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"OPTIMIZATION OF 01 MW ON-GRID SOLAR POWER PLANT"

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OPTIMIZATION OF 01 MW ON-GRID SOLAR POWER PLANT

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DEPARTMENT OF CHEMICAL ENGINEERING

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Dedication

To my lovely mother and kind teachers.

Abstract

Prevailed energy crisis and its high cost has become one of the most critical challenge that pushed the people around the world to look for the renewable energy resources to accomplish the rising demand and to overcome the scarceness of currently available resources.

In the Islamic Republic of Pakistan (Pakistan), the power generation and supply mainly include thermal (fossil fuel, natural gas and coal), hydro and nuclear power plants. The current power deficit in the country is 7,000 MW. With Pakistan being one of the world's richest areas of solar energy, where annual sunshine duration reaches above 2,500h that is among the world's top, it was the need of time to conserve the power available in the country and to shift on to renewable energy sources like Solar Energy.

In 2015-16, I worked on installation of 1MW Grid-Tied Solar Power System project in Parliament House, Islamabad which involved designing, installation of panels and associated accessories like Inverters and Panels.

As Project Manager, I did my best to select the best available equipments that included solar panels and we were quite successful in that. However, still there is lot of room for improvement of overall system efficiency and the door was always open for working on it. This has encouraged me to study and research about different techniques that would help us improve the year around efficiency of our 1MW Grid Tied Solar Power System Project installed in Parliament House.

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Chapter 1
Introduction

1.1 Background

Renewable energy resource utilization can address the both most developing issues of the world in the current era which mainly include rapid depletion of conventional fossil fuel reserves and drastic climate changes. Pakistan is naturally blessed with different renewable energy resources; out of which solar is the main technologies.

The rising concerns over the environmental impacts of fossil fuels and their continuous exhaustion has forced the world to look for the alternatives. Renewable Energy (RE) resources offer a cleaner and potentially cheap alternative to the fossil fuel based power generation. As the energy consumption, an indicator of economic growth, continues to rise the use of renewable energy resources will become certain.

Pakistan have a huge prospective for various renewable energy resources such as solar. Pakistan is fortunate to have a climate that is characterized with the availability of sun throughout the year. The huge potential for Renewable Energy resources across the country also provides an opportunity to realize distributed generation and micro-grids to power up the villages currently disconnected from the national grid. However, the Renewable Energy resources contribute less than 2% to the energy mix of the country [1]. To promote the solar energy, we initiated the project under Green Parliament initiative to set a precedent for rest of the country. Completed in record time of just 10 months, 1MW Grid-Tied Solar Power Plant Crowned Parliament House Pakistan as first ever with a renewable energy project for this much capacity.

We used state of the art equipment in this project, however, still there is room for improvement which will be main theme of this research. This encouraged me to study and research about different techniques that would help us improve the year around efficiency of our 1MW Grid Tied Solar Power System Project installed in Parliament House.

Mostly in Pakistan, domestic solar power systems are as a defense mechanism against the frequent power shutdowns faced by the domestic consumers. Consumers use solar power to charge their batteries, and consume the stored power in case in load blackouts events. This requires the use of battery backups which are expensive and are inefficient. It presents its own challenges as well as opportunities for the researchers to explore to cope with this problem in form of Grid-Tied solar power system.

This project of Grid-Tied Solar Power Plant of Parliament House was to spread awareness regarding the On-Grid system that will not only save capital costs for domestic users, but also play role to counter the ever growing energy problems of the country. This Thesis is based on some of the proposals that can be applied to effectively improve the efficiency of Solar System by up to 15%.

1.2 Solar PV

Since renewables are becoming the typical energy sources in recent years, solar PV is capitalizing on its position in this market. For new capacity installation, currently solar energy is believed to be one of the most economic power source. Being the fastest growing source among the renewables, with an annual average growth rate of 7.8% (Figure 1.1), Solar PV accounts for almost all the growth to be associated with solar energy today. Currently, China is the leader in world solar powered system installed capacity, with Germany at the second place. By 2050 India would be second to China in terms of PV power demand and would meet a good portion of its energy demand with its own PV accounting for 30% of the global PV [2].

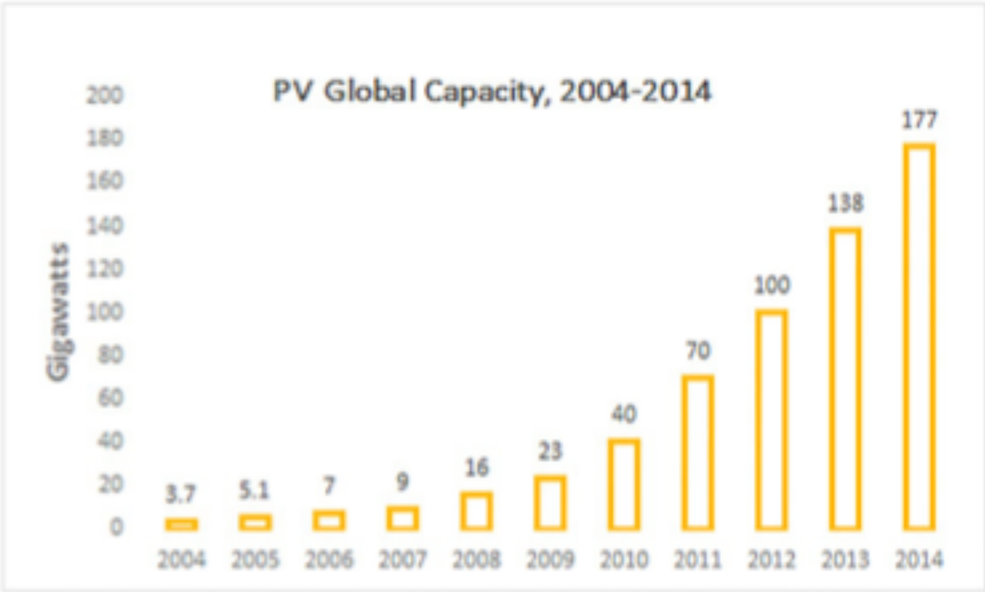

Figure 1.1 Solar PV Capacity 2004-2014

1.3 Solar in Pakistan

Pakistan, is economically mainly dependent on agriculture, is rich in many energy resources. An account of its primary energy resources has been provided in Table 1-2. Despite of such huge resources, the country is passing through its nastiest energy crisis. With 83% of its 190 million population connected to the grid [3], the power demand frequently exceeds beyond 23,000 MW in peak hours, which results in shortfall surges of over 7,000 MW. Consequently, necessitating load shedding for prolonged periods of time. The gap between supply and demand is adding up with each passing day.

All sectors whether it is commercial, domestic or industrial are victims of power outages across the country. Secondly, since fossil fuels on the are mainly imported, which take away a good portion of the foreign exchange with them. An idea about the energy consumption by source is presented in Figure 1.2. Energy problems in the country need to be addressed immediately, and country has to play as a responsible and environment friendly nation.

Table 1-2. Primary Energy Resources of Pakistan (Nonconventional and Renewable)

Energy Resource	Potential	Ref. Source
Wind	340,000 MW	[3]
Solar	2,900,000 MW (Theoretical)	[4]
Biomass	>50,100 GWh	[6]
Geothermal	100,000 MWe	[7]

Solar photovoltaics, being a clean source with no noise, is the best among the renewables energy sources. Though the capital investment is high in solar system, yet it is suitable for country, keeping in view the current scenario. Firstly, Pakistan has a huge solar potential of around 3 TW, with an average global insolation of 5-6 kWh/m2/day for over 90% of its area. According to estimation, covering 0.30% of Baluchistan area with 20% efficient solar panels would produce enough electricity to meet all of Pakistan's energy demand. Another benefit of Solar system is that the load nature is such that PV can be easily incorporated into the present infrastructure in both centralized and distributed forms. Besides, distributed PV would help reduce the load on Pakistan's existing transmission and distribution system. Thirdly, require very less time to install, so it is best in terms of installation. This will resultantly alleviate the country to an extent of its dependency on imported fossil fuels.

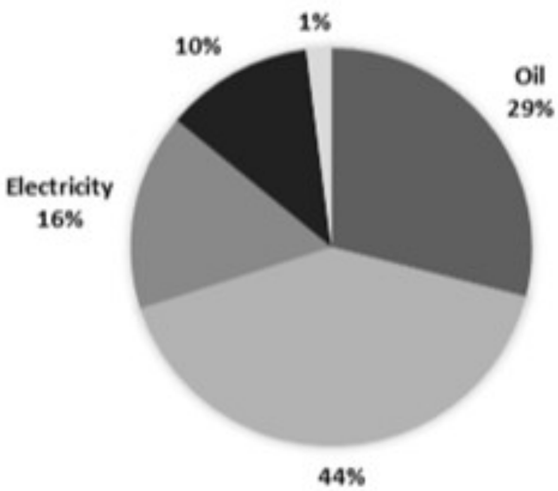

Figure 1.2 Energy Consumption by Source

Despite these coincidences and favorable conditions, Pakistan has barely gained from solar PV. Even the concept of large scale PV for power is a relatively new here. It's only now that the country has taken the initiative to integrate PV into its energy mix. Recently the country started investing in mega solar PV projects. Pakistan's parliament is the world's first lower house to be fully powered with solar PV. A 1 MW PV plant has been setup to power the plant. A net metering facility of 356 kW at Pakistan Engineering Council (PEC) building in Islamabad is also operational. Apart from that, 1-10 kW systems for commercial and residential use are operational throughout Pakistan.

With the launch of China-Pakistan economic corridor (CPEC) project, the country also plans to develop the world's largest solar park by the name of Quaid-e-Azam solar park in the Cholistan desert, Punjab. It will be a 1000 MW plant of which 100 MW power has already been feeding the national grid since 2015. As per Alternative Energy Development Board, some 40 projects with a capacity of around 1211.4 are being developed across the country. According to renewable energy experts, the country is expected to add over 3000MW solar power through net metering to national grid to cope with ever growing energy crisis [4].

1.4 Problem statement

Shortfall in demand and supply of electricity is one of the great hurdles in the current economic growth of Pakistan which is increasing with each passing day. The difference between the electricity supply and demand had reached new heights of up to 60% in the summer of 2014. There has been widespread load shedding reported in the 16 years passed. According some rough estimates about 12 hours a day in urban areas and 20 hours a day in rural areas have been reported. (NEPRA, 2012). Electricity power short fall during 2010 was observed up to 4600 Mega Watt and it is becoming worse with the passage of time. During 2014 Energy deficit up to 7000 MW was observed.

- During the study of year around efficiency of Solar Power, it was observed that solar panels are not receiving maximum available sunlight which greatly effects the efficiency.[5]
- The efficiency of PV module is directly proportional to the temperature of module and as the temperature usually remain very high at installed site, the efficiency of PV module is affected.
- Solar Panels are exposed to direct environment and its efficiency depends on the sunlight it is exposed too. With dust on its surface, the area exposed to sunlight is reduced which in turn reduces the energy generation. [6]

1.5 Objectives

i. Taking advantage of maximum available sunlight by utilizing Solar Concentrator technique.
ii. To improve the solar efficiency of Solar system by controlling the temperature of solar panels using Splash water technique.
iii. To clean the Solar Panels periodically, as a result maximizing the effective surface area of PV module.

1.5 Organization of Thesis

This study will be structured into four chapters.

Chapter 1 gives the Introduction to the study and answers of pre-requisites required for starting research and describes background of the study, problem statements, objective, methodology, significance and its importance.

Chapter 2 gives relevant literature review from working of Solar Cells, to importance/need of grid-tied solar power system and its working with its relevance with the installed 1MW Grid-Tied Solar Power Plan in Parliament House and the current situation of Pakistan.

Chapter 3 presents the methods that could be used to improve the overall efficiency of installed 1MW Solar Power Project in Parliament house and analysis of obtained through simulation by software.

Chapter 4 discusses the experimental setup to prove the along with their results and recommendation.

Chapter 5 concludes the result of both sprinkling water and solar concentrator technique experiments.

References

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Chapter 2

Literature Survey

This chapter gives an insight into the Pakistan's energy mix, and covers detailed literature review on Solar cell technology, basic working of solar cells, working of Grid-Tied Solar system and components of Grid-Tied Solar Power system.

