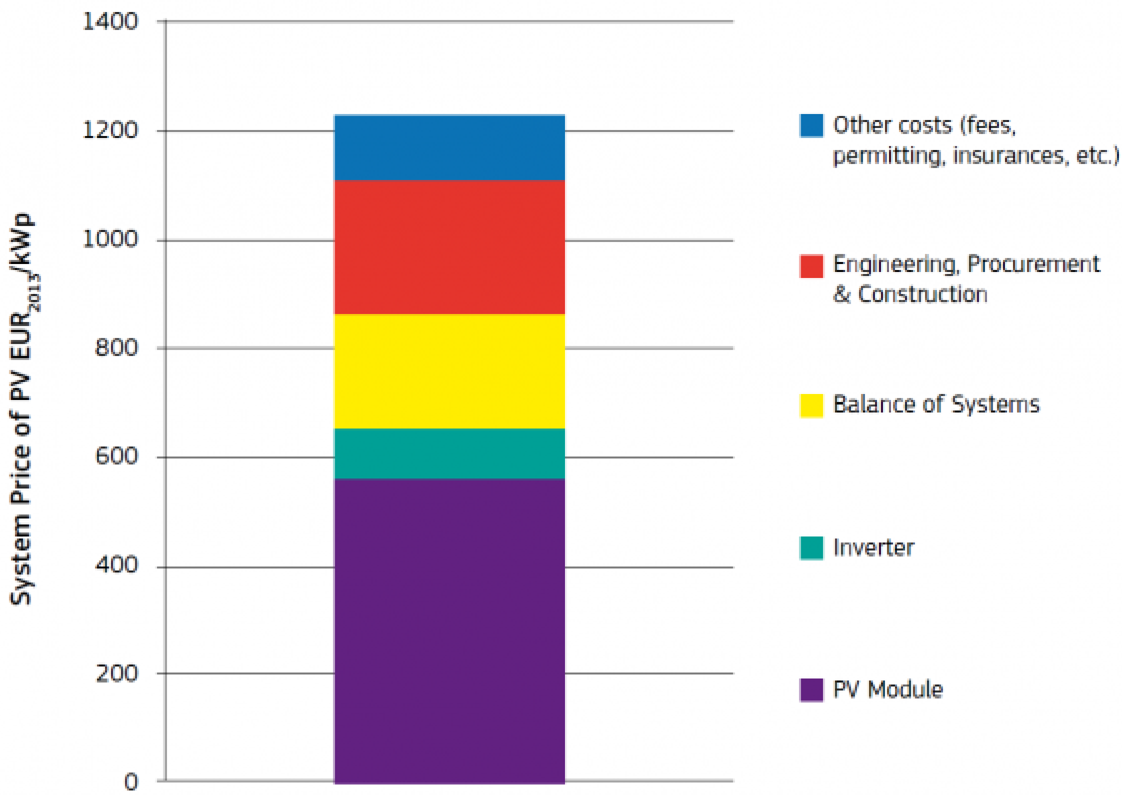
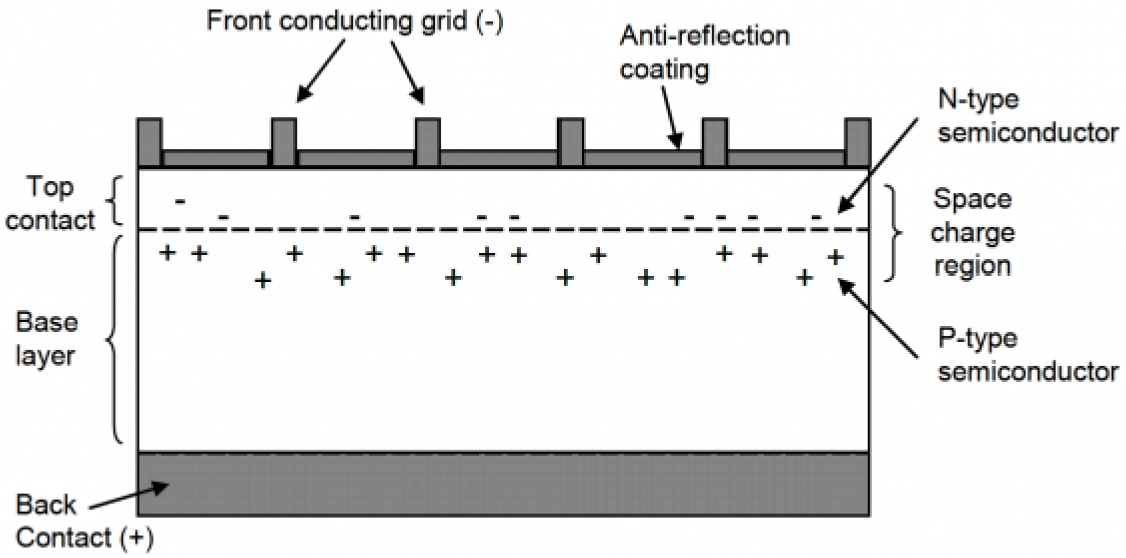
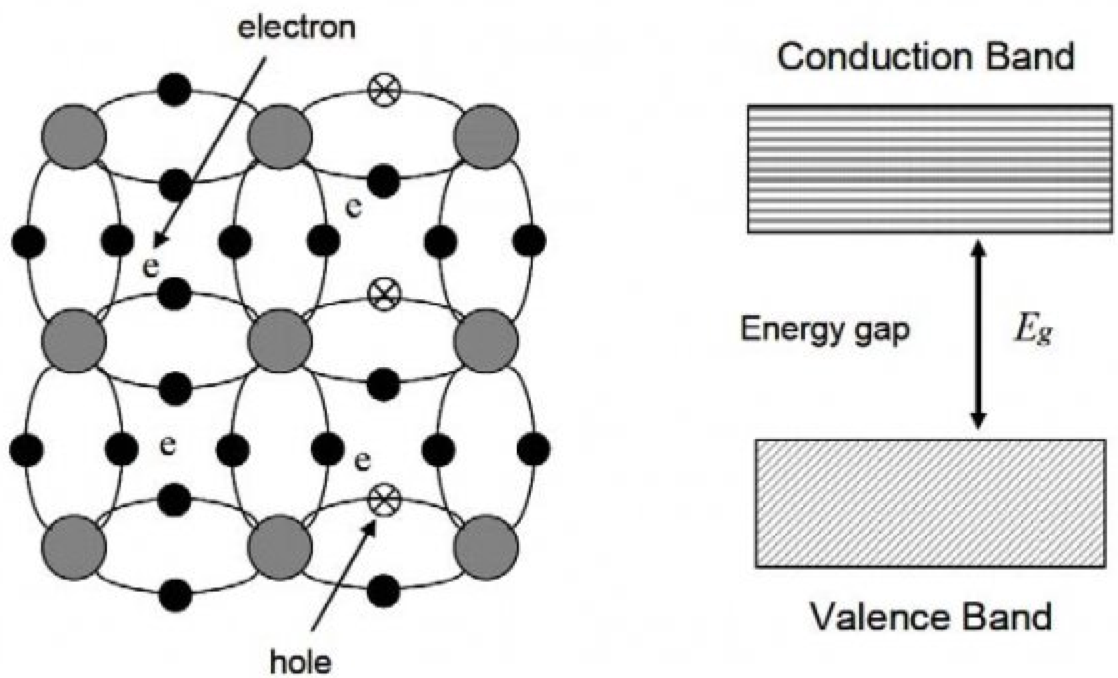


Figure 11:



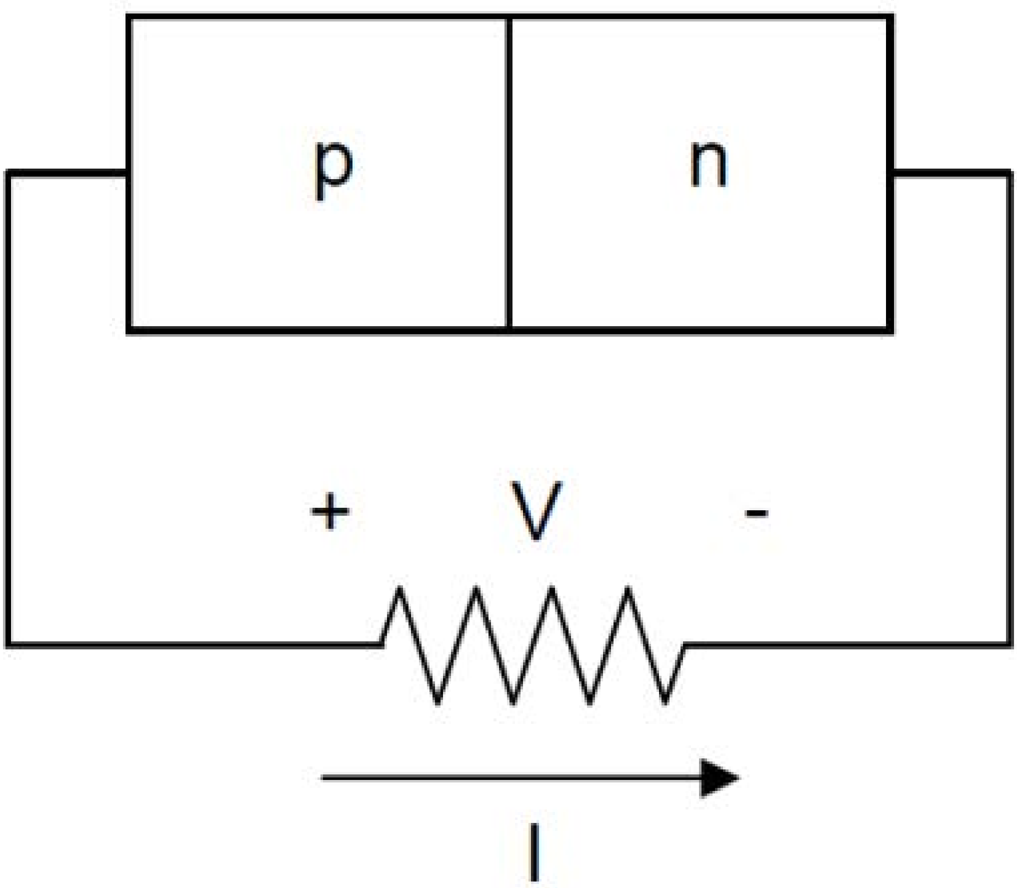
9

Figure 12: Figure 9 :



