STUDY AND DESIGN OF GRID CONNECTED SOLAR PHOTOVOLTAIC SYSTEM AT PATIALA, PUNJAB

A Thesis Report Submitted In Partial Fulfillment of The

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MASTER OF ENGINEERING

In

Power System and Electric Drives

Submitted by

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CERTIFICATE

I hereby certify that the work which is being presented in this thesis entitled, **"STUDY AND DESIGN OF SPV GRID CONNECTED SYSTEM AT PATIALA,PUNJAB"** in partial fulfillment of the requirements for the award of degree of **Master of Engineering (Power System and Electric Drives)** in the **Department of Electrical And Instrumentation Engineering,** at **Thapar University, Patiala**, is an authentic record of my own work carried out under the supervision of **Mr. Souvik Ganguli (Asst. Professor)** and refers other researcher's work which are duly listed in the reference section.

The matter embodied in this thesis has not been submitted for the award of any other degree to any other university.

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This is to certify that the above statement made by the candidate is correct and true to best of my knowledge.

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ABSTRACT

The depletion of fossil fuel resources on a worldwide basis has necessitated an urgent search for alternative energy sources to meet up the present day demands. Solar energy is clean, inexhaustible and environment-friendly potential resource among renewable energy options. But neither a standalone solar photovoltaic system nor a wind energy system can provide a continuous supply of energy due to seasonal and periodic variations. Therefore, in order to satisfy the load demand, grid connected energy systems are now being implemented that combine solar and conventional conversion units. The objective of this work is to estimate the potential of grid quality solar photovoltaic power in Patiala district of Punjab and finally develop a system based on the potential estimations made for a chosen area of 100 m^2. Equipment specifications are provided based on the availability of the components in India. Annual energy generation by proposed Grid connected SPV power plant is also calculated. In the last, cost estimation of grid connected SPV power plant to show whether it is economically viable or not.

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List of Abbreviations

kW_p	kilo Watt peak
SPV	Solar Photovoltaic
MWh	Mega Watt hour
GW	Giga watt
MW	Mega watt
MT	Metric Tonnes
MU	Million Units
I(sc)	Short circuit current
V(oc)	Open circuit voltage
KVA	Kilo Volt Ampere

Organization of the Thesis

This thesis consists of six chapters. The first chapter discusses theory regarding introduction to energy, energy scenario for world, India and Punjab. Basically focuses on why we need to go for renewable energies and why we prefer solar energy. The second chapter is based on solar photovoltaic technology, in which Basic building block of PV system and types of solar photovoltaic system are discussed in detail. In the 3^{rd} chapter deals with summary of work carried out by various researchers on solar photovoltaic system and objective of thesis is also identified. From Fourth chapter start our results tables which shows us how much solar potential available at Patiala district of Punjab and possible plant capacity for an arbitrarily chosen area also calculated. Fifth chapter deals with study of grid connected solar photovoltaic systems and gives an analysis of the design of solar grid connected power plant, its cost estimation and annual energy generation by plant. The conclusions and the scope of further work are detailed in Sixth chapter.

INTRODUCTION WITH ENERGY

Chapter 01

1.1 INTRODUCTION

Energy plays a pivotal role in our daily activities. The degree of development and civilization of a country is measured by the amount of utilization of energy by human beings. Energy demand is increasing day by day due to increase in population, urbanization and industrialization. The world's fossil fuel supply viz. coal, petroleum and natural gas will thus be depleted in a few hundred years. The rate of energy consumption increasing, supply is depleting resulting in inflation and energy shortage. This is called energy crisis. Hence alternative or renewable sources of energy have to be developed to meet future energy requirement.

1.2 ENERGY CLASSIFICATION

Energy can be classified into several types:

1.2.1 Primary and Secondary Energy

Primary energy sources are those that are either found or stored in nature. Common primary energy sources are coal, oil, natural gas, and biomass (such as wood). Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to earth's gravity. The major primary and secondary energy sources are Coal, hydro power, natural gas, petroleum etc.

Primary energy sources are mostly converted in industrial utilities into secondary energy sources; for example coal, oil or gas converted into steam and electricity. Primary energy can also be used directly. Some energy sources have non-energy uses, for example coal or natural gas can be used as a feedstock in fertilizer plants.