2.1 Pakistan Energy Mix

As per GIS data, Pakistan faces an annual Global Horizontal Irradiation greater than 1600kWh/m2. The province of Balochistan, in fact, most of its parts, face GHI greater than 1800kWh/m2. Upper Sindh receives the same share as shown by the GIS data Figure 2.1 [1]. The average monthly solar radiation intensity remains 136.05 to 287.36 W/m2.

Southern Punjab along with the above mentioned provinces can produce up to 83 MW power per month because of the solar radiation intensity they get. This intensity ranges from 1500W/m2/day to 2750 W/m2/day for around 10 hours a day. In an area of 100 m2, 45 MW to 83 MW power per month may be generated in the above mentioned regions [2].

Pakistan is blessed with a huge solar energy potential, stretching across the vast plains of Southern Punjab and the Upper Sindh alongwith the barren plains of Balochistan. The average annual solar radiation intensity per day (1971- 2000) during the months of May, June and July in Pakistan is above 2500W/m2 as shown in Figure 2.1 below.

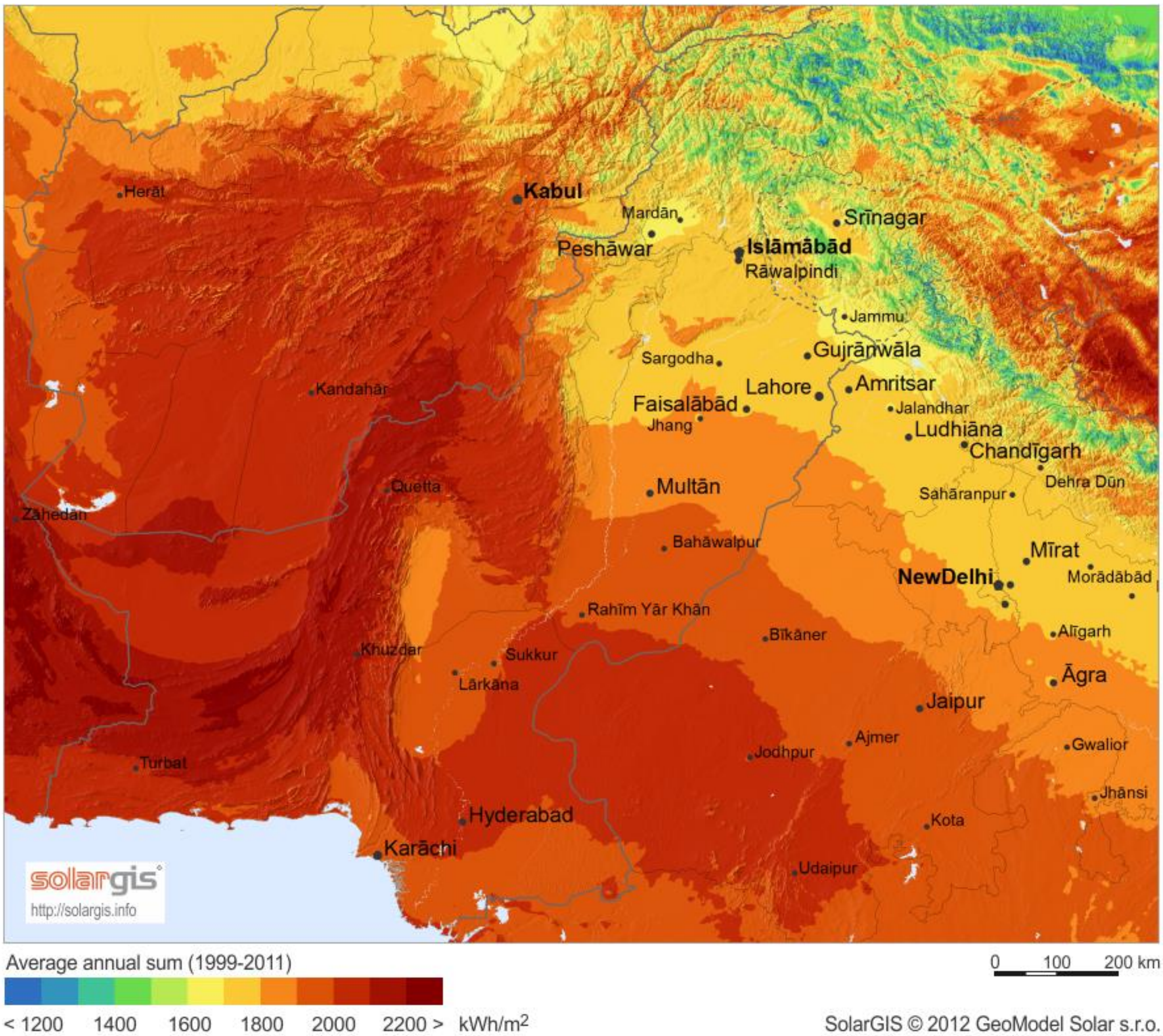

Figure 2.1 Average annual sum of Global Horizontal Solar irradiation in Pakistan

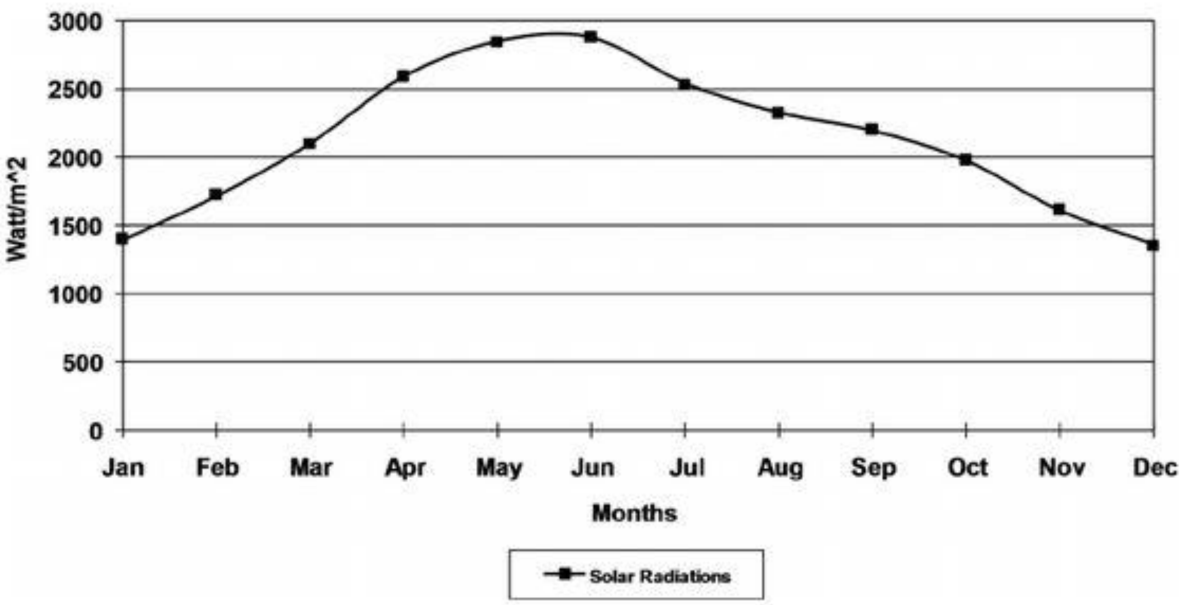

Figure 2.2 Average annual solar radiation intensity (W/m2/day) in Pakistan during (1971-2000)

There is encouraging potential in many parts of the country for solar power generation. Especially in areas of Southern Punjab, Sindh and Balochistan where studies suggest that in an area of 100m2, 45MW to 83MW power can be generated during a month in these regions.

In light of these reports, the government has initiated and completed 1MW Grid-Tied Solar Power Plant in Parliament house to set precedent for rest of the country.

With Solar being the frontrunner in Pakistan's renewable energy initiative, it is important to make sure that solar is to be used at its maximum potential. Apart from low conversion efficiency for sub-grade quality panels, there are some intrinsic non-linear properties of a solar cell which effect its performance and limit its output. This results in power outputs which don't match with the name place rating.

2.2 Solar Cells Introduction

Solar cell is basically a semiconductor p-n junction which does the work of conversion of sunlight into electricity. [3] Crystalline silicon solar cells have been dominating the photovoltaic market since early 1950's. The reason for so much use of Silicon is because of its property of being non-toxic and plentifully available in the earth crust. In last few years, improvements in design, performance have reduced cost and quality of solar cells.

This has opened up the doors for their deployments in applications like rural electrification projects, water pumping, and telecommunications equipment.

Our main focus in this thesis is improving the year around efficiency of Solar Powered Project installed in Parliament House through different techniques, however, before we proceed, let us have a brief look on how solar system works.

2.3 Basic Working of Solar Panels

Sunlight consists of energetic particles which are known as Photos. Solar panel works by allowing these photons to knock electrons free from atoms and this way generating a flow of electricity.

Solar panels actually comprise many smaller units called photovoltaic cells which is basically a sandwich that is made of two slices of semi-conducting material, normally silicon. However, since photovoltaic cells need to establish an electric field, which only occurs when opposite charges are separated.

To achieve this result, silicon is doped with phosphorous in top layer that adds an extra electrons making that layer negatively charged. In the meantime, the bottom layer is doped with boron, which results in electron deficiency, thus making the bottom layer positively charged.

This all combines to an electric field at the junction between the silicon layers. Thus when a photon of sunlight knocks an electron free, the electric field will push that electron out of the silicon junction.

These free electrons then travel through a external circuit from n-type layer to p-type layer, providing a flow of electricity. [4]

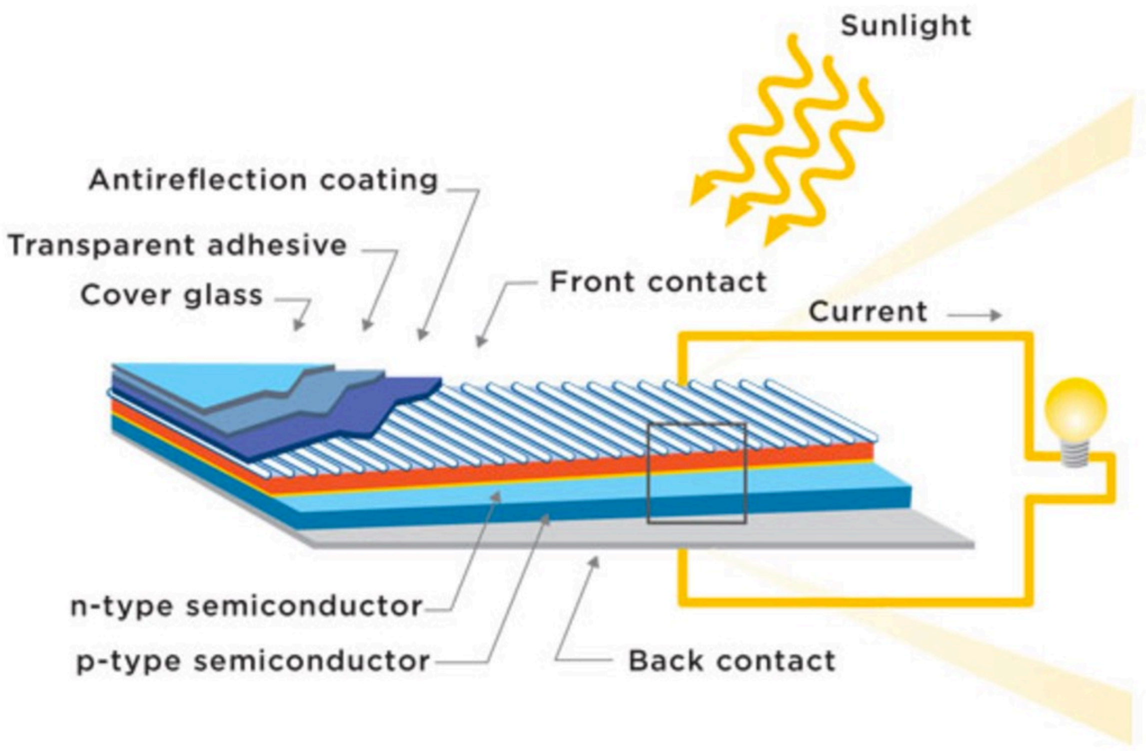

Figure 2.3 Break-Down of Solar Cell

When Solar Panels were first introduced, they were mostly used for off-grid purposes that is having a battery backup system powering homes in remote locations, telecommunication towers, water pumps etc.