10b

Figure 13: Fig. 10b :



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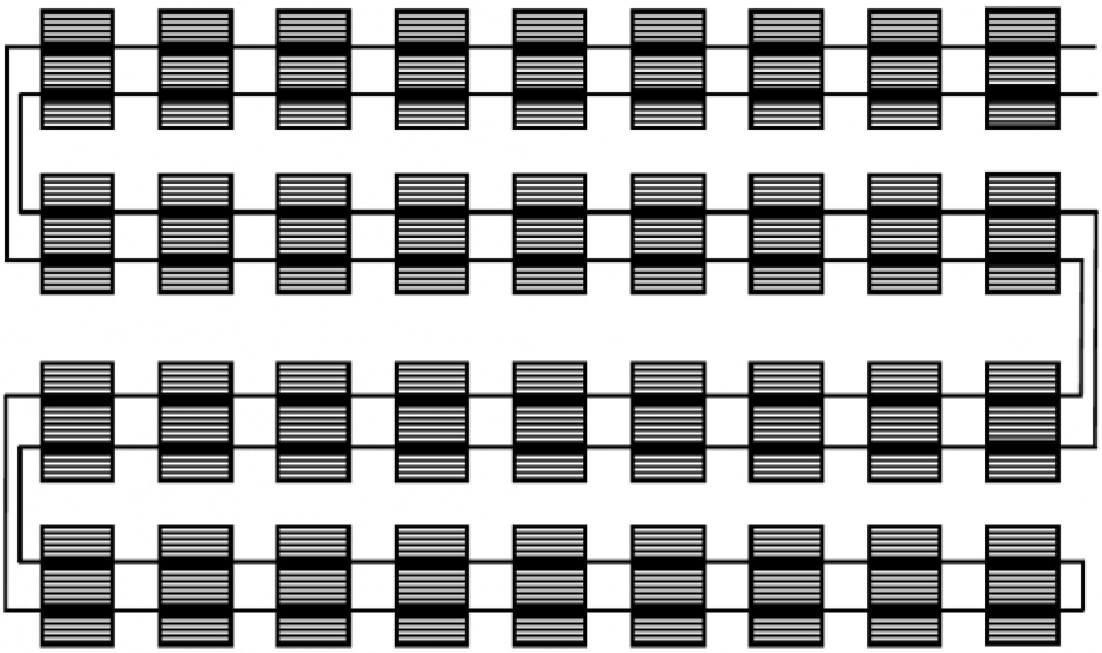
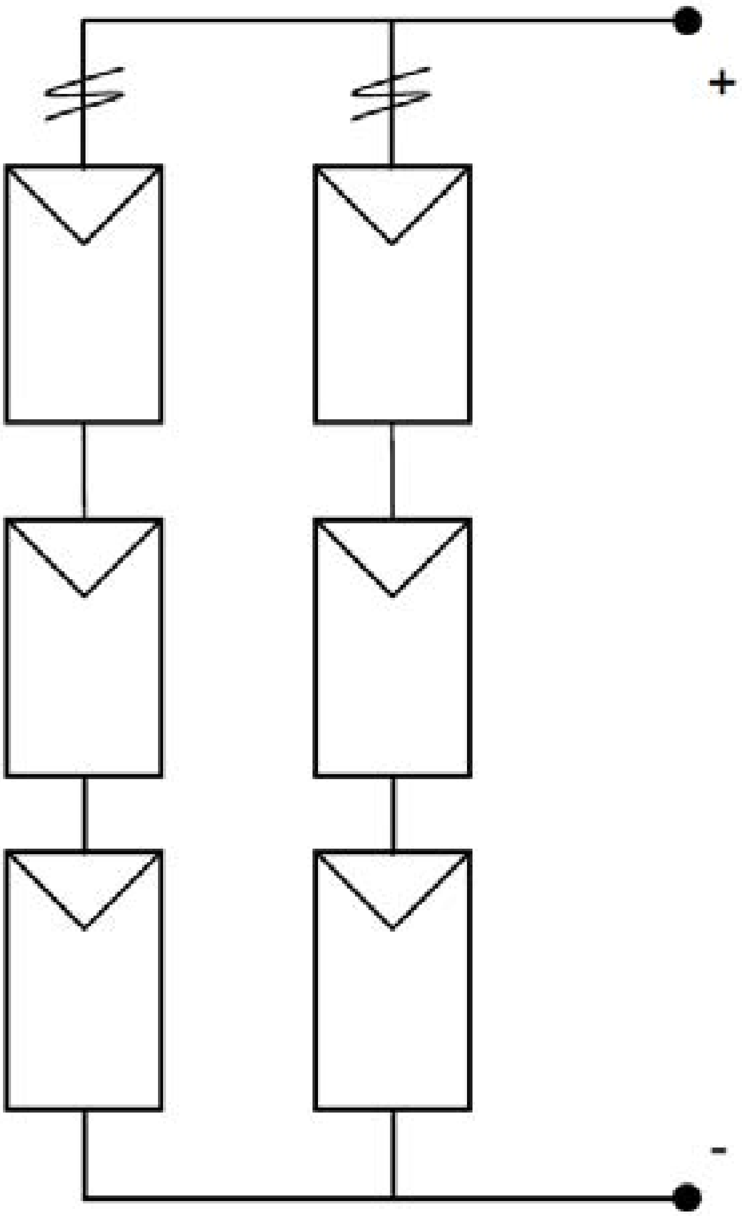


10c

Figure 15: Figure 10c :



10d

Figure 16: Figure 10d :

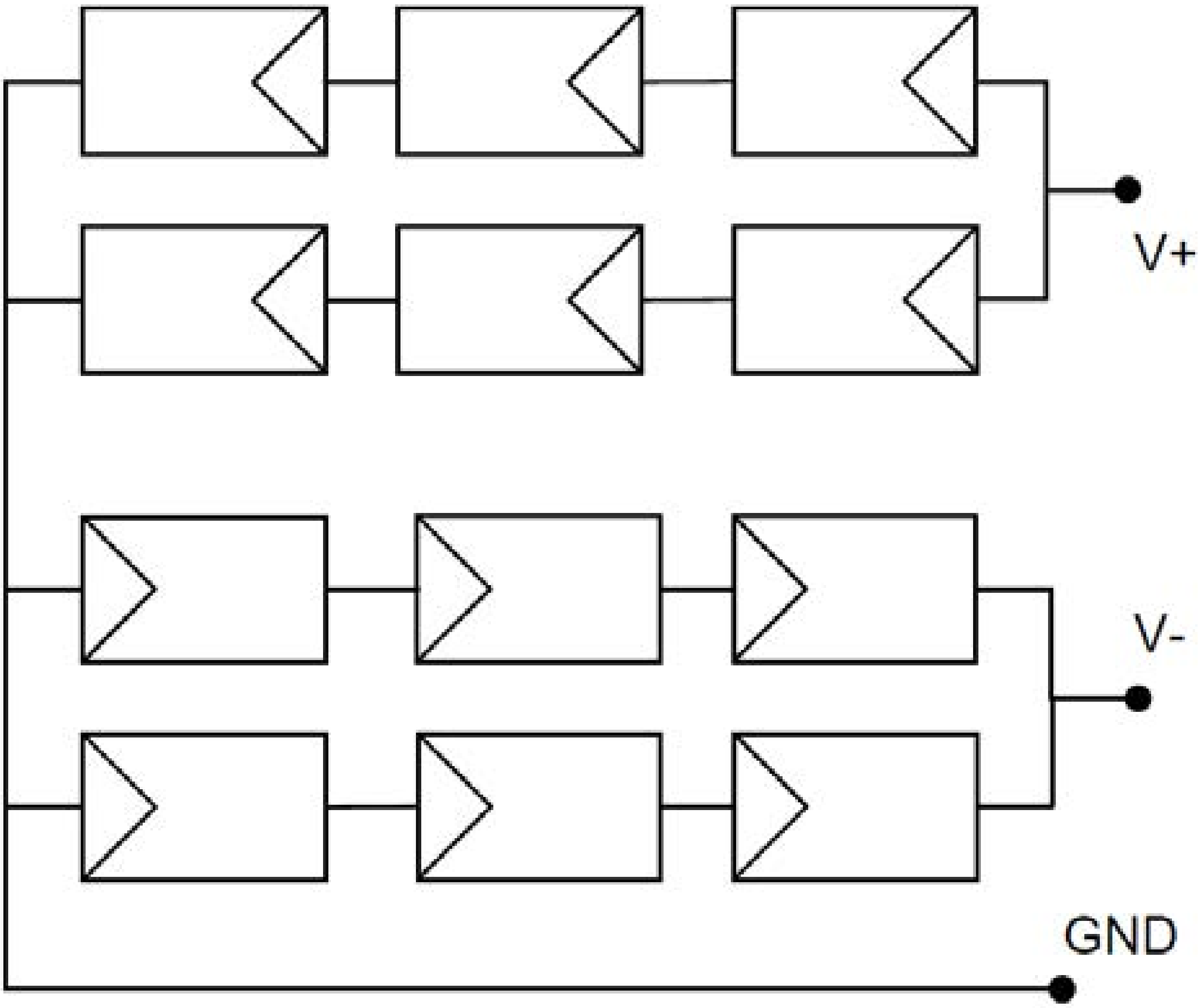


Figure 17:

10b

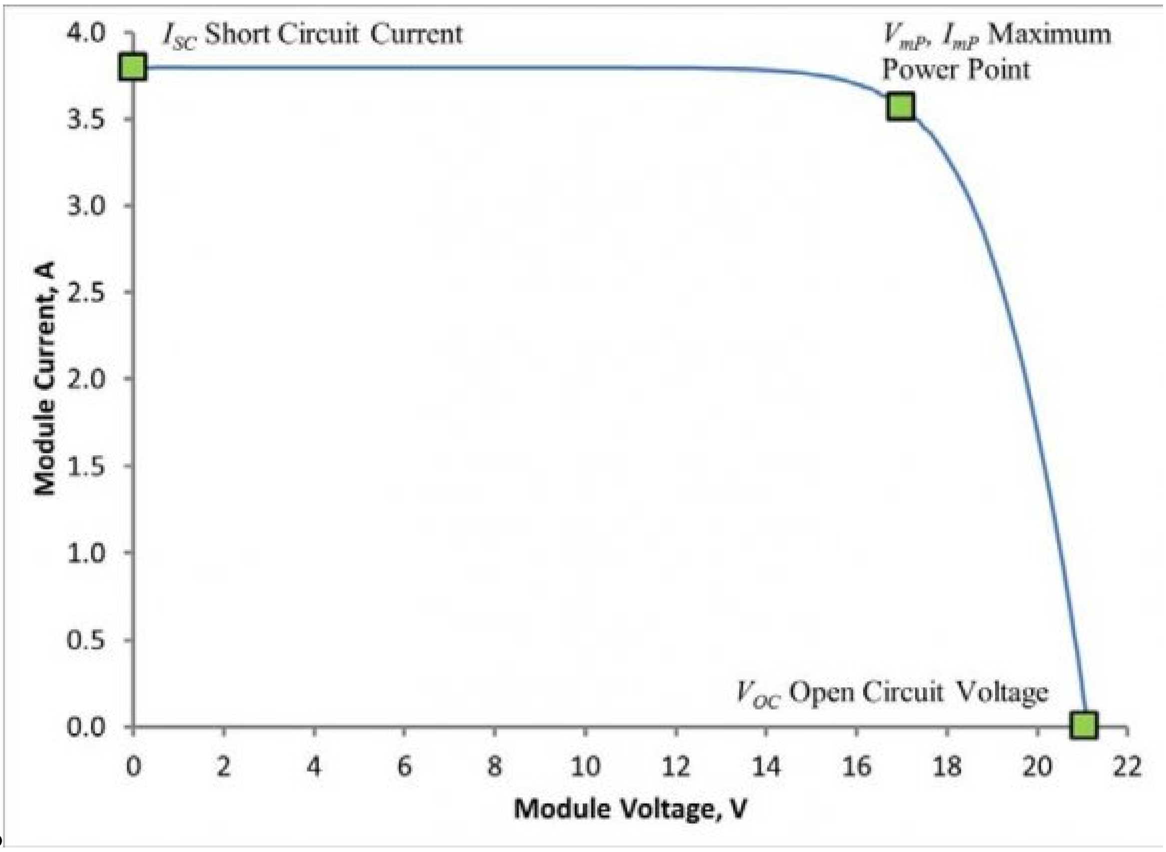


Figure 18: Figure 10b :

10e

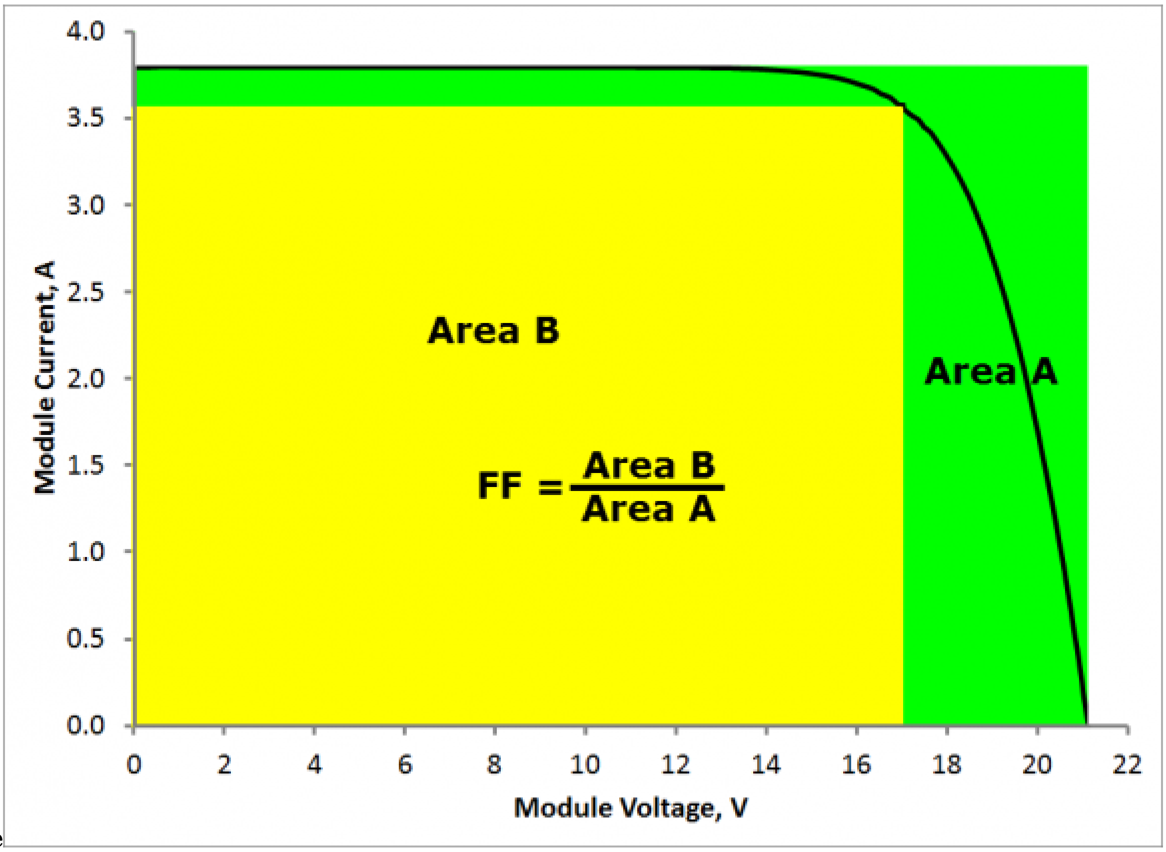
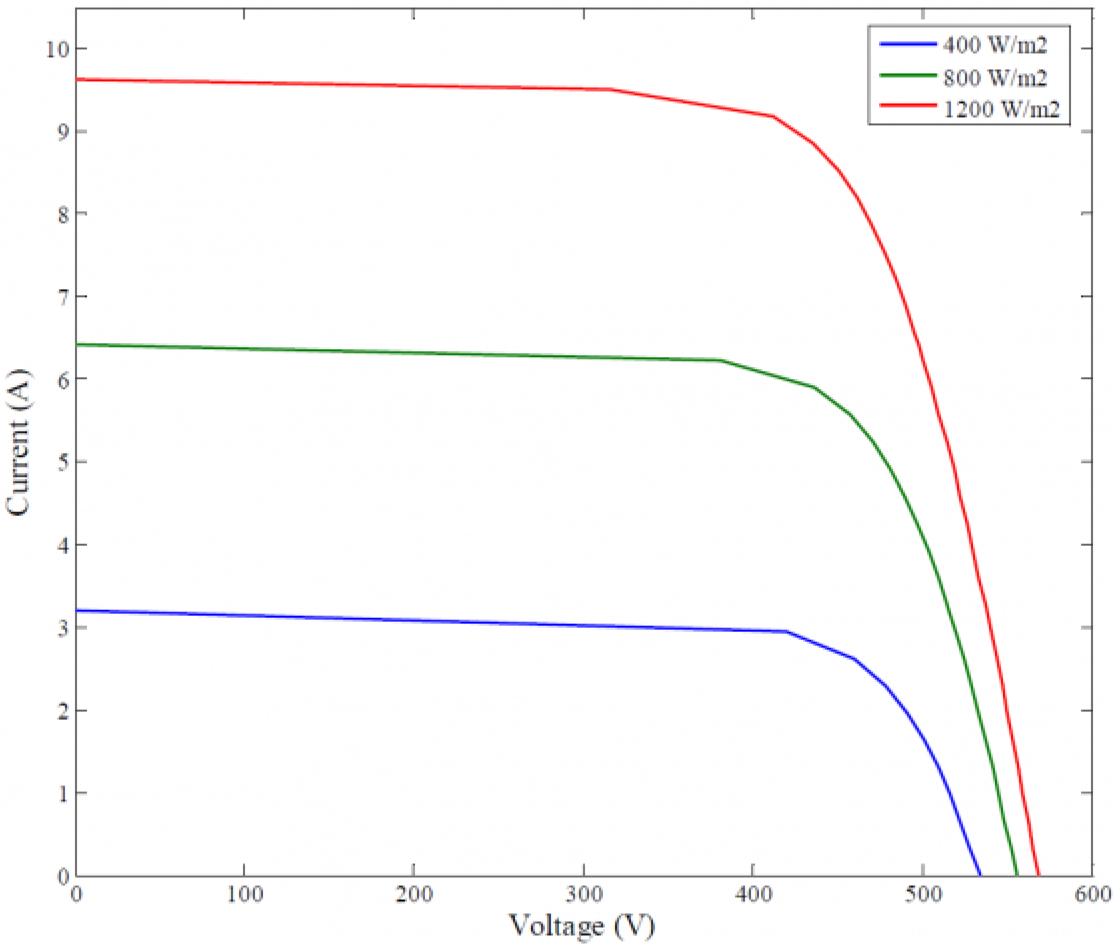