1.2.2 Commercial Energy and Non Commercial Energy

The energy sources that are available in the market for a definite price are known as commercial energy. By far the most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world. In the industrialized countries, commercialized fuels are predominant source not only for economic production, but also for many household tasks of general population.

The energy sources that are not available in the commercial market for a price are classified as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural households. These are also called traditional fuels. Non-commercial energy is often ignored in energy accounting.

1.2.3 Renewable and Non- Renewable Energy

All forms of energy are stored in different ways, in the energy sources that we use every day. These sources are divided into two groups -- renewable (an energy source that we can use over and over again) and nonrenewable (an energy source that we are using up and cannot recreate in a short period of time).

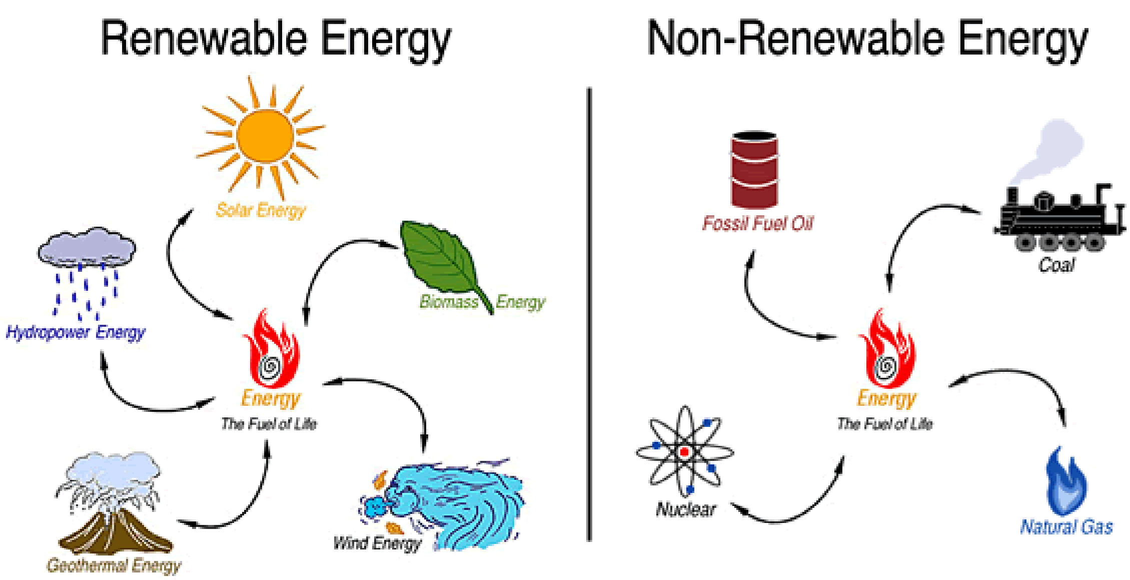


Figure 1.1: Renewable Energy Sources and Non-Renewable Energy Sources

Renewable and nonrenewable energy sources can be used to produce secondary energy sources including electricity and hydrogen. Renewable energy sources include solar energy, which comes from the sun and can be turned into electricity and heat. Wind, geothermal energy from inside the earth, biomass from plants, and hydropower and ocean energy from water are also renewable energy sources.

However, we get most of our energy from non-renewable energy sources, which include the fossil fuels -- oil, natural gas, and coal. They're called fossil fuels because they were formed over millions and millions of years by the action of heat from the Earth's core and pressure from rock and soil on the remains (or "fossils") of dead plants and animals. Another nonrenewable energy source is the element uranium, whose atoms we split (through a process called nuclear fission) to create heat and ultimately electricity.