A solar cell converts sunlight into electricity. It is essentially an electronic device which produces current and a voltage to produce power. The absorption of light forces the electron to a higher state and evidently movement of the very electron in the circuit.

The mobile electron dissipates energy to the load and returns to the cell itself. Nearly all photovoltaic conversion materials are in essence a p-n junction.
The basic processes and mechanisms in the operation of a solar cell are:

- The generation of light-generated carriers;
- The collection of the light-generated carries to generate a current;
- The generation of a large voltage across the solar cell; and
- The dissipation of power in the load and in parasitic resistances.

Current from incident light is generated in two steps viz absorption of incident photons for the formation of electron hole pairs given that the energy of the incident photon is greater than the band gap. In the second step, these carriers are collected by the p-n junction.

The carriers are separated by the electric field within the semiconductor. The minority carrier (generated by light) upon reaching the junction will be swept across the junction by the electric field at the junction where it will end up being a majority carrier. Connecting the base and emitter of the solar cell will lead to light generated carriers to flow through the external circuit as shown in Figure 2.3.

The collection probability is the probability that a light generated carrier will be absorbed within the certain region of the junction and thus will contribute to the ligt-generated current. The probability is dependent upon distance that carrier must travel as compared to the diffusion length.

The probability also depends on the surface properties. The collection probability will be low if the generated carrier is more than a diffusion length away from the junction and vice versa.

However collecting the light generated carriers in itself isn't sufficient for the generation of power. A voltage needs to be generated as well as current. Voltage is generated courtesy of "Photovoltaic effect". The movement of electrons to the n-type side and movement of holes to the p-type of the junction is caused by the collection of light generated carriers by the p-n junction.

Under short circuit conditions, no charge is built up. But if the light generated carriers are not allowed to leave the cell, it would lead to a large number of electrons in the n-type side of the junction. Inevitably the number of holes at the p-type side will also increase.

These polarizing charges separated by the junction will lead to formation of a strong electric field. The diffusion current would increase when this electric field decreases as it acts as boundary between the two charges. An equilibrium would be formed through which a voltage would exist in the junction. The difference between the light generated current and the forward bias current is the new current generated from the solar cell.

This leads to both the formation of a voltage and a current across the junction and hence power. These individual solar cells when interconnected together and encapsulated in a weather proof package is called a panel/module. Furthermore, these panels/modules when connected in series and parallel are known as an array.

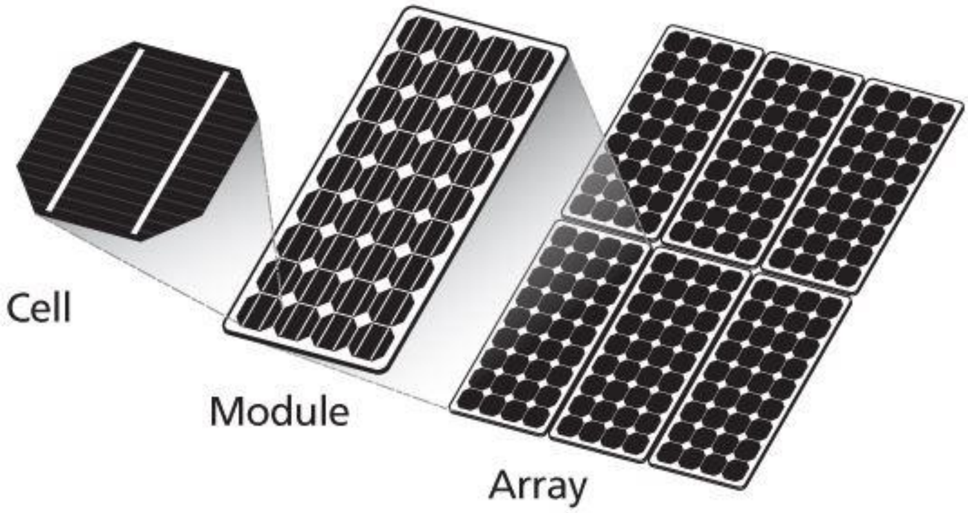

Figure 2.4: PV cell, module and array

The generated current voltage (IV) curve is actually a super positioned dark IV curve of a solar cell with a light generated one. For power to be extracted the IV curve must lie in the fourth quadrant. So this is the point where illumination by light comes in to help shift the curve in the fourth quadrant.

Short circuit current (ISC) of a solar cell is when the open circuit voltage or when the voltage across the cell is zero. This is due to the generation and collection of light generated carriers. The short circuit current depends upon the following factors.

- Area of solar cell
- Number of incident photons
- Spectrum of incident light
- Optical properties of cell
- Collection probability

Similarly, the open circuit voltage (VOC) is the maximum voltage from a solar cell. The forward bias of a solar cell due to the junction characterizes this open circuit voltage. The maximum power from a solar cell is a product of ISC and VOC.

The ratio of the maximum power from a solar cell to the product between open circuit voltage and short circuit current of a panel is known as the fill factor (FF). FF is a measure of the squareness of the IV curve (as shown in Figure 2.5).

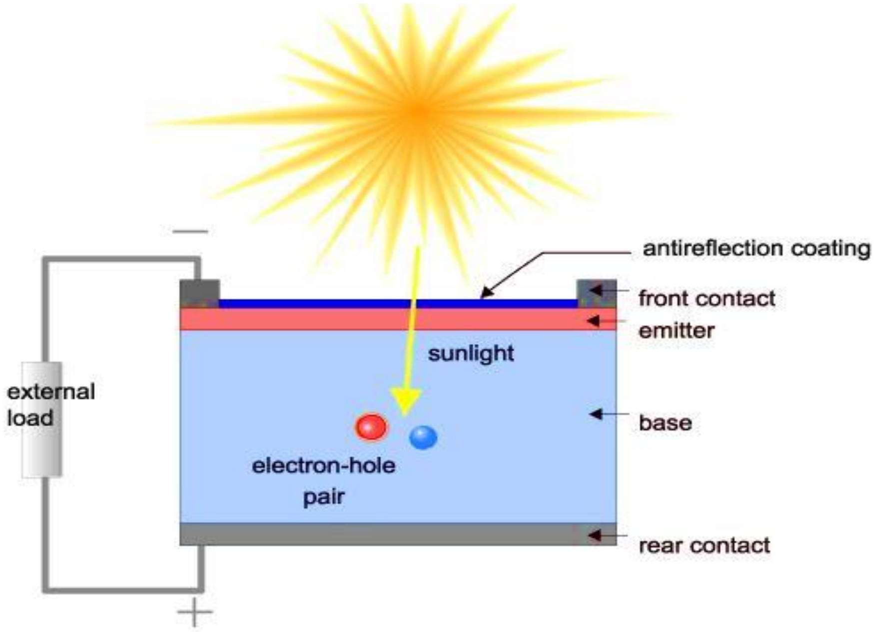

Figure 2.5 Solar Cell Structure

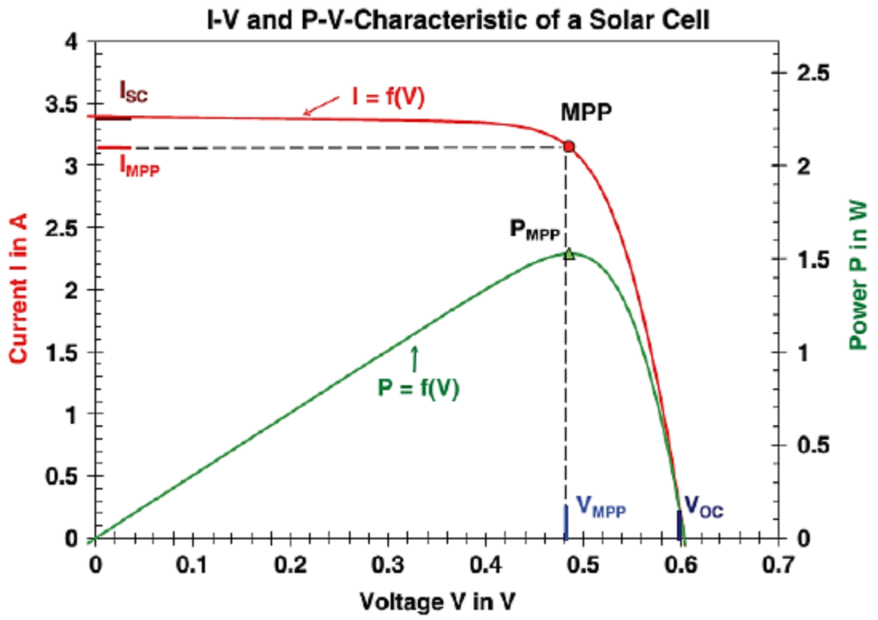

Figure 2.6 Characteristic IV and PV curves of Solar Cell

However, in recent years, solar power has experienced significant growth for Grid-Tied applications where the power is provided into the electricity grid. Surprisingly, Grid-Tied Solar Power systems now accounts for over 90% of the global solar market. [5]

2.4 Latest Trends in Solar PV

In 1839, Alexandre Edmond Becquerel discovered that certain materials when exposed to light produced small amounts of electric current. William Grylls Adams who along with his student Richard Evans Day, discovered in 1876 that selenium produced electricity when light shines on it.

These discoveries paved the way for development and commercialization of PV technology in times that followed. It took more than a century, however, for the concept of electrical power from sunlight to become more than just a lab experiment. Since then, the solar cell industry grown dramatically [6].

Photovoltaic technologies, today, are classified into three main divisions, called generations of solar cells. We have first, second and third generations of solar cells.

2.4.1 First Generation of Solar Cells

These cells are generally based on silicon wafers. These are also called crystalline Si (c- Si) solar cells. Two types are monocrystalline Si (mono-Si) and polycrystalline Si (multi- Si) solar cells. Cell efficiency of 25.6% has already been attained in lab [7] and modules are performing at around 15 – 20% efficiency.

The PV market is mainly dominated by these solar cells and can easily be sighted on rooftops. Silicon technology accounts for over 80% of all the solar panels sold around the world [8]. Key traits of the technology are high efficiency and stability. These cells however, are energy intensive in fabrication, rigid and less stable in harsh environments such as the space.

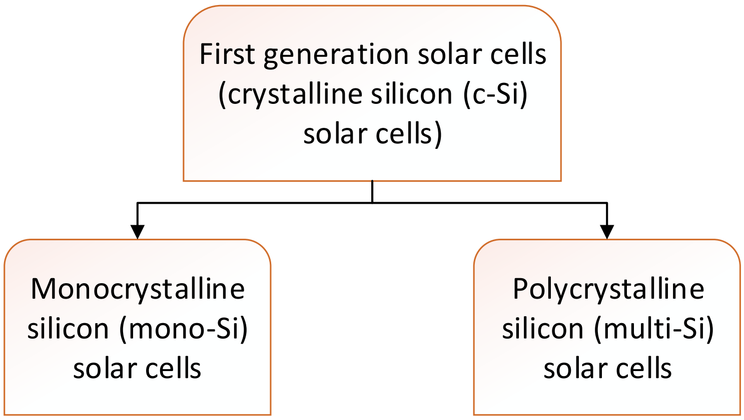

Figure 2.7 First generation solar cells are crystalline silicon solar cells. Crystalline silicon solar cells are either monocrystalline or polycrystalline silicon solar cells

2.4.2 Second Generation of Solar Cells

Second generation solar cells are usually known as thin film solar cells. The cells take the name because, compared to first gen solar cells they are developed from very thin layers of semiconductors. In most of the cases, the layers are just a few micrometers thick [9].

Well commercialized second generation cells include devices developed of materials such as amorphous silicon, copper indium gallium diselenide (CIGS) and cadmium telluride (CdTe). For these types, module efficiency in the range of 10-15% for commercialized cells are not uncommon [11]. Copper indium diselenide (CIS) and thin film polycrystalline Si PV technologies also have commercial value. Thin film monocrystalline Si solar cell technology has recently been commercialized.

Another category which has attracted enough research interest is copper zinc tin sulfide/selenide (CZTS) system based thin film devices. Unlike CIGS, where expensiveness of indium, or CdTe, where resource limitedness of tellurium and toxicity of cadmium are major concerns, CZTS system uses earth abundant and non-toxic elements. Figure explains second generation of solar cells by mentioning the type of cells included in this technology.