Figure 19: Fig. 10e :



10
9
8
7
6
5
4
3
2
1
0
Current (A)
0
100
200
300
400
500
600
Voltage (V)
400 W/m2
800 W/m2
1200 W/m2

Figure 20:

11

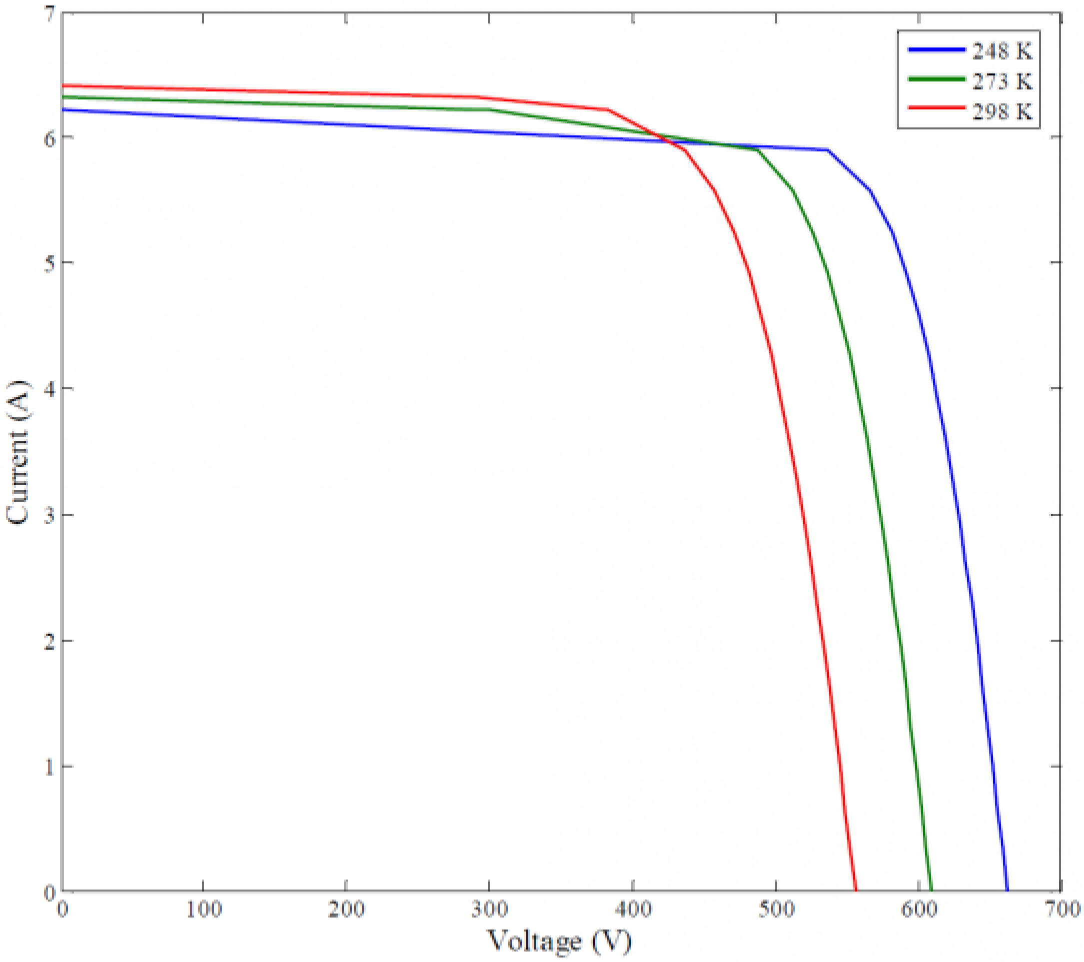
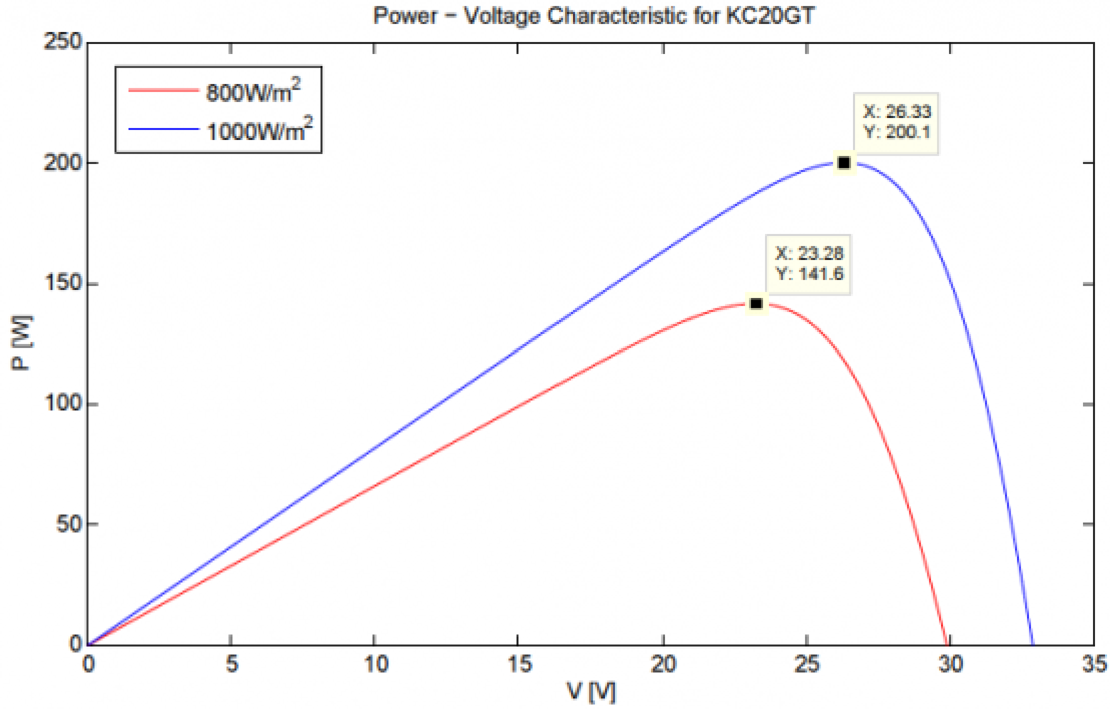


Figure 21: Figure 11 :



12

Figure 22: Figure 12 :