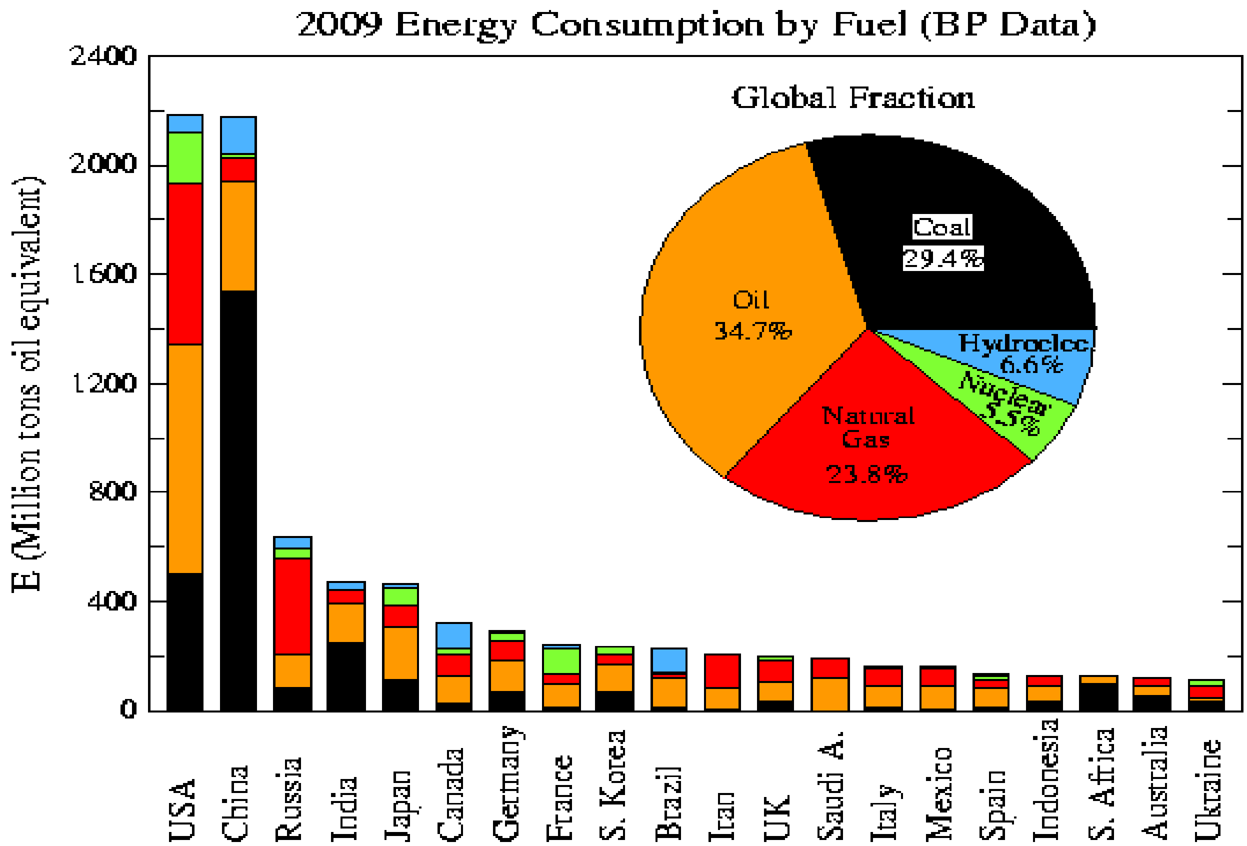
We use all these energy sources to generate the electricity we need for our homes, businesses, schools, and factories. Electricity "energizes" our computers, lights, refrigerators, washing machines, and air conditioners, to name only a few uses. We use energy to run our cars and trucks. Both the gasoline used in our cars, and the diesel fuel used in our trucks are made from oil. The propane that fuels our outdoor grills and makes hot air balloons soar is made from oil and natural gas.

1.3 ENERGY SCENARIO

The present energy scenario is discussed under categorical division of World, India and Punjab.

1.3.1 World Energy Scenario

Global economic recession drove energy consumption lower in 2009 – the first decline since 1982. World primary energy consumption – including oil, natural gas, coal, nuclear and hydro power – fell by 1.1% in 2009. Hydroelectric power generation increased by 1.5%.