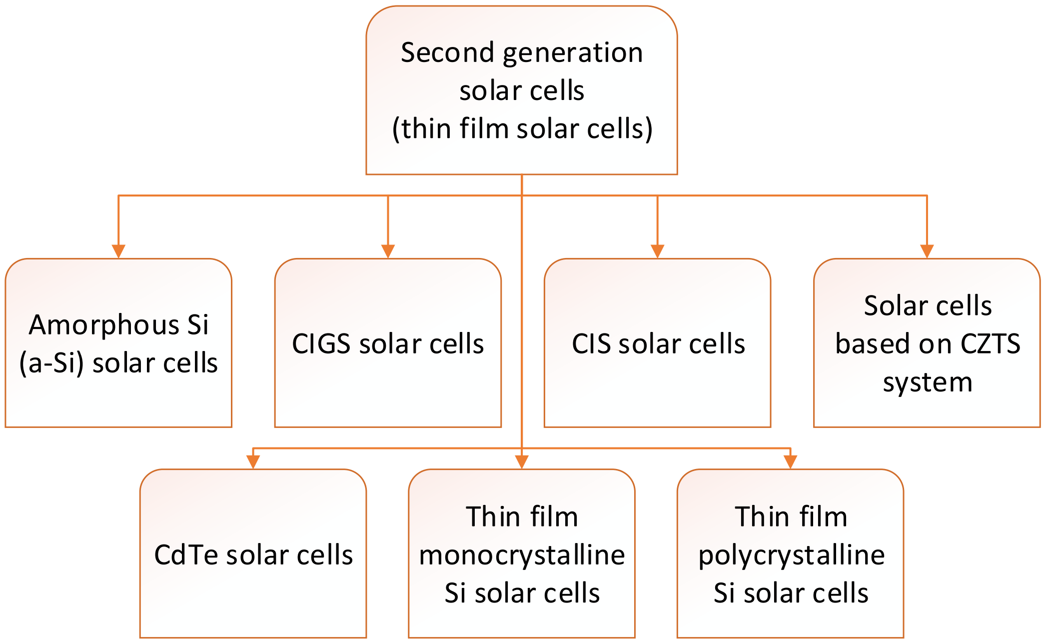

Figure 2.8 The second generation of solar cells comprises of a number of thin film solar cells

The technology is famous for its overall lower costs than first generation solar cells. Lower prices result mainly as a result of less material consumption in these cells than first generation cells. Mechanical flexibility of modules is another attractive feature of this technology.

However, the technology uses high vacuum, inert atmosphere and high temperature treatments (in many cases) for processing, making the fabrication process energy intensive and requires expensive processing tools, thus incrementing the overall prices of these cells. Solution based processes for thin film deposition, which are less energy intensive and don't necessarily require very expensive tools, are currently being researched [10].

2.4.3 Third Generation of Solar Cells

The previous two generations mentioned, had their own benefits due to which they exist till today, however, there are fundamental limitations with either of the two, due to which the PV industry has not been able to extend to its full potential. Post 2020, photovoltaics, as a huge profitable industry, will be under immense pressure for improved performance. Improved performance would mean reduced price per watt of electricity generation. Third generation approaches aim to reduce costs to $0.50/watt, potentially to $0.20/watt or even lower, primarily by increasing efficiencies and yet maintaining environment friendliness and robustness of these modules .

The capital cost of a PV system can be divided into PV module cost and balance of system (BOS) cost. Module cost is determined by raw material costs, cell manufacturing/processing and module assembly costs. The balance of system cost includes cost of items, such as the structural system, the electrical system and the storage system (if storage is required).

Materials cost of the total cost of a cell varies from technology to technology. Irrespective of the technology used, lower material consumption certainly reduces the overall cost per watt of electricity generated. This means we have to search for materials that are easily available, yet we shall be using the least amount of material possible in developing modules.

Furthermore, if processing costs are reduced by adopting low cost processing routes, the overall cost per watt of electricity generated can further be reduced. This implies that the cost of each process step needs to be carefully examined and thus reduced where possible [11]. Improving efficiency further leverages a reduction in costs, because the smaller area required per watt also reduces balance-of-systems costs .

The next generation idea relies on various underlying concepts to go as close to the Carnot limit of 95% efficiency as possible, and hence achieve the afore mentioned objectives.

Nanotechnology lies at the heart of these approaches. The approaches may mainly be related to effects/processes such as 1) multiple energy threshold processes 2) multiple electron-hole pair generation per incident photon 3) hot carrier effects 4) solar thermal electric systems 5) thermionic conversion to electricity 6) thermoelectric power generation 7) thermophotovoltaics and 8) thermophotonics.

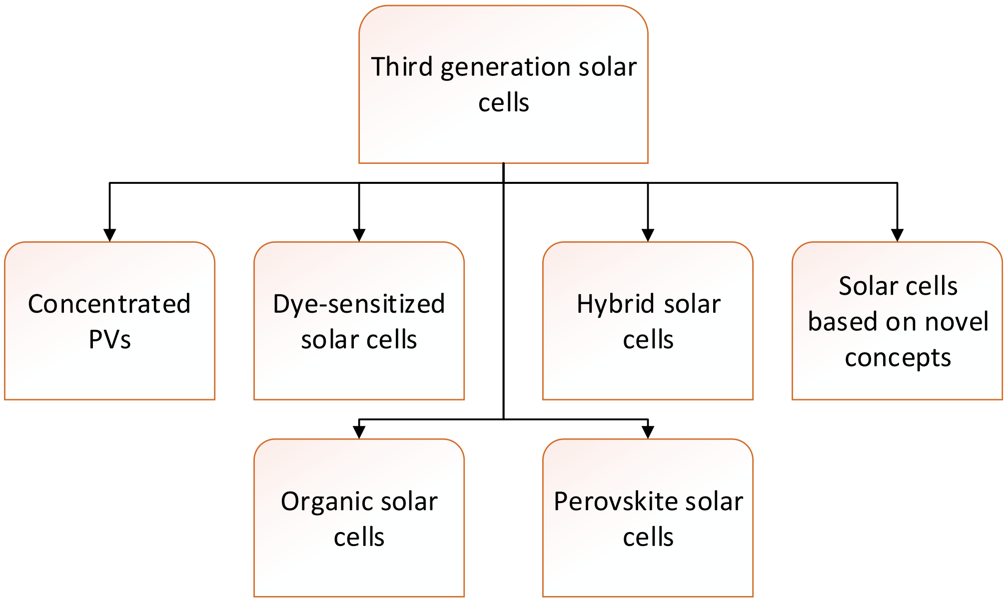

Figure 2.9 Third Generation Solar Cells

Progress in molecular electronics and nanostructure engineering in general, suggested material systems comparable to Si, when it comes to cost, abundance and non-toxicity. Many of such photoactive materials such as conductive polymers or perovskites are solution processable.

Further materials research needs to be conducted to have materials of performance and stability comparable or even superior to Si. Current research in this generation of PVs has resulted in a number of new solar cells such as Concentrating PVs (CPVs), Dye-sensitized solar cells (DSSCs), Organic solar cells (OSCs), Hybrid solar cells, Perovskite solar cells and solar cells based on novel and emerging concepts (such as quantum dots/wires/wells and super lattice technologies).

The diagram in figure elaborates these different types of third generation solar cells. The technology is mainly under research and demonstration phase, however, the technology shows great promise and commercial production of some third generation solar cells such as organic solar cells as already been started [12].

2.4.4 Hetrojunction Solar Cells

A heterojunction is defined as the interface between two dissimilar materials. The first semiconductor heterojunctions were prepared by Anderson in 1960. In heterojunction solar cells, the interface or junction is formed between two dissimilar semiconductors (Figure 2.10). The heterojunction transforms into a voltage source when radiations of particular spectral distribution fall on it. It was in the 1950s when Perlman theoretically evaluated the PV characteristics of an abrupt PN heterojunction solar cell and came up with the conclusion that heterojunction devices based on the window effect may offer certain advantages over the contemporary homojunction cells. [13]

Window effect is the generation of electron-hole pairs in and near the space-charge region on the narrow-band gap side of the interface, when photons of energies that are between the two band-gap energies, pass through the wide band-gap heterojunction material.

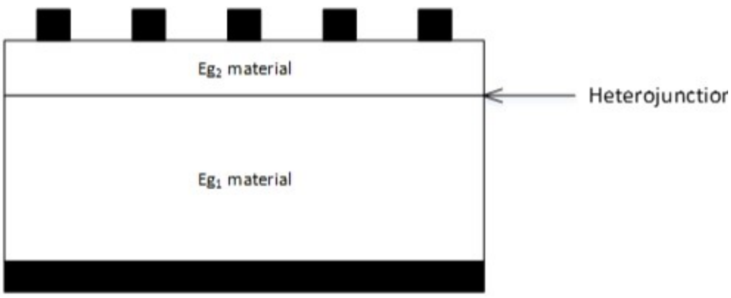

Figure 2.10 Basic Structure of Hetrojunction Solar Cells

2.4.5 Polar Hetrojunction

In planar heterojunction solar cells, the donor and acceptor materials of different band structure are stacked upon each other in sequence that develops a planar interface between the two materials. The concept of planar heterojunction for organic photovoltaics was first introduced in 1979 by Tang.

For excitons, the diffusion length lies in the range of 10 – 20 nm, thus excitons generated beyond 20 nm from the planar heterojunction interface often don't make their way to the interface, and are thus lost before dissociation, making planar heterojunction organic solar cells low quantum efficiency devices. For this reason planar heterojunction structure is frequently avoided in solar architecture [14].

2.4.6 Bulk Hetrojunction

To do away with the problems with planar heterojunction devices, the concept of bulk heterojunction was introduced. In a bulk heterojunction, the donor and acceptor materials of different energy band structure are mixed in a bulk state. Bulk heterojunction varies from the planar heterojunction in that instead of keeping the donor and acceptor separated from each other, the two phases are intermixed so that they interpenetrate throughout the bulk of the photoactive layer.

As a result, phase separation in the nanometric scale could be realized. In turn the heterojunction interface now extends through the entire of the photoactive layer. Thus it can be rightfully quoted that bulk heterojunction solar cells are sensitive to the morphology of the photoactive layer at the nanoscale [15].

2.4.7 Diffused Junction Solar Cells

Diffused-junction solar cells relay on a PN junction for its operation. The PN junction is developed through diffusion of the dopant atoms under high temperature conditions. Further to avoid surface recombination, SiO2 etc. passivation layers are grown on the surface of c-Si. SiO2 is thermally grown at high temperatures to passivate the surface.

This is followed by spiking the metal through the passivation layer to make direct contact with the active layer. Whereas high efficiency cells often use passivation at the rear of the cell as well. Again, spiking is done to ensure direct contact of the rear metal with the photoactive material.

Although the surface is almost recombination free, but the metal contacts are sites of high recombination, responsible for reducing the overall cell efficiency. Thus, by opening the dielectric layer, a trade-off between surface passivation and contact area is made. To further reduce recombination, highly doped layers beneath the contacts are developed, which serve to provide the back surface field and avoid the minority carriers from recombining at the metal contacts. All these fancy manufacturing steps add to the net price of diffused-junction c-Si solar cells [16].

2.4.8 Metal Oxide/Silicon Heterojunction Solar Cells

Silicon heterojunction solar cells (SHJ-SCs) technology was investigated as an alternative to the more costly diffused-junction based Si solar cells. SHJ-SCs often involve a combination of hydrogenated amorphous silicon (a-Si:H) and crystalline silicon (c-Si). In SHJ-SCs the highly recombination-active metal contacts are separated from c-Si by inserting a few nanometer thick intrinsic a-Si:H. Intrinsic a-Si:H is a wide band gap semiconductor which serves dual role of simultaneously passivating as well as contacting the c-Si surface. SHJ-SCs have currently been able to reach efficiencies as high as 23.7%.

From a processing view point, SHJ-SCs have an edge over the diffused-junction solar cells, because SHJ-SCs fully exploit the superb passivation properties of a-Si:H. Further, SHJ-SCs requires low temperature (< 200 °C) processing, which in turn facilitates the use of relatively thin wafers without causing substrate warping. Similarly, SHJ-SCs avoid many of the processing steps mentioned above for diffused-junction solar cells .