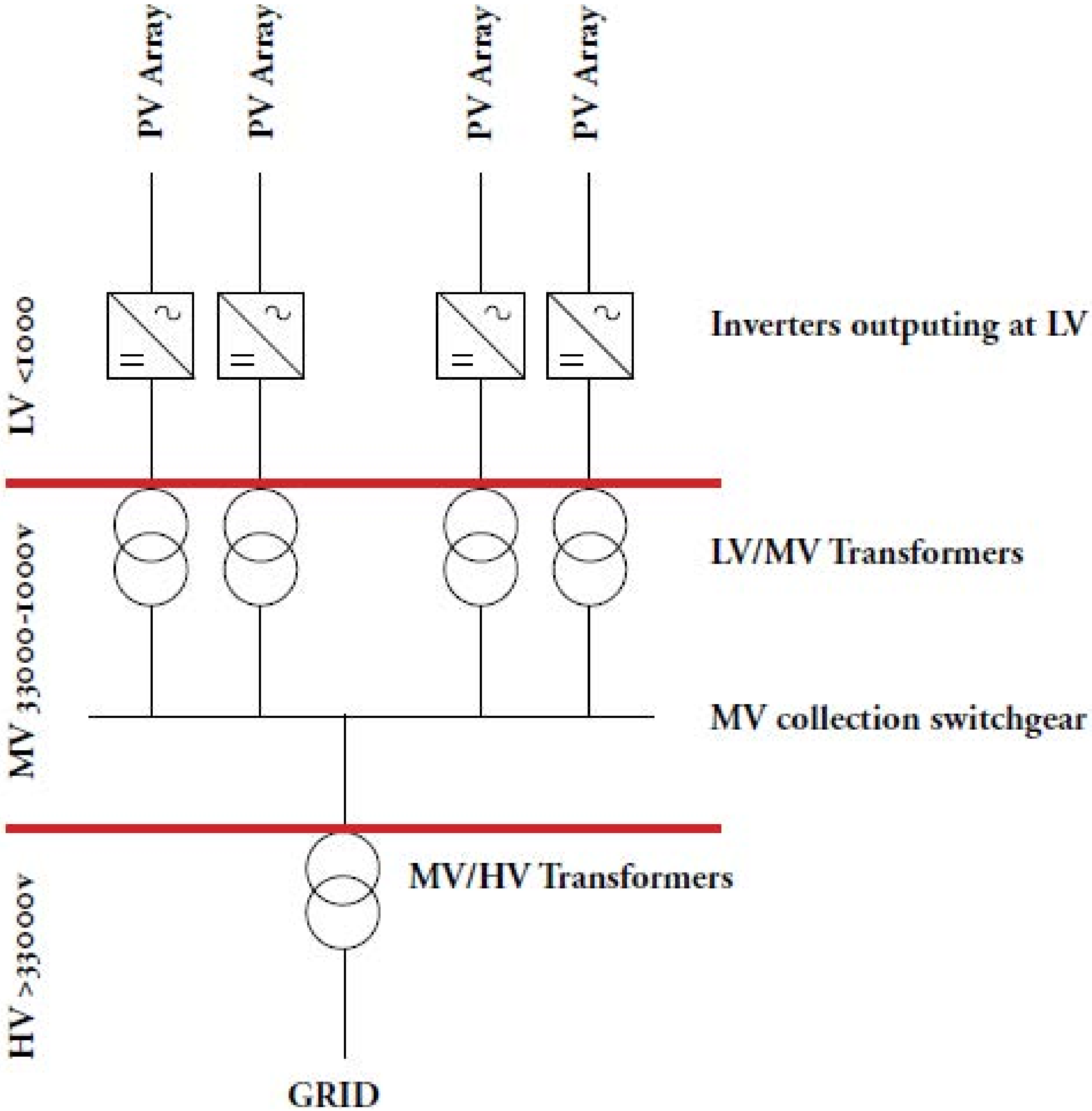

PV Array
PV Array
PV Array
PV Array
LV <1000
Inverters outputing at LV
MV 33000-1000V
LV/MV Transformers
MV collection switchgear
HV >33000V
MV/HV Transformers
GRID

Figure 23:

14

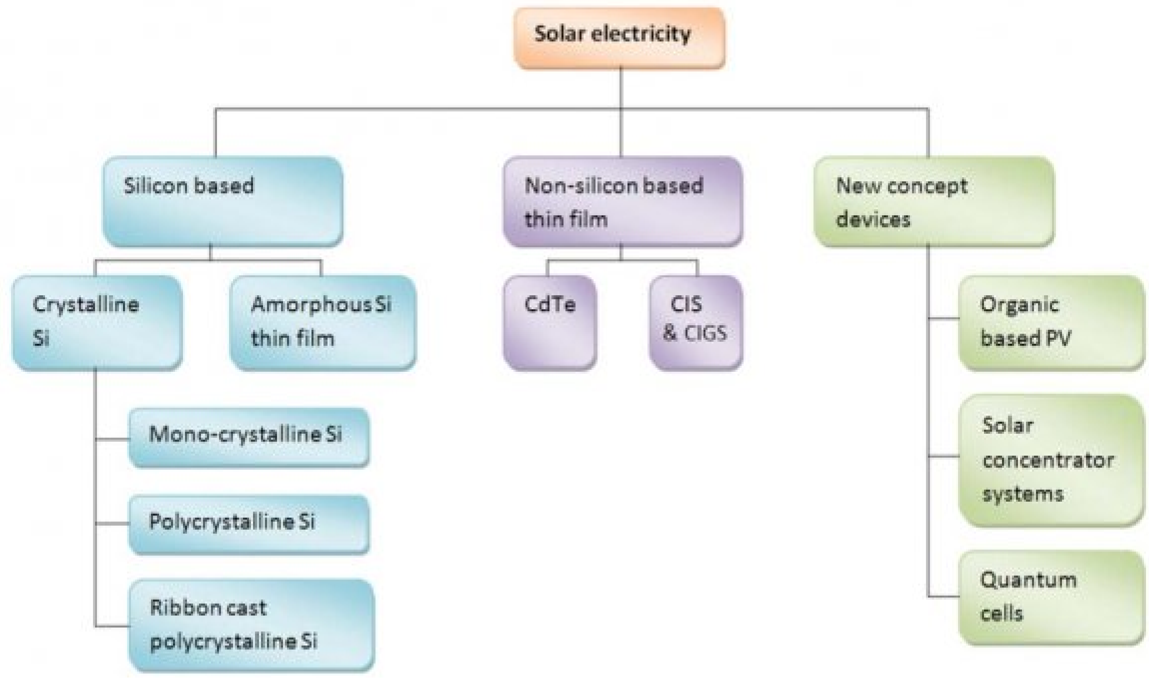


Figure 24: Figure 14 :

15

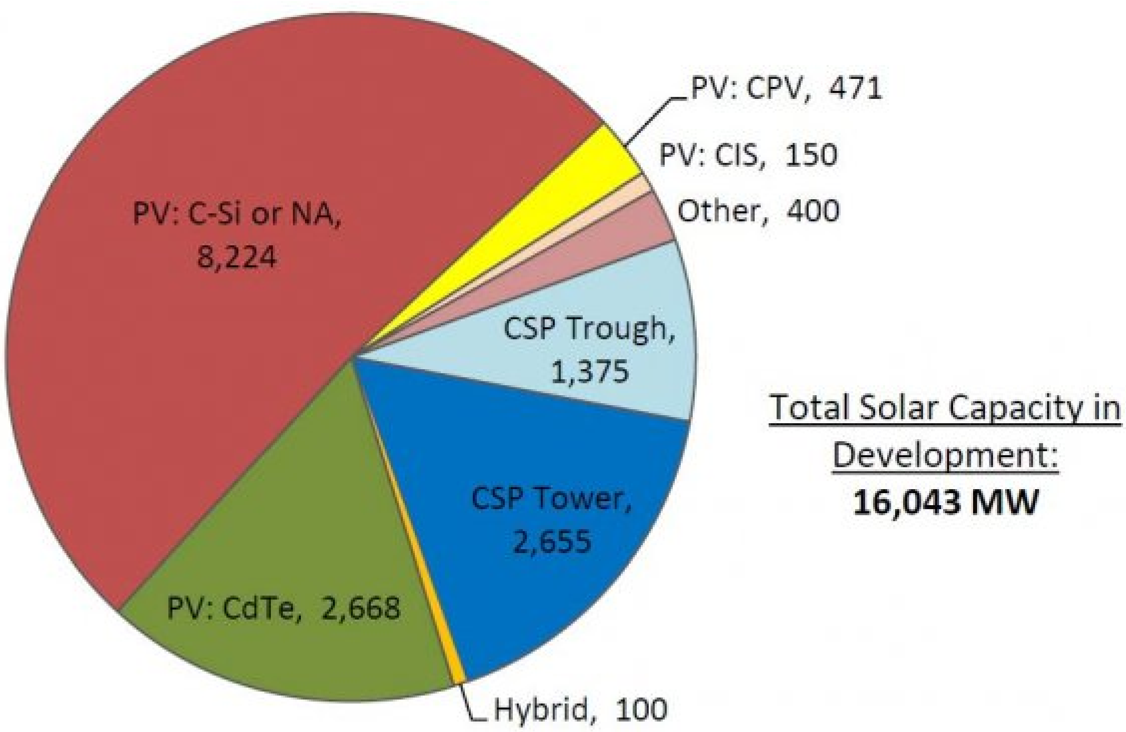
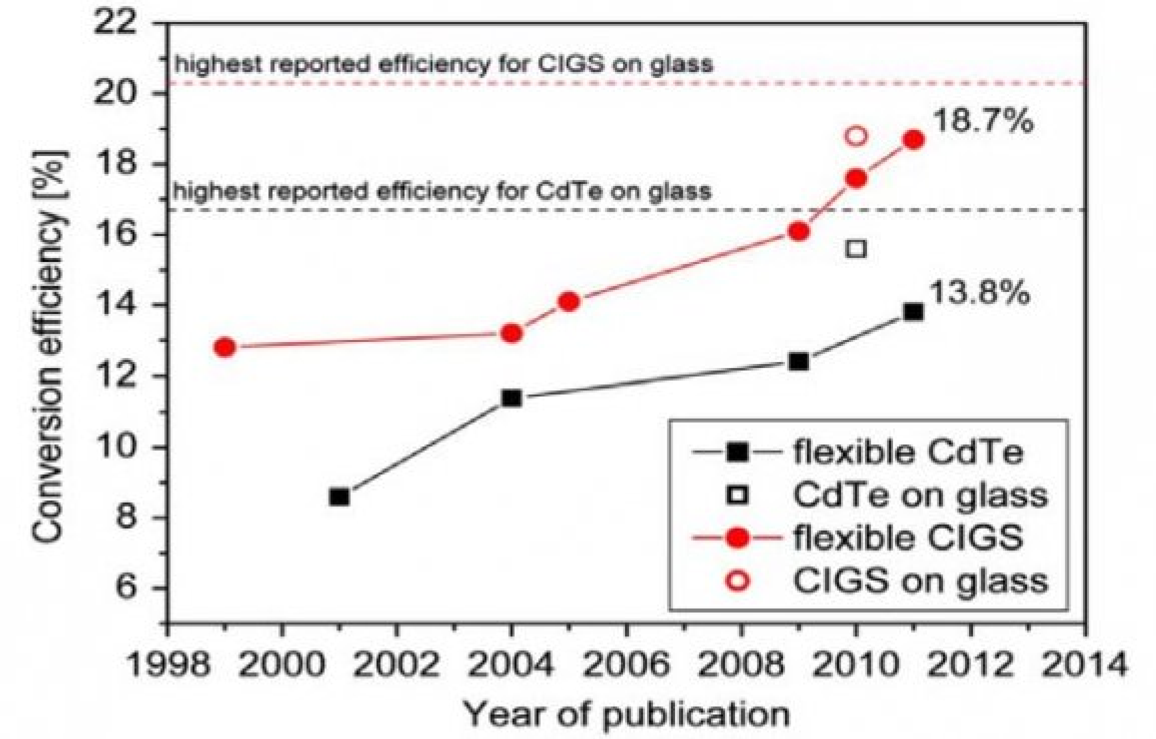
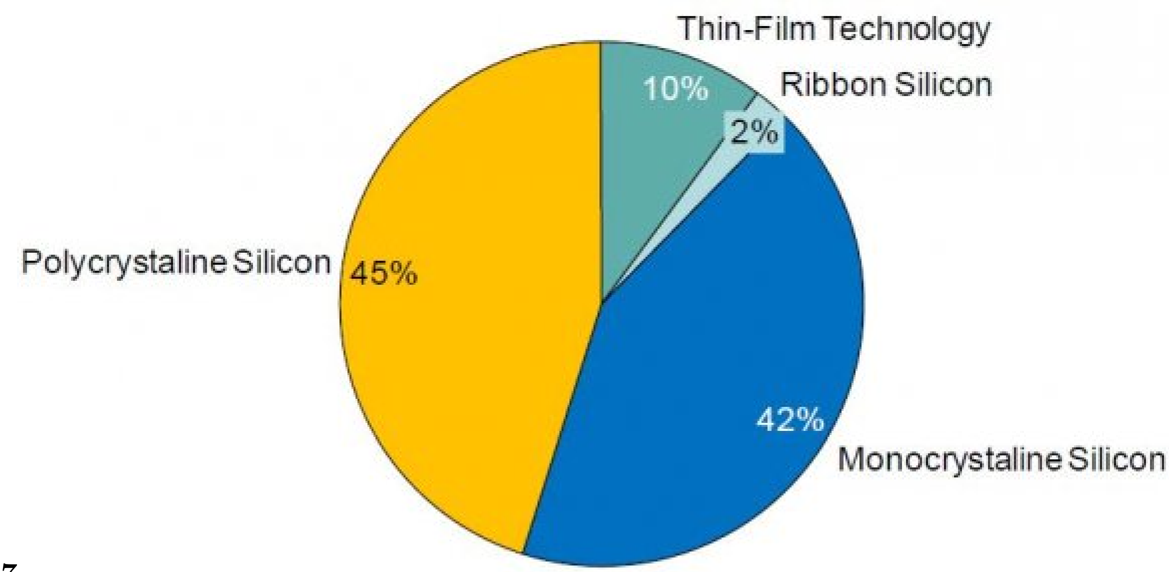