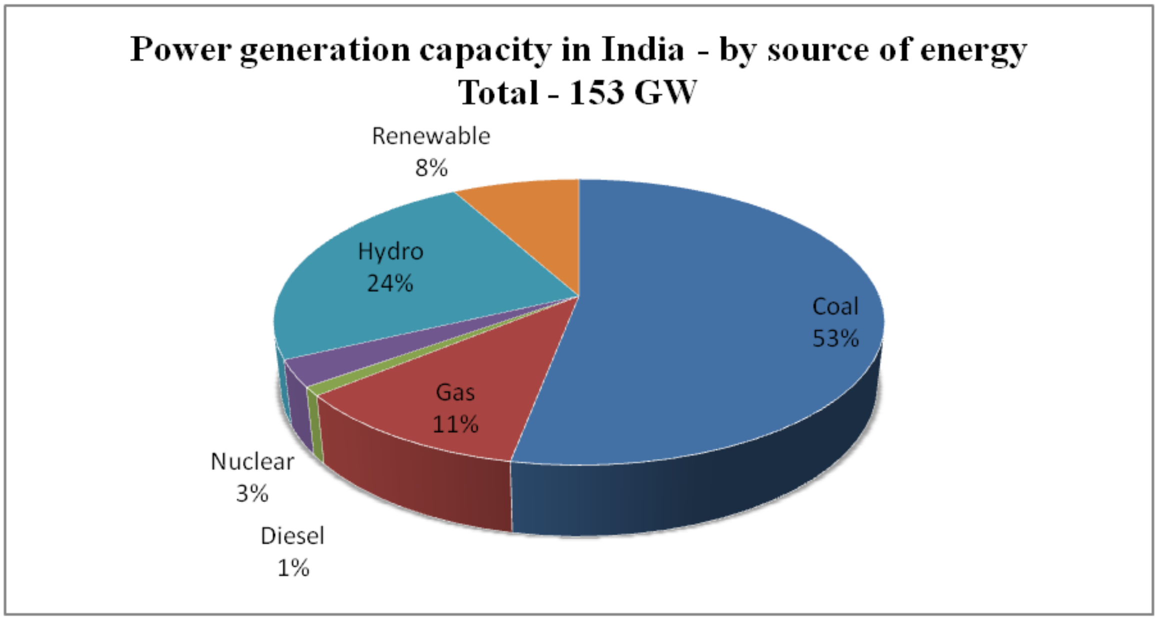
Source: Ministry of Power, GoI

Graph 1.1: Power generation capacity in world by source, 2009

1.3.2 Energy Scenario In India

By end of year 2008, India had power generation capacity of about 152 GW. Even with such an installed base, about 17% of the villages in India are non-electrified, which would translate to about 450 million. With a growing economy, the demand for power is growing at about 6% every year and the peak load demand is expected to reach 176 GW by 2012.

The Indian power sector is highly dependent on coal as a fuel, with 53% of the total installed capacity being coal based generation. Given the current scenario, coal consumption by the power sector is likely to reach levels of 173 mn Metric Tonnes by 2012. According to the Ministry of Coal, the existing coal reserves are estimated to last for another 40-45 years. [22]



Source: Ministry of Power, GoI

Graph 1.2: Power generation capacity in India by source, 2009

About 11% of the total power is sourced from oil & gas. Apart from automobiles and industry, the power sector is the largest importer of oil & gas in India. For 2008, the total oil imports accounted for 7% of the GDP.

India's per capita consumption of energy is far lower than that of the world average. Even with such a low per capita consumption, during the year 2008-09, the power deficit is about 11% in total demand and a deficit of more than 12% in peak load demand. This clearly signifies that the available fuel is not sufficient to meet the rising demand for energy of India.

1.3.2.1 Status of renewable energy in India

In the present scenario, renewable resources emerge as the best alternative. At present, renewable energy accounts for about 11% of India's installed generation capacity of 152 GW. Much of this capacity is wind-based (about 11 GW), with the share of solar power being only about 6 MW. India is blessed with an abundance of non-depleting and environmentally friendly renewable resources, such as solar, wind, biomass, hydro and cogeneration and geothermal. Wind energy sector, which has shown tremendous growth in the recent year, dominates the renewable energy sector in India.