SHJ-SCs employ charge selective contacts in the form of doped a-Si:H deposited on top of the intrinsic a-Si:H passivating layer. Often both the front and rear of the photoactive layer are deposited with doped a-Si:H over the intrinsic a-Si:H. In such a case, P-type a- Si:H serves as a hole selective layer, whereas N-type a-Si:H serves as electron selective contact. [17]

Efforts are underway to avoid the doped a-Si:H so as to further simplify the manufacture process. Even attempts have been made to avoid the intrinsic a-Si:H passivation (at least from one side) as well. During such attempts other heterojunction technologies have emerged. Most prominent among these are the hybrid organic/Si heterojunctions e.g. the PEDOT:PSS/Si, spiro OMeTAD/Si, P3HT/Si heterojunctions, etc., and metal oxide/si heterojunctions like the MoOx/Si. WOx/Si etc.

Although organic/Si heerojunctions could reduce the cost significantly in terms of low/room temperature processing, but the efficiency has also remained low (≤ 13%) for such designs. In this regard, the metal oxide/Si heterojunctions have been much successful with efficiency touching the 20% mark.

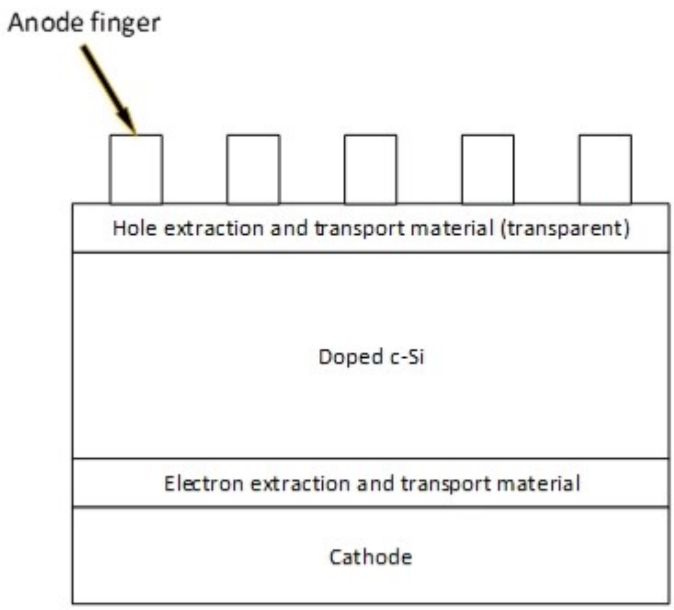

Figure 2.11 Basic structure of a PN junctionless Si solar cell

The metal oxide/SHJ-SCs present a dopant free, room/low temperature processed solar cell technology. It doesn't rely on a PN junction for its operation. A basic configuration of such type of cell is shown in Figure 2.11. As the technology doesn't employ PN junctions for charge separation, it has to have some mechanism for active charge separation. For this reason, charge selective contacts such as metal oxides are employed for selective charge extraction and transport in these devices.

Efficient CSCs allow one type of carrier to pass through, while blocking the other. Thus, we have two types of CSCs; the electron selective contacts (ESCs), also known as electron extraction layers (EELs), and the hole selective contacts (HSCs), also known as hole extraction layers (HELs) (Figure 2.11). Metal oxides such as MoOx, ZnO, WOx, TiOx are popular CSC materials for metal oxide/SHJ-SCs. These devices employ the use of metal oxides on at least one side of the doped c-Si photoactive layer.

2.5 Benefits of Grid-Tied Solar Power System

The domestic solar PV systems consist of mainly four components that are solar panels, battery, charge controller, and inverter. The cost of solar PV installations comes primarily from solar panel and battery storage with each contributing roughly half towards the total cost. The batteries having such high capital cost are usually lead- acid batteries and last only around a year with solar PV system thus requiring periodic replacements with high recurring costs.

Domestic solar PV installations in Pakistan are mostly in grid-connected topology where the solar power is used to charge battery backups for usage in case of load shedding event. We note that there are two major problems in the way solar PV systems are used in domestic applications [18].

Firstly, for the grid-connected systems, the real-time usage of solar power produced requiring no batteries makes sense. However, consumers in Pakistan are forced to store the power for use during load shedding hours. This approach requires the battery back-ups that account for around half of the total cost of solar PV systems installed.

The problem does not stop here, the shorter life of batteries requires periodic replacements thus adding more towards the life cycle costs. Other types of batteries such as Li-ion are also available that that promise longer life-time, but have much higher cost than the conventional lead-acid batteries.

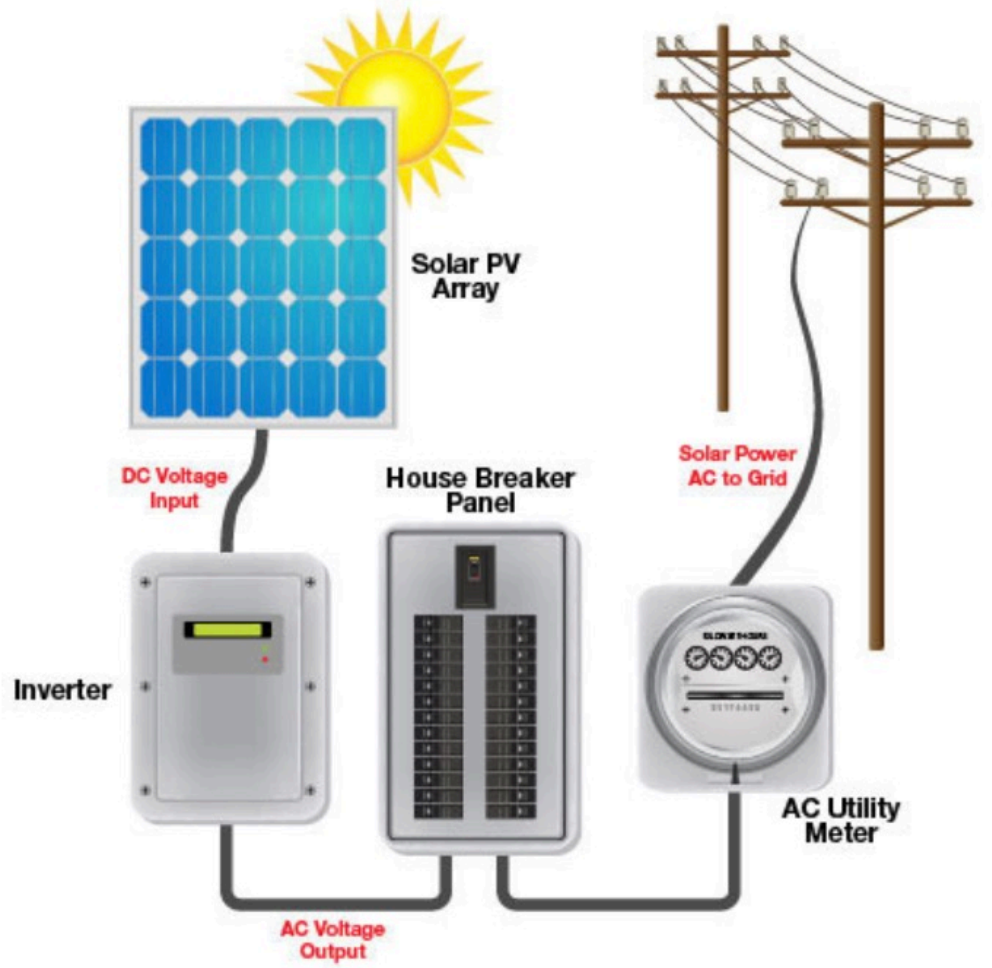

Figure 2.12 Grid-Tied Solar System

There are other alternatives to the batteries for energy storage, but most of them are either expensive or not suitable for domestic applications. The ultra capacitors have been proposed for the energy storage for quite some time now, but the technology is costly as well as will take time to mature. Hence, we believe that there should be a usage strategy in which users can use the produced solar power without the need of storage while still having the same functionality that they currently strive for.

Secondly, the current usage strategy have a lot of draw backs. The consumer convert the stored DC power to AC with process being highly inefficient due to the use of low quality inverters. They are also forced to operate only a small set of appliances running on a separate wiring.

The consumers are also not aware of the amount of energy stored and are unable to manage the stored power according to their will. We believe that there is a need of a practical energy management system that helps consumer in better utilizing the available power.

As established earlier, the current strategy of using domestic solar panels have significant drawbacks in terms of cost and usability. The use of battery backups seems unavoidable to tackle the problem of load-shedding, but incurs significant capital and recurring cost. The separate wiring used for the inverter backups limits the freedom in choice of appliances that consumer want to operate and also is not aesthetically pleasing.

In current scenario, using a grid-tied Solar Power System is perfect solution for domestic users. This will eliminate the use of battery backup with solar, as the excess power is fed back to grid and recorded through two-way metering mechanism, for which the user is rewarded. The 1MW Solar Power Plant project of Parliament House is of this nature i.e. Grid-Tied, and has been awarded the first net metering license by NEPRA.

With the current supply demand gap scenario and expected increase in energy usage in future, this scheme can prove very vital. On the whole, the reduced cost of solar PV systems wll motivate more consumers to deploy such solutions and the effect will propagate.

2.6 How Grid-Tied Solar Power System Works?

On Grid-Tied Solar Power is connected directly with the main grid and there is no need battery back-up system to store any excess energy. If system is producing more energy with solar panels than energy being used by connected load, the excess energy is sent to grid’s power company.

Opposite to that, if the system load consumes more electricity than is generated, it will be billed for only the excess consumption [19].

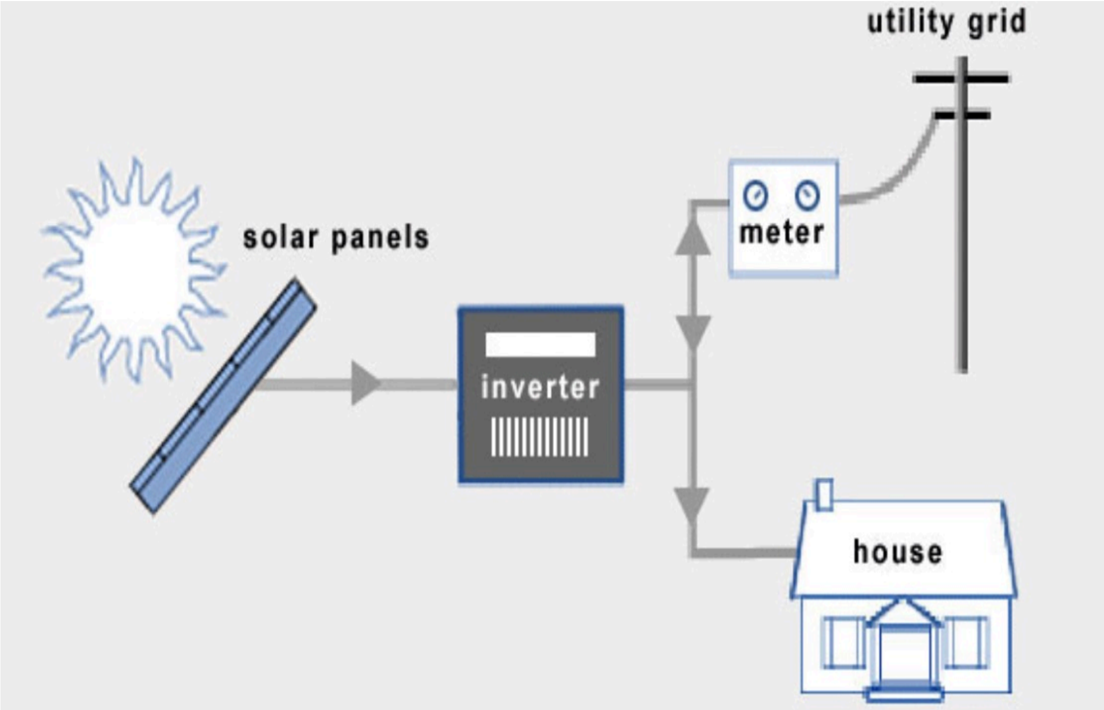

Figure 2.13 Grid-Tied Solar System Diagram

Power generated by Solar Panels is converted into alternating current (AC) by inverter for use by system. If there is load connected, the power runs through switch board to the load.