Figure 25: Figure 15 :



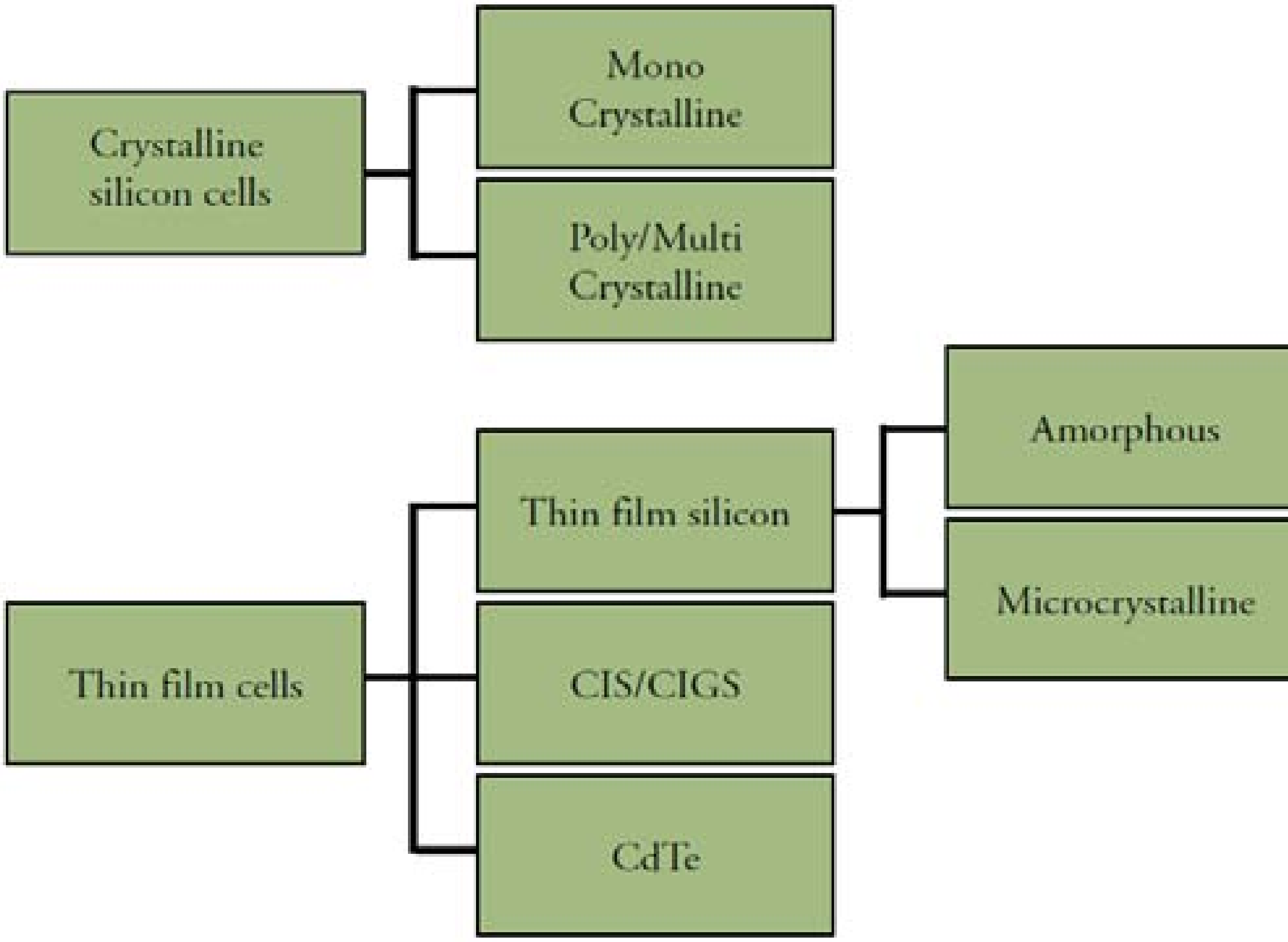
1516

Figure 26: Figure 15 :Figure 16 :



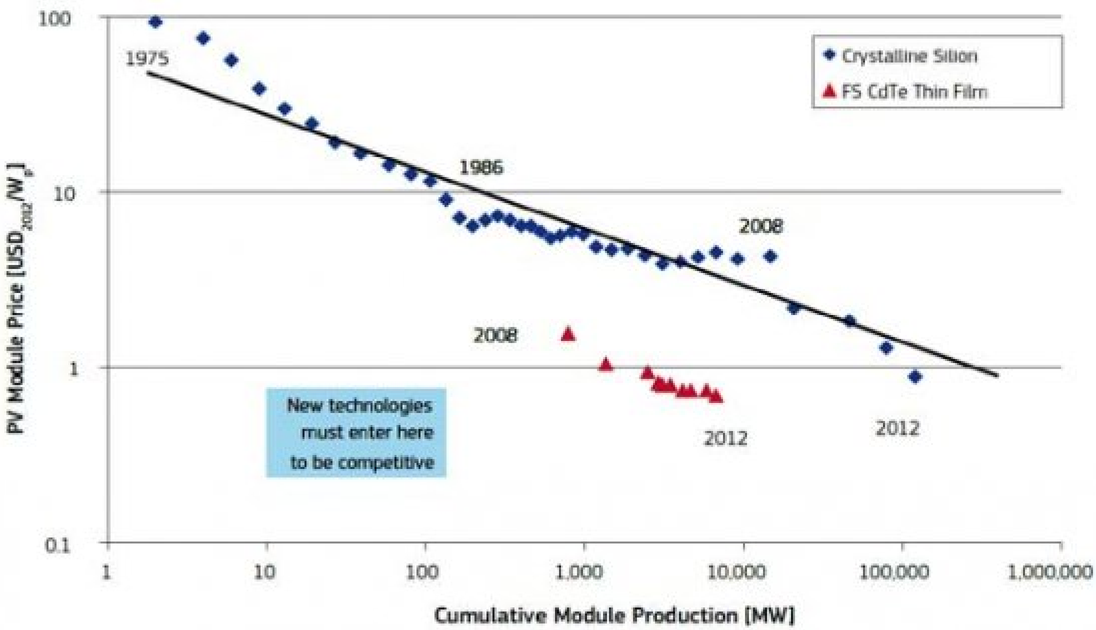
17

Figure 27: Figure 17 :



18

Figure 28: Figure 18 :