No.	Source/ System	Achievements during 2009-10 (up to 31.12.2009)	Cumulative achievements during 2009-10 (up to 31.12.2009)
A. Grid Interactive Renewable Power			
1.	Biomass power (agro residues)	131.50 MW	834.50 MW
2.	Wind power	683 MW	10925.00 MW
3.	Small hydro power (up to 25 MW)	129.15 MW	2558.92 MW
4.	Cogeneration- bagasses	253.00 MW	1302.00 MW
5.	Waste to energy	4.72 MW	65.01 MW
6.	Solar power	3.10 MW	6.00 MW
	Subtotal (in MW) (A)	**1204.47 MW**	**15691.43 MW**
B. Off Grid/ Distributed Renewable Power			
7.	Biomass power / cogen. (non bagasses)	39.80 MW	210.57 MW
8.	Biomass gasifier	4.10 MWeq.	109.62 MWeq.
9.	Waste to energy	3.91 MWeq.	37.97 MWeq.
10.	Solar PV power plant & street lights	0.086 MWp	2.39 MWp
11.	Aero generator/ hybrid system	MW	0.89 MW
	Subtotal (in MW) (B)	**47.876 MWeq.**	**361.44 MWeq.**
	TOTAL (A+ B)	**1252.346 MW**	**16052.87 MW**

Table 1.1: Status of renewable energy in India

India has an abundance of solar radiation, with the peninsula receiving more than 300 sunny days in a year. PV is progressively becoming more attractive, than other renewable sources of power, as its cost declines. The various factors leading to decline in cost includes setting up of large scale plants, integration across the value chain, declining cost of raw material, reducing material consumption and higher efficiency of modules.

1.3.2.2 Solar power as a solution to the Indian power scenario

Due to its proximity to the equator, India receives abundant sunlight throughout the year. Solar PV solution has the potential to transform the lives of 450 million people, who rely on highly subsidized kerosene oil and other fuels, primarily to light up their homes. Renewable energy source is a practical solution to address the persistent demand supply gap in the power industry.

The following features of solar power make it the most viable renewable source of energy for India:

- Solar energy is available in abundance.
- Available across the country – unlike other renewable sources, which have geographical limitations
- Available throughout the year
- Decentralized / off-grid applications – addressing rural electrification issues
- Modularity and scalability.

The PV approach is particularly suited for the geographical and socio-economic features of this country having highly skewed energy distribution between urban and rural areas.

1.3.2.3 Solar PV applications in India

The range of applications for solar PV in India is very different from the global mix. Globally, grid connectivity accounts for nearly 75% of the installed capacity and off-grid lighting and consumer applications for the balance 25%.Currently, PV installations in India, almost entirely consist of off-grid connectivity and small capacity applications, used mostly for public lighting, such as street lighting, traffic lighting, and domestic power back up in urban areas and small electrification systems and solar lanterns in the rural areas. In recent years, it is also being used for powering water pumps for farming and small industrial areas. Government organizations like railways, telecom and other agencies are the major consumers of PV solar systems in India [23]. The installed base of solar PV systems in India as of December 2009 is given below:

PV Based Systems	Total Installations
Solar Street Lighting System	54,795
Home Lighting System	434,692
Solar Lanterns	697,419
Solar PV Pumps	7,148
Solar PV generation Plants	2.12 MWp

Source: MNRE Website data, January 2009

Table 1.1: Status of installed base of solar PV systems in India

1.3.3 Energy Scenario in Punjab

The state of Punjab is the first state in the Country which has allowed interstate sale of power generated from NRSE projects in accordance with open access regulations of the appropriate commission as per the addendum notified to the NRSE policy-2006 issued on 11/6/2009.

Energy generation statistics in Punjab is

- Total power sales by PSEB (Punjab State Electricity Board): 41625 MU's,
- Total power generation: 26897 MU's,
- Net energy purchased: 14728 MU's
- Energy Purchase from NTPC: 7291 MU's
- NRSE Generation: 231 MU's.

The State at present is facing acute power shortages. Accelerated addition to generation capacity is required to meet the demand and to achieve higher growth rates. The State Government has decided to set up two new Thermal Power Stations namely 1980 MW Talwandi Sabo and 1320 MW Rajpura in the private sector on BOO basis through tariff based competitive bidding as per case-II guidelines of Government of India. 540 MW Goindwal Sahib Thermal Power Plant is also being set up by M/s GVK Power Limited on BOO basis. Punjab is far away from the coal mines/fuel sources. Higher freight on the coal/fuel substantially enhances the cost of power. That is why Punjab Govt. also focusing of installing Non-conventional and Renewable Energy power plants. Mostly on biogas and solar. Good solar insolation level available at PUNJAB of 4-7Kwh/mtr2/day.