If there is no-connected load while solar power is being produced, it gets sent to the grid which is measured by the two-way meter. The utility company will pay for this exported excess electricity produced by Solar system. This is called Net-Metering. [9]

Apart from selling the excess energy to utility, one other major benefit of Grid-Tied Solar power system is saving the capital cost as no battery backup is required.

2.7 Components of Installed Power System in Parliament House

Grid-Tied Photo Voltaic Solar Power System installed in Parliament Building is made up of seven main components as below:

i. Silicon Mono Crystalline Photo Voltaic Solar Modules/Panels
ii. Combiner Boxes

iii. DC Distribution Cabinet
iv. Automatic/Communized controlled Grid-Tied Inverters
v. AC Distribution Cabinet/Anti-Counter current Cabinet
vi. Step Up Isolation Transformer 11 kV
vii. Metering Device/System

2.7.1 Specifications of Silicon Mono Crystalline Photo Voltaic Solar Modules

The Parliament House 1MW Solar Project consists of 3940 pieces of 255W polycrystalline PV modules and installed capacity is 10047 Wp. 1180 pieces of module are mounted at 31 degree on the Parliament House rooftop, and 2760 pieces are mounted with 14 degree on Parking Lot rooftop.

Table 2.1 below shows the specifications of 255Wp solar panel:

Electrical Parameter	Content
Rated Power	255Wp
Peak voltage	30.0 V
Peak Current	8.49 A
Short Circuit Current	9.01 A
Open Circuit Voltage	37.7 V
Current Temperature Coefficient	0.050%
Voltage Temperature Coefficient	-.32%
Power Temperature Coefficient	-.42%

Table 2.1 Specifications of PV Module

2.7.2 Specifications of Automatic/Communized controlled Grid-Tied Inverters

02 x 250KVA and 01x500KVA Photovoltaic (PV) Grid inverter were used to convert the DC produced from PV modules to AC.

Table 2.2 shows the specifications of 250KVA Invertor are as below:

Electrical Parameter	Content
Input Peak DC Power	275KWp
Input Peak DC Voltage	1000V
The range of MPPT	440-850V
Rated output AC Power	250Kw
The precision of MPPT	99%
Input Peak Current	625A
Rated AC Voltage	400V
Rated AC Frequency	50Hz
Total Harminic distortion rate	THDK3%
Power Factor	>99%
Maximum Effeciency	97.4
Ingress Protection	IP20
Ambient Temperature	-20+55c
Ambient Humidity	0-95%
Communication protocol/interface	RS485

Table 2.2 Specifications of 250KVA Inverter

Table 2.3 shows the specifications of 500KVA Invertor are as below:

Electrical Parameter	Content
Input Peak DC Power	550KWp
Input Peak DC Voltage	1000V
The range of MPPT	440-850V
Rated output AC Power	500Kw
The precision of MPPT	99%
Input Peak Current	1250A
Rated AC Voltage	400V
Rated AC Frequency	50Hz

Total Harmonic distortion rate	THDK3%
Power Factor	>99%
Maximum Efficiency	97.7
Ingress Protection	IP20
Ambient Temperature	-20+55c
Ambient Humidity	0-95%
Communication protocol/interface	RS485

Table 2.3 Specifications of 500KVA Inverter

All the 03 installed inverters have following protections:

- AC Over-voltage protection
- Overclocking Protection
- Under Frequency Protection
- Temperature Protection
- AC Over-Current Protection
- DC Over-Current Protection
- DC Over-Voltage Protection
- AC Over-Voltage Protection

Apart from that, the inverters have ability to monitor the isolated island quickly and monitor the connection between power grid and solar network. If the grid is off, the inverters will automatically disconnect the solar system for safety purposes.

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Chapter 3

Methodology

The main theme of this research was to device a solution to improve the overall efficiency of installed 1MW Grid-Tied Solar Power Plant in Parliament House.

3.1 Commons Issues that Effects the Performance of Solar System

One method to decrease the high cost per kWh of electricity is to improve the performance of PV module systems. Since extraction of electricity from solar energy is considered to be very expensive when compared to conventional fossil fuel electricity [1]. So it is very important to extract as much energy as possible from sun light.

During the study of year around efficiency of Solar Power, it was observed that solar panels are not receiving maximum available sunlight which greatly effects the efficiency. [2]

Furthermore, the efficiency of PV module is directly proportional to its temperature. As normally the temperature remain very high at installation site, resultantly the efficiency of PV module is affected.

PV Modules are directly exposed environment and its efficiency depends on the sunlight, to which it is exposed. When it has dust on its surface, the area exposed to sunlight is reduced, resulting in effecting its performance in negative way. [3]

So to ensure solar panels remain at optimal designed temperature and are also clean, sprinkling water technique is adopted while for making use of maximum available sunlight, solar concentrator technique is used.

3.2 Cleaning and Cooling Down Solar Panels by using Sprinkling Water Technique

Pakistan being full of sunshine, environment is very suitable for Solar Energy. However, the temperature usually remains very high. PV module has a property of negative temperature coefficient and as a result, when temperature of solar panels increases, efficiency of power generation decreases gradually. Apart from heat, another factor that greatly effects the efficiency of PV panel are dust particles. It is because it reduces the visible/exposed surface area to direct sunlight that in return result in less photon movement [4].

To control and minimize the effect due to this reason, a Sprinkling Water cooling system can be used for installed solar power plant in parliament house to reduce the temperature of modules. This system will serve two purposes simultaneously: cleaning the solar panel surface from dust, thus exposing more area to direct sunlight and secondly, maintaining the temperature of solar panels. Accordingly, will achieve more power generation from 1MW installed solar system [5].

An very cost effective way of improving efficiency and reducing the rate of thermal degradation of a solar panel is by controlling the operating temperature of its surface. This can be achieved by cooling the module using sprinkling water. Cooling of PV panels is considered the less expensive technique that is used to improve PV panel performance.

One of the main obstacles that face the operation of solar panels is overheating. This is resulted due to excessive solar radiation and high ambient temperatures. Overheating reduces the efficiency of the panels a lot. The ideal P–V characteristics of a solar cell for a temperature variation between 0 °C and 75 °C are shown in Figure 3.1.

P–V characteristic is the relation between the electrical power output P of the PV Module and the output voltage, V, while keeping the temperature and irradiance constant. If any of those two factors, namely temperature and solar irradiance, are changed the whole characteristics change.

The maximum power output from the solar cells decreases as the cell temperature increases, as can be seen in Figure 3.1. Temperature coefficient of the Solar panels used in this research is −0.5%/°C, which means that for every 1 °C of temperature rise there is efficiency drop by 0.5%. So it is clear that heating of the PV panels can affect the output of the panels drastically.

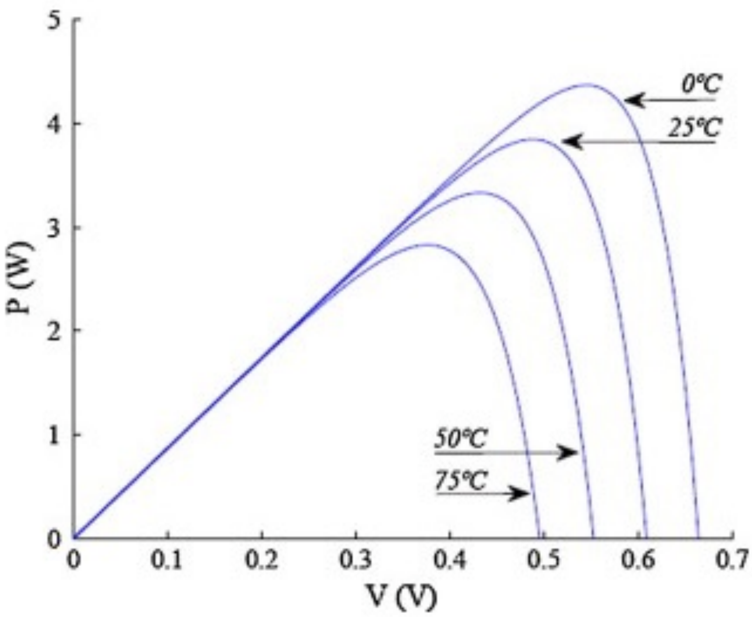

Figure 3.1 Relation of Power/Temperature of Solar Panel

A long-term performance modeling of a proposed solar-water pumping system was carried out which consists of a solar panel cooled by water, a water pump, and a water storage tank. Cooling of solar panel is then achieved by introducing water trickling configuration at the top of the solar panel (upper surface) upper surface of the panel. Another type of solar panel cooling is by using water pipe at the back of modules. This will lowers the operating cell temperature by approx. 20K, and increases power output by approx. 9% [6].

To investigate and evaluate the performance of solar panel module, an experimental rig was developed with the proposed cooling technique. The results of the experiment indicated that due to the heat loss between water and the PV panel's upper surface, an increase of about 17% in system output is achieved at peak conditions. The Long-term efficiency of the system is estimated by integrating test results in a simulation package and also by using site radiation and temperature data. Through the simulation results of the system's annual performance, it was indicated that an increase of 5% in delivered energy from the PV module is possible during dry and warm seasons.

Most of the time research carried out on Solar panel cooling is concentrated on building applications. Such an application of solar panel in buildings can be used for the production of electricity. Such dual system requires the optimization of air flow rate to achieve significant PV cell cooling. It is found that solar panels with rear air ducting can reduce operating temperature by 25◦C [7]. This air cooling technique with balanced flow rate for a PV array was very economical only for large-scale PV systems [8] only, and for adjusting air flow rate, temperature controller is required. Width of air duct behind the inclined PV modules has a great effect on PV cell temperature. It was found that if the gap is greater behind the modules, cooling will be more due to natural convection [9]. Data from Experimental results of commercial solar modules shows that PV cooling can increase the electrical efficiency and the total efficiency of the system [10].

Another appropriate technique for solar panel cooling is by using water flow over the surface of the solar panels. By using this technique, a surplus of 10.5% in electric power is achieved [11]. For this experiment, DC motor pump and small diameter nozzles are utilized to perform water layer along PV module surface. There are three main benefits of applying this technique: decrease in cell temperature, increase in incident radiation due to radiation refraction, and surface cleaning due to water flow. However, there is also a drawback of the system which is the power required by the pump to circulate cooling water. Thermal analysis and energy balance of PV cells is modeled based on climate variables such as cell temperature, ambient temperature, and solar radiation [12].

The model is found to be accurate to within 7 K of measured temperature values. Solar panel powered water pumping systems has been widely used in remote areas because its operating cost, which normally competes with conventional energy supply systems. For this purpose, different models have been developed, such as the Solar panel project model given by Clean Energy Decision Support Centre [13].

For two reasons, cooling is required in PV applications:: it increases the lifetime of the PV cells significantly and reduce PV module area by increasing output power of the module.

3.3 Implementing Solar Concentrator

To get use of all the available sunlight, the use of Solar concentrators will be experimented. As its name suggests, it help concentrating the solar light on the photo voltaic cells.

It actually is a light bucket that focuses sunlight onto a small area through making use of components like lenses and mirrors which collect arriving sunlight and then help on focusing it resourcefully onto a solar panel array. Consequently, it help get more sunlight received on solar panel which is then converted into usable electric energy.

The experimental setup for implementing this technique will include large reflecting surfaces, mirrors or other devices to successfully carry out this experiment.

Low cost reflecting mirrors, lenses and light focusing concentrators are a good solution. These mirrors concentrate the light intensity over the whole surface of the panel, that works effectively. The effect is more electrons are generated because of more raditation and hence the output power of solar module increases tremendously. However, because of increased light radiation for longer duration, raises the temperature of the panel which would inversely reduce the open circuit voltage (V_{oc}) and decrease the efficiency. For solving problem of heating of solar panel, a proper cooling system may be needed to sustain the Solar panels performance.

The values of short circuit current and open circuit voltage were measured under different conditions of tracking. Values were obtained from different combination and the output power was calculated. The findings from the experiments shows that through using concentrators, a 30% mean rise of short-circuit (I_{sc}) currents can be achieved. Results also show that PV module with only tracking gives higher output than the system without tracking; but the system with reflecting mirror. Great results were obtained with concentrators and mirrors installed with the PV module. With the help of negligible power consumption by concentrators and less complexity when compared to sun tracking system, use of concentrator or reflecting mirrors is very economical compared to sun tracking. Furthermore, setting up reflectors and concentrators is very easy. This system is very cost- effective, easy as well as don't need any maintenance or other complicated equipments.