2014

Figure 29: Year 2014 J

Derate Factors for Photovoltaic System Components

Table 6. PVWatts Default Derate Values

Component Derate Factors	PVWatts Default	Range
PV module nameplate DC rating	95%	0.80–1.05
Inverter and transformer	92%	0.88–0.98
Mismatch	98%	0.97–0.995
Diodes and connections	100%	0.99–0.997
DC wiring	98%	0.97–0.99
AC wiring	99%	0.98–0.993
Soiling	95%	0.30–0.995
System availability	98%	0.00–0.995
Shading	100%	0.00–1.00
Sun-tracking	100%	0.95–1.00
Age	100%	0.70–1.00
Overall DC-to-AC derate factor	77%	0.09999–0.96001

Figure 30:

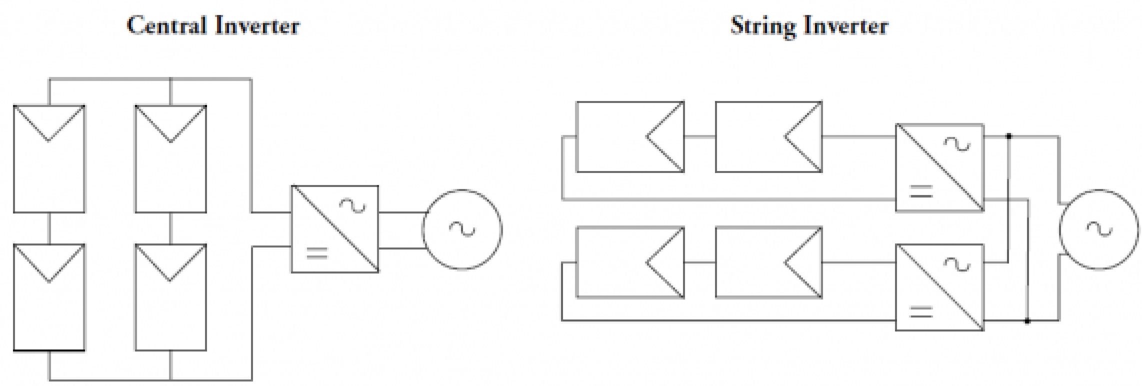


Figure 31:

Figure 32:

Figure 33:

Figure 34:

Figure 35:

Figure 36:

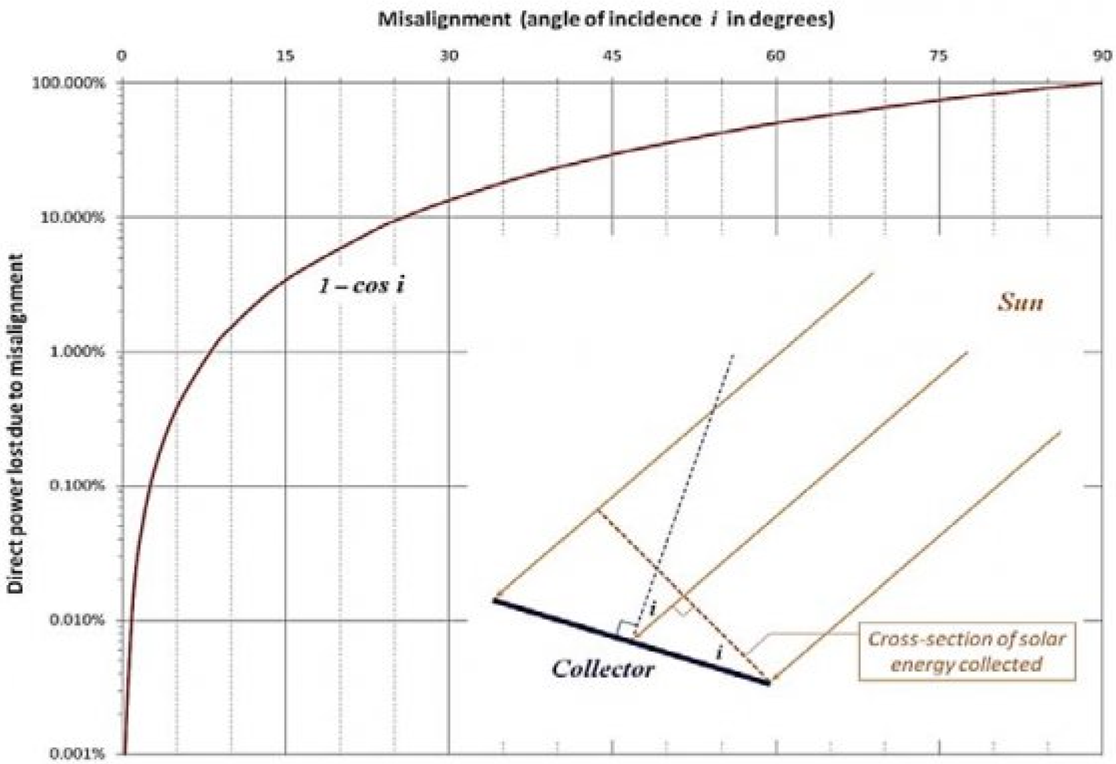


Figure 37:

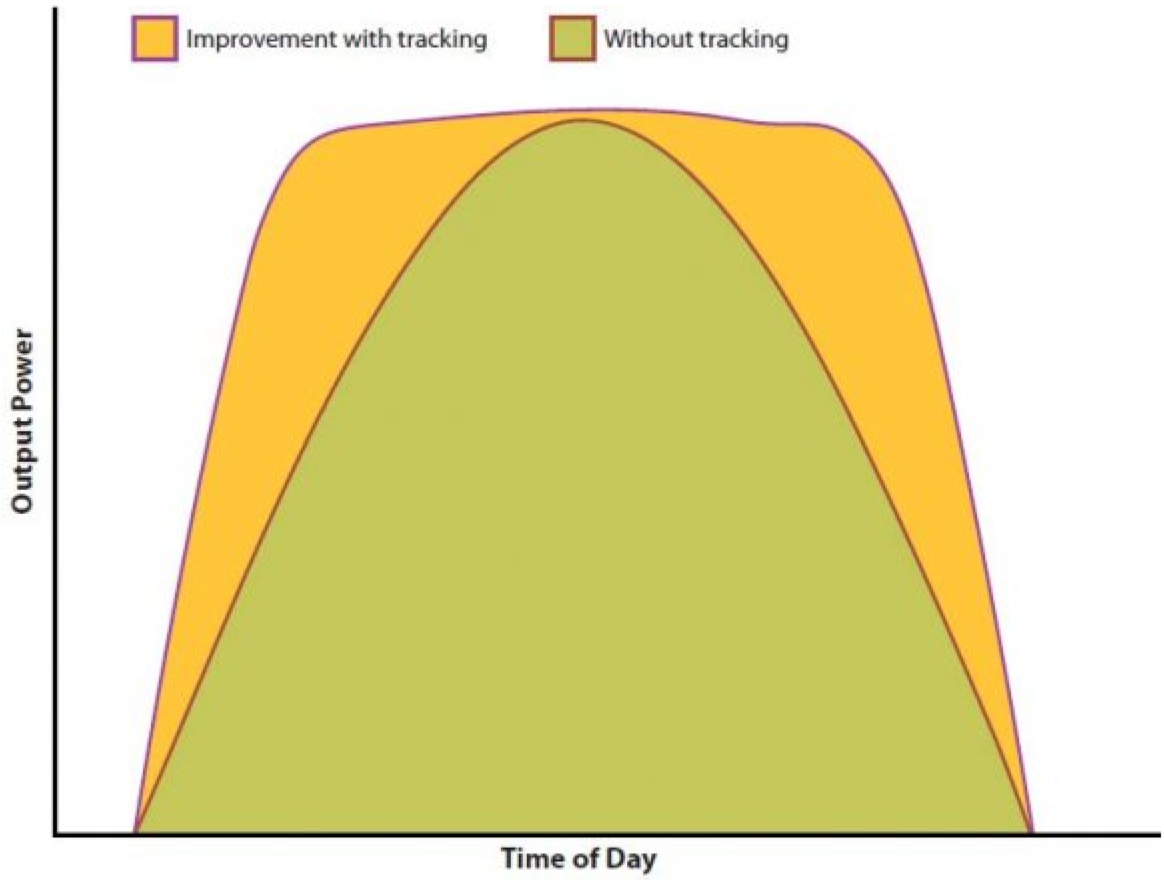

Improvement with tracking
Without tracking
Output Power
Time of Day

Figure 38:

Figure 39:

Figure 40:

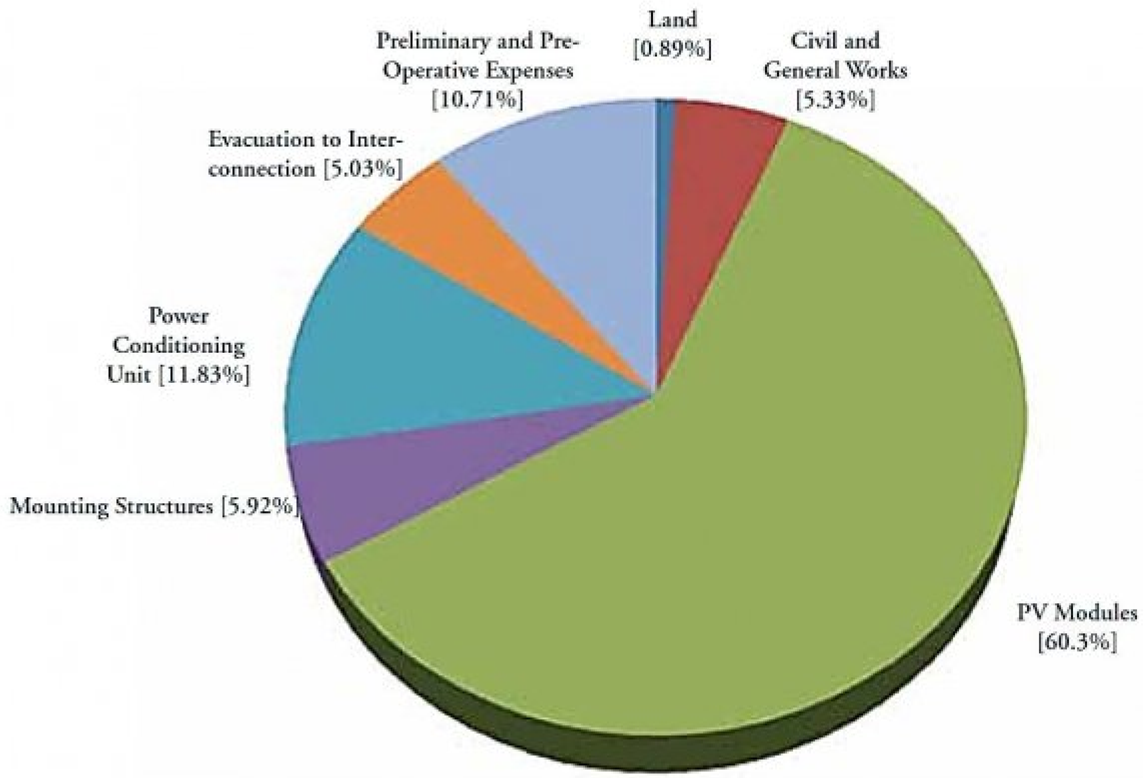


Figure 41:

Figure 42:

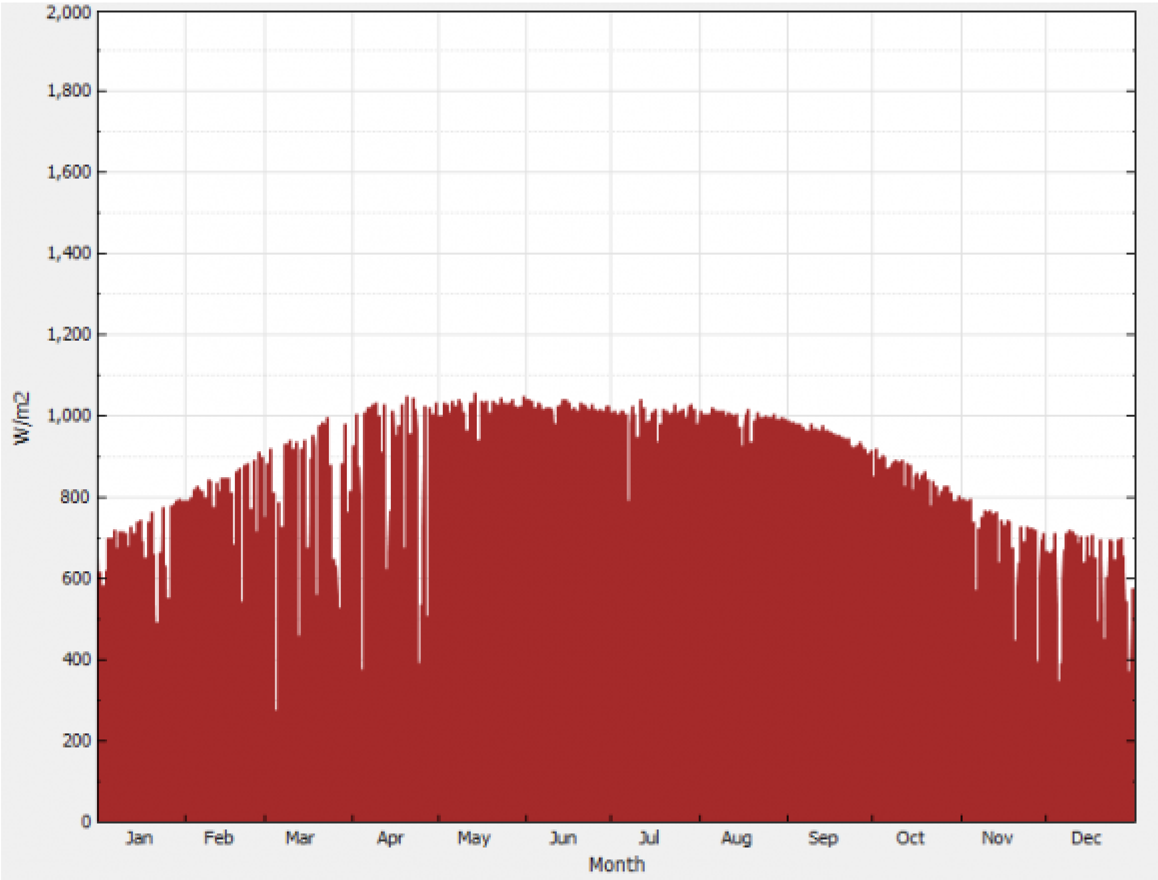


Figure 43:

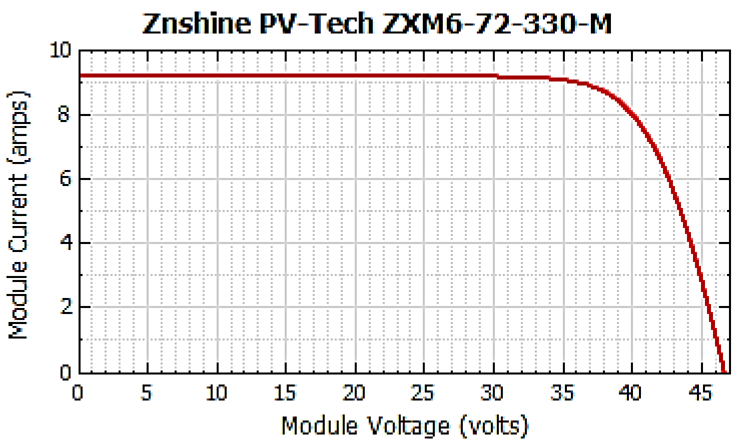


Figure 44:

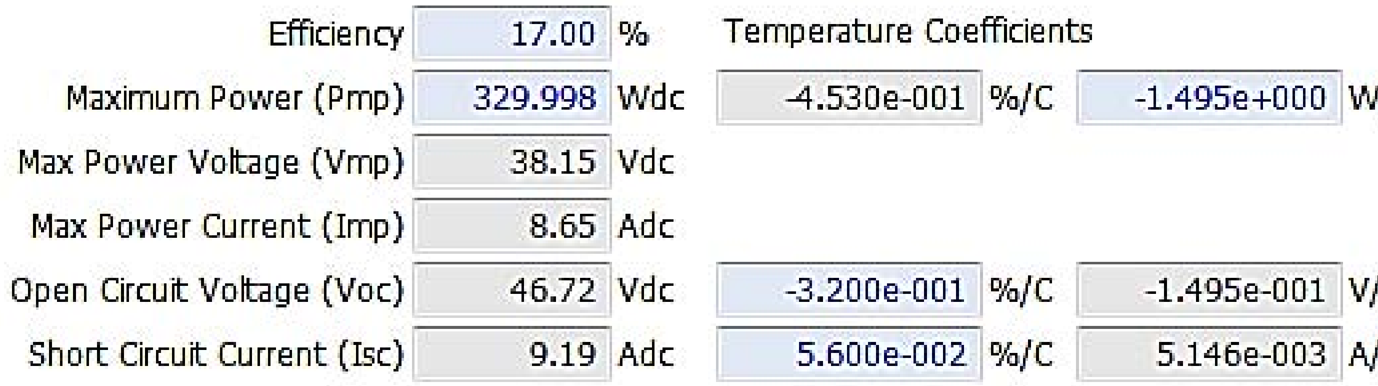


Figure 45:

3

Technology	Crystalline Silicon	Amorphous Silicon	Cadmium Telluride	Copper Indium Gallium Di-Selenide
Abbreviation	c-Si	a-Si	CdTe	CIGS or CIS
Cost ($/Wp, 2009)	3.1-3.6	2.5-2.8	2.1-2.8	2.7-2.9
Percentage of Global installed capacity	78%	22%		
Thickness of cell	Thick layers (200-300 µm)	Thin layers (<1 µm)	Thin layers (<1 µm)	Thin layers (<1 µm)
Current commercial efficiency	12-19%	5-7%	8-11%	8-11%
Temperature coefficient for power (typical)	-0.5%/ o C	-0.21%/ o C	-0.25%/ o C	-0.36%/ o C

Figure 46: Table 3 :

6

I	Lost = 1 - cos(i)	i	hours Lost
0°0%		15°1	3.40%
1°0.02%		30°2	13.40%
3°0.14%		45°3	30%
8°1%		60°4	>50%
23.4°8.30%		75°5	>75%

Figure 47: Table 6 :

4

	Flat Panel horizontal surface	Fixed mounting, optimum angle	1-axis tracking	1-axis with seasonal adjustment	2-axes tracking
Energy boost in comparison to optimum tilt	-15%	0%	20%	26%	32%
Initial marginal cost per m 2	0%	5%	10%		20%

Figure 48: Table 4 :

degradation, and the existing PV power plant. Utility PV power plants around the world were also reviewed. The System Advisor Model (SAM) software developed by National Renewable Energy Laboratory (NREL) has been used to predict the total direct capital cost of the 20 MW PV plant as $88.0 million (M), and total installed cost as $ 97.202 M; or $4.86 M/MW. This is almost half the cost of the CSP using parabolic trough plants. ??he

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