The generation of electricity from solar energy varies morning to evening throughout a day, depending upon the intensity of light. At noon, maximum power can be extracted because the intensity of light is at its peak at that time. Moreover, the orientation of panel is also very important factor that should be taken in to consideration. If solar panel is mounted in a way that it receives maximum power specially at noon on sunny day, the received power will be minimum in the morning and evening and maximum at noon. If solar panel is mounted perpendicular to light, it will generate maximum power as compared to other incident angles.

Since electricity produced by PV module is directly proportional to the intensity of light radiation it is receiving, so in to increase the efficiency of the system a concentrating technique may be a better solution. This would considerably decrease the cost of generation of electricity by PV panels [14].

One easy way to improve the performance of PV system is using cost effective reflecting mirrors and light concentrators. Because of the minimum cost and simplified setup of reflecting mirrors, conventional technologies make low price manufacturing possible.

In current generation (being sold in market presently), theoretical efficiency of a PV cell is said to be near 25% to 30% while a practical efficiency is around 17% [15]. When we apply cooling technique through air or water, efficiency of the system can be increased to a greater value [16]. Figure 1 below shows the inclination of solar panel to the trajectory of the sun in Pakistan.

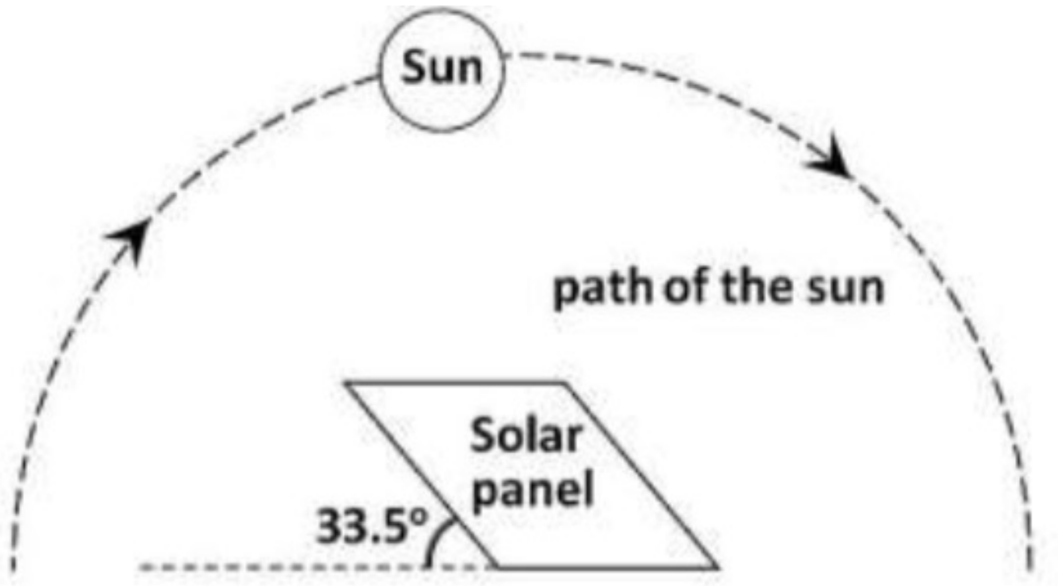

Figure 3.2 Trajectory of Sun

Performance improvement of PV panel by means of all the systems nearly involves the process of increasing the sun light radiation intensity over the panel, which in turn increases the output current accordingly and output voltage is somewhat increases. The relation between voltage and current of a PV cell is shown below in formula A]:

$$V_{OC} = \frac{kT}{e} ln\left(\frac{I_{ph}}{I_{01}} + 1\right) \quad (A)$$

Where,

V_{OC} = Open circuit voltage
k = Boltzmann constant
T = Device temperature
e = Elemental charge
I_{ph} = Photo current
I_{01} = Current due to recombination of bulk charge carriers

3.3.1 Using Solar Concentrators

Concentrated and dispersed light reflectors are used for the purpose to reflect intense and focuses sun light. This convenient method is so useful especially on bright sunny days, as it considerably enhances output of PV module.

Moreover, further to that, it also help to minimize the hazards of hot spots development because of intensity of thrown radiation on some part of panel, which therefore, not only improves the performance but also increases life-time of PV modules. However, its mechanical strength can be a drawback, because of gusty winds, diffused reflectors may be subjected to damage easily, but that can be fixed easily.

3.3.2 Reflecting Mirrors

Basically reflection of light through mirrors is the easiest and most effective way of light reflection. Through reflecting light over the solar panel, output currents and nominal voltage increases. Because of that, the performance of the PV panel system is improved. Also reflecting mirrors are very economical and easily available everywhere.

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Chapter 4

System Implementation and Optimization

In this chapter, we will discuss the details of experiments performed on methods/goals we have already identified in Chapter 3, to improve the efficiency of our installed 1MW Solar Power Plant system in Parliament House.

4.1 Implementation of Sprinkling Water Technique

To perform the sprinkling water test, a water pumping setup was made so test can be performed in different conditions. The setup was constructed as follow:

1. Monocrystalline PV module, having maximum power of 60. It was connected to variable resistance for the purpose of acquiring I-V characteristics curve.
2. The horizontal and inclination of Monocrystalline PV module were changed manually, through-out the test. This was to ensure that balanced incident radiation is received on the surface of solar panel.
3. Temperature of Solar Panel was measured when it was exposed to radiation.
4. Cooling water flow rate is maintained constant to ensure proper results. It was around 4 litres/minutes.
5. Water temperature used for cooling purposes was almost close to ambient temperature.
6. During the process, PV module temperature was measured before and after the cooling with sprinkling water was initiated.
7. To record radiation and temperature measurements, a data logger and data was recorded over a period of one minute.

To achieve maximum PV cell operating temperature, typical summer days were selected for the test.

For plotting I–V characteristics curve of the Solar panel, voltage and current are measured for different range of resistances and at different cell temperatures and radiation.

For better results understanding, tests of PV module I-V characteristic curve were carried out with and without water cooling. PV moduel output power of the developed module was measured at different ambient temperatures and solar radiation. A major different difference in the power output (area under the curve) between the two module temperature, on which tests were conducted, was reported and shown in Figure 4.1. This shows that heat loss by convection due to application of water flow above the PV module upper surface caused the significant reduction of about 26◦C in cell operating temperature at radiation level 1000 W/m2, which improved its effeciency.

4.1.2 Results

The PV module of 60W was tested for different radiation levels, during the process of cooling its surface, for the purpose to verify the linearity between maximum power and radiation level. As evident from Figure 4.2, highest power voltage is constant for the different radiation intensity and whereas, the highest power current & radiation have linear behavior.

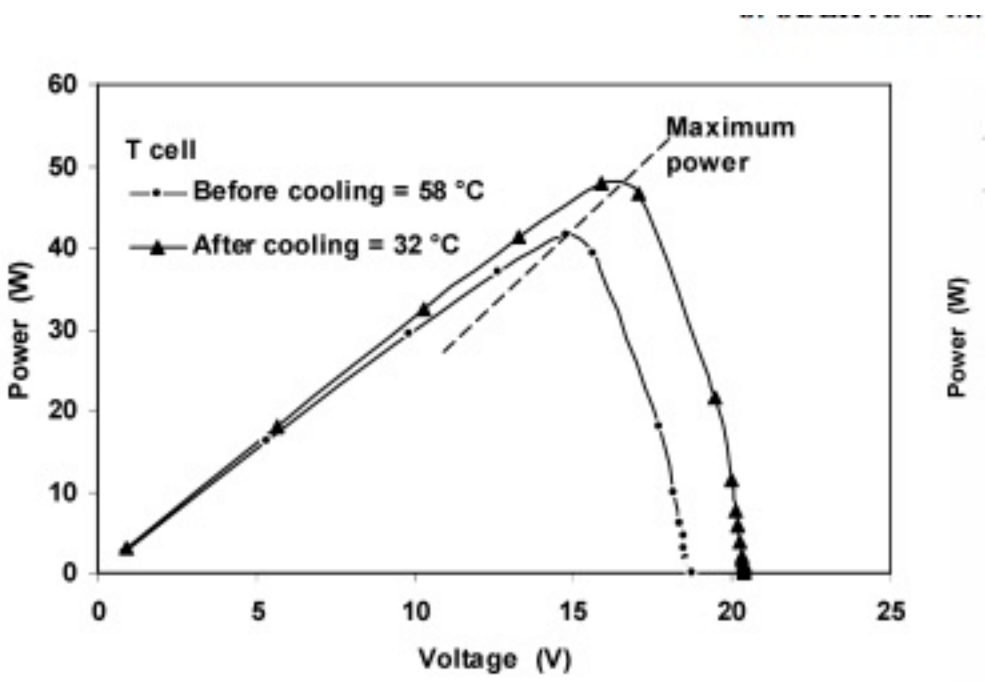

Figure 4.1 The effect of water cooling on voltage-power characteristic curve of the PV module. Radiation on PV module surface is equal 1000 W/m2.

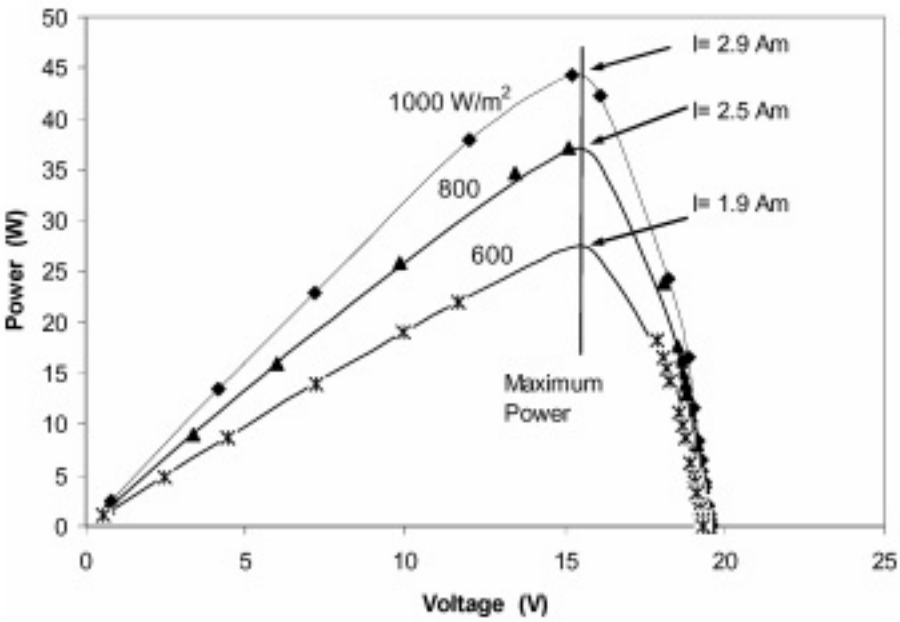

Figure 4.2 Maximum power of the PV module during surface cooling, and at different radiation levels. Surface temperature during cooling is 40◦C.

Figure 4.1 shows the gain in output power of the PV module attained by the different sources of cooling water. In typical summer day, PV module surface temperature in a was found to be around 58 degree Celsius. As this is well above the STP, it caused decrease in power output of PV module by around 5%. So with introduction of water cooling technique using storage tank, around 15% improvement in power was achieved, which is huge.

For cooling PV module, if instead of water from storage tank, underground water is utilized, it will further improve the efficiency by decreasing the temperature of PV module. This is because underground water does not go through significant variation around the year and this will maintain PV module operating at almost constant temperature around the year. As evident from Figure 4.2 that using an underground water having temperature of 25◦C, caused an 8% surplus in output of PV module.

Another preferred standpoint of utilizing water for cooling the upper surface of the PV module is the expansion in surface input radiation on account of the refraction in water layer, and this impact was accounted while taking quick readings of the photo voltaic module yield control amid the dry and wet surface of comparative temperatures. To begin with, the PV module control is estimated amid water stream; water stream is then stopped, and instantaneous power measured is logged in. The impact of utilizing the created cooling procedure on PV module yield control for a scope of radiation, and module surface temperature equivalent to 33 degree Celcius is appeared in Figure 4.1. Although the improvement in power is because of two factors: the decrease of radiation incident angle (θ) because of refraction in water layer, and cooling by regular convection. This is obvious from Figure 4.1 that radiation incident angle on dry surface is higher than with water drops ($\theta 1 > \theta 2$), which causes an expansion in input radiation during PV module cooling.

Photo Voltaic module output power rises in the range 4–10%, for radiation level between 400–1000 W/m2. It is again evident from Figure 4.1 that PV module output power is increased significantly through use of installed cooling technique because of beam refraction. Furthermore, there were no significant salt deposits on the photo voltaic panel surface due to its inclination and effect of gravity, which helped in continuous water flow and any deposit removal. This is because the bigger particle deposits are dodged by the water filter that was coming through pump assembly.

Since thermocouples were fixed to the surface of PV module by using glue, and there was a possibility of imperfect contact with the surface, there was some error error in test results in the temperature measurement of the PV's upper surface. However, this error was very negligible as it was in range of 0.1–0.3◦C for measured temperatures (25–60◦C). The effect of this uncertain condition on the maximum PV module power in Figure 4.2 was established to be just within range of 0.15–0.35%.

4.1.3 Water Consumption Calculations

Experiments showed that optimum water requirement for 1 PV module having capacity of 255 is 03 (03 liters/module) and 12 liters of water is required for cleaning/cooling down temperature of 1KW installed Solar Power system. So for the purpose of cooling down the temperature of 255K

PV modules installed in 1MW solar power plant of Parliament house, 12000 liters of water will be required.

4.2 Implementation of Solar Concentrators Technique

In this experiment, we will be using commonly used reflecting mirrors for the purpose of performance improvement of PV module.

Owing to the the geometry of sun and earth and location of Pakistan on map, we kept PV module inclined at 34.5 degree to horizontal axis. The PV Module was positioned to the north-southern direction. The reflecting mirrors for experiment were attached to the edges of the PV Module. The reflecting mirror was aligned in a way that maximum amount of sun radiation was reflected over the PV module. Reflecting mirror must be inclined at 1200 to get maximum output of PV module, if its size is identical to the size of PV module. However, if reflecting mirror size is twice the size of the solar panel then there isn't requirement of1200 inclination.

Electrical specification of solar panel used in the experiment: [At STC (1000 W/m2, AM 1.5 spectrum and 25 degree of cell temperature)]

- *Peak Power (P_{max}) : 10.0W*
- *Voltage (V_{mp}) : 17.0V*
- *Current (I_{mp}) : 0.58 A*
- *Open Circuit Voltage (V_{oc}) : 21.6 V*
- *Short Circuit Current (I_{sc}) : 0.68 A*

PV Module dimensions which was used were 0.357m x 0.302m and the dimension of each reflecting mirror used were 0.55m × 0.6m. Total of 02 nos. of reflecting mirrors were used for reflection of sun- light over the panel at any time of the day. The dimensions of the reflecting mirrors used are 0.55m x 0.6m.

Figure 4.3 shows the experimental setup.

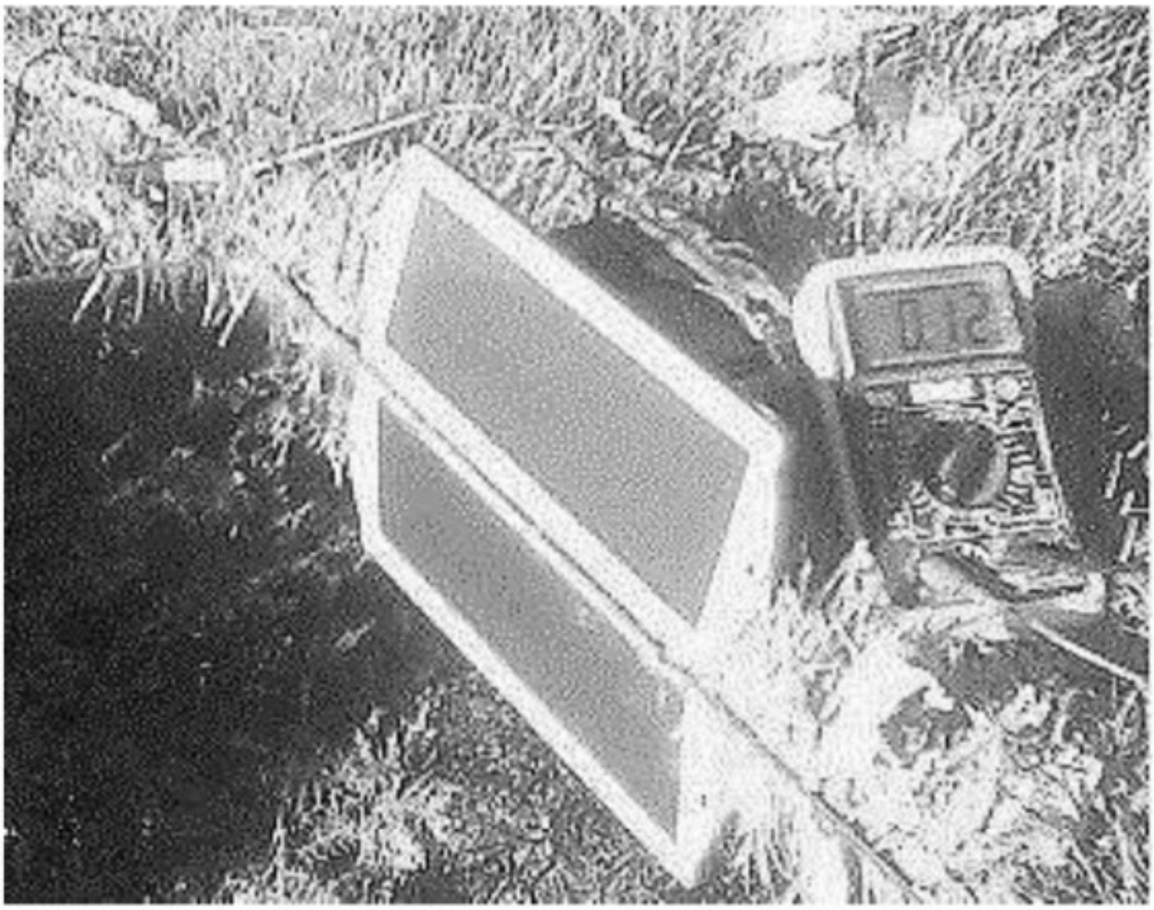

Figure 4.3 Experimental Setup for Solar Concentrator

Sunny bright and clear day was chose to perform this experiment. The data obtaine from the experiment was recorded and then summarized. Afterwards, graph was plotted using that data which is shown in figure 4.4.

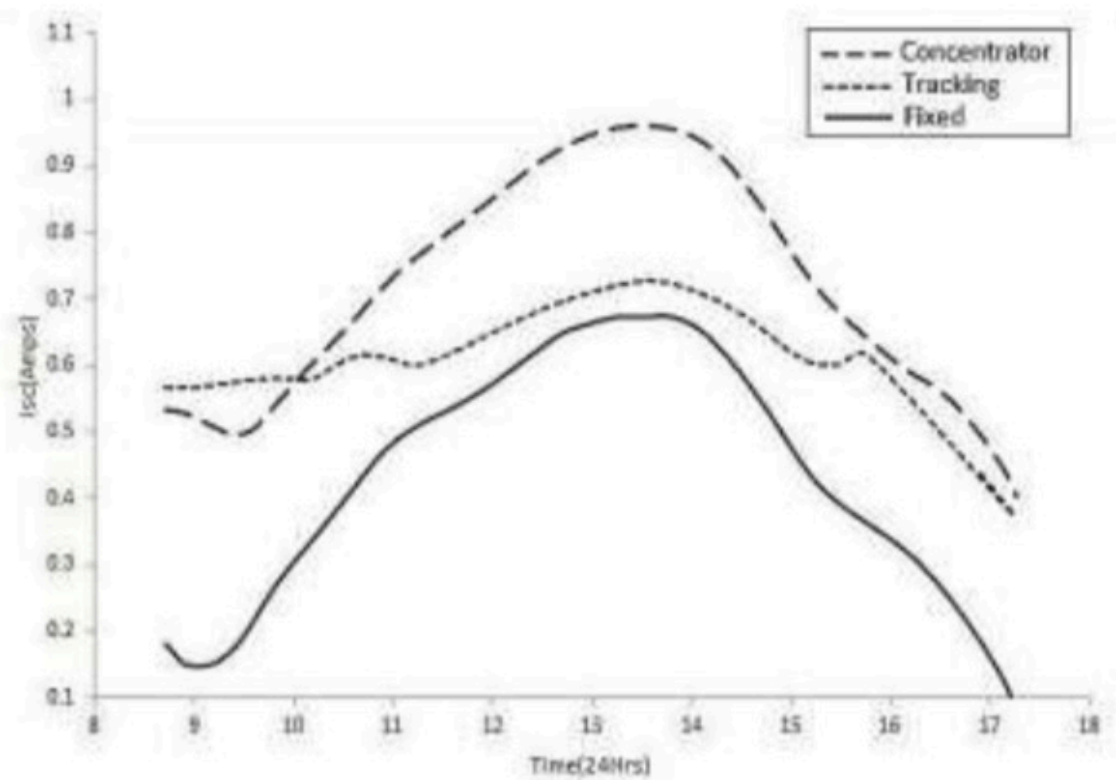

Figure 4.4 Short circuit current (Isc) timely changes of PV module

4.2.1 Results

As evident from the curves in figure. 4.4, it can be derived that, for any time during a day, the value of short circuit current I_{sc} with reflector mirror is always higher than the I_{sc} without using the reflector mirror setup. During sunny and clear day, it is understood fact that radiation intensity will be maximum at noon yielding maximum output power. From morning to noon, power output increases gradually, and afterwards, from noon to evening, it starts decreasing. So improvement of solar panel best occurs during mid-day or noon with reflectors, when short circuit current with reflectors goes above than the short circuit current with tracking over a wide range. This normally occurs at noon between 12pm to 3pm. These are the hours when we can get maximum solar radiation.

So if we made perfection in this part of the day, it will yield more results as compared to morning or afternoon. On average there is increase of 25% in Isc. It has been noted that, the average increase in Isc was about 20%, in major part of the day. Nevertheless, with optimization of mirror size, the performance can be further improved. Another point regarding the data recorded from the experiment is that the readings were noted under different methods, but with some time gap, and during that passage of time, the readings of pyrometer were not changed. This suggests that there is no alteration in solar irradiance during transition period.

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Chapter 5

Conclusion

The results obtained from experimenting sprinkling water technique demonstrates how the electrical power output is increasing as more heat is taken away from the solar panel. Based on the experiments performed in controlled environment, the power output of air cooled solar panel increases when compared to solar panel without cooling. It is worth noting that with introduction of water cooling technique using storage tank, around 15% improvement in power was achieved, which is huge.

Similarly, the results obtained from experimenting solar concentrator techniques shows that by using the reflecting mirror, the performance of solar panel/PV module can be greatly improved. A significant advantage of using reflecting mirror is that they are very in-expensive and cost effect and readily available in the market. This technique is making the usage of solar panel by making it more feasible in countries of the world like Pakistan, by overall reducing cost of electricity generation through Solar panels through improvement of the PV solar system efficiency installed at home. The easy installation and cheapness of this system, is yet another advantage.

Since output of average power has increased significantly during mid-day using reflecting mirrors, so the panels which are equipped with mirrors are also able to be used for those equipments, which has high rating power inputs requirements. For example, running of water pumps load, which was commonly used for irrigation purpose. Furthermore, setting up this reflecting mirror is very simple and straightforward process. It can be easily attached to wooden structure. Despite the advantages of using solar concentrator technique mentioned above, there are some shortcomings of this system, which can be easily solved like:

1. Due to uneven distribution of light radiation on the surface of PV module, formation of heat spots is very likeable. However, this problem can be overcome by using reflecting mirrors of size bigger than that of solar panels. This will ensure uniform distribution of reflected light throughout the PV module.

2. By implementation of reflecting mirrors with large surface area, they may be exposed to winds which can cause damage to the. This problem can be easily overcome by setting up strips of reflectors in louvers way on the extreme edges of PV modules.

Moreover, proper maintenance of reflecting mirrors will be required on daily basis which mainly include cleaning its surface, so the reflected rays are distributed uniformly over the entire solar panel for giving the best performance results.

Despite both pros and cons of using solar concentrator technique to improve the efficiency of installed Solar system, its pros easily overweigh any of its disadvantage.

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