For promotion & development of non-conventional and renewable energy programmes / projects Punjab Energy Development Agency, PEDA was formed in September 1991 under Society's Registration Act. 1860 and governed by Board of Governors (BOG). PEDA is working towards a sustainable energy future.

1.3.3.1 Solar Photovoltaic Power Projects (Mw Scale) On Build, Own & Operate Basis

Projects allocated total capacity 19 MW.

- SPV Power Plant Cap. 2MW in Distt. Amritsar commissioned and Inaugurated on 15th Dec.'2009.

- 2x50 KWp Grid interactive SPV power plants at village Bajak, Dist Bathinda and Punjab mini secretariat building, sector 9, Chandigarh.

- 200 KWp Grid interactive SPV power plant at village Khatkar Kalan, Distt. Nawanshahar. which is the native village of Shaheed–E-Azam Sardar Bhagat Singh has been started and being completed.

- SPV Power Plant of capacity 25 KWp for Solar Passive Complex of PEDA.

- MOU (Memorandum of Understanding) signed with BPCL for development of a 1 MW SPV Power Plant at Lalru in Punjab- PPA SIGNED, planned to be commissioned by March'2010.

- MOU signed with M/s. Enterprise Business Solutions Inc., USA for setting up of a 5MW SPV Power Plant in Punjab, PPA signed and planned to be commissioned by June'2010.

1.4 ENERGY AND POLLUTION

The usage of conventional energy resources in industry leads to environmental damages by polluting the atmosphere. Few of examples of air pollution are Sulphur dioxide (SO_2), Nitrous oxide (NO_X) and Carbon oxides (CO, CO_2) emissions from boilers and furnaces, chloro-fluro carbons (CFC) emissions from refrigerants use, etc. In chemical and fertilizers industries, toxic gases are released. Cement plants and power plants spew out particulate matter and volatile organic compounds (VOCs). But most of the renewable energy is pollution free. So it will be better to go for renewable energies.

1.5 WHY WE PREFER SUN NON-CONVENTIONAL ENERGY SOURCE THAN ANOTHER NONCONVENTIONAL SOURCES

Various types of non conventional energy sources are such as geothermal ocean tides, wind and sun. All non conventional energy sources have geographical limitations. but Solar energy has less geographical limitation as compared to other non conventional energy sources because solar energy is available over the entire globe, and only the size of the collector field needs to be increased to provide the same amount of heat or electricity. It is the primary task of the solar energy system designer to determine the amount, quality and timing of the solar energy available at the site selected for installing a solar energy conversion system so among all these solar energy seems to hold out the greatest promise for the mankind. It is free, inexhaustible, non-polluting and devoid of political control. Solar water heaters, space heaters and cookers are already on the market and seem to be economically viable. Solar photo voltaic cells, solar refrigerators and solar thermal power plants will be 'technically and economically viable in a short time. It is optimistically estimated that 50% of the world power requirements in the middle of 21st century will come only from solar energy. Enough strides have been made during last two decades to develop the direct energy conversion systems to increase the plant efficiency 60% to 70% by avoiding the conversion of thermal energy into mechanical energy. Still this technology is on the threshold of the success and it is hoped that this will also play a vital role in power generation in coming future.

1.6 ENERGY FROM SUN

In one minute, the sun provides enough energy to supply the world's energy needs for one year. In one day, it provides more energy than the world's population could consume in 27years. The energy is free and the supply is unlimited. All we need to do is find a way to use it. The largest solar electric generating plant in the world produces a maximum of 354 megawatts (MW) of electricity and is located at Kramer Junction, California. Since India has abundant sources of RE especially sunlight, it can cater to all the energy needs of the country. The country receives an average radiation of 5 KWh per square meter (m) per day and with 2300 to 3200 sunshine hours per year. The potential of solar photovoltaic has therefore been estimated at 20 MW per square km and that of solar thermal applications at 35 Mw per sq m.

1.7 WAYS FOR CONVERTING SOLAR ENERGY INTO ELECTRICAL ENERGY

There are two ways by which we can convert solar energy into electrical energy. These are as shown in figure 1.2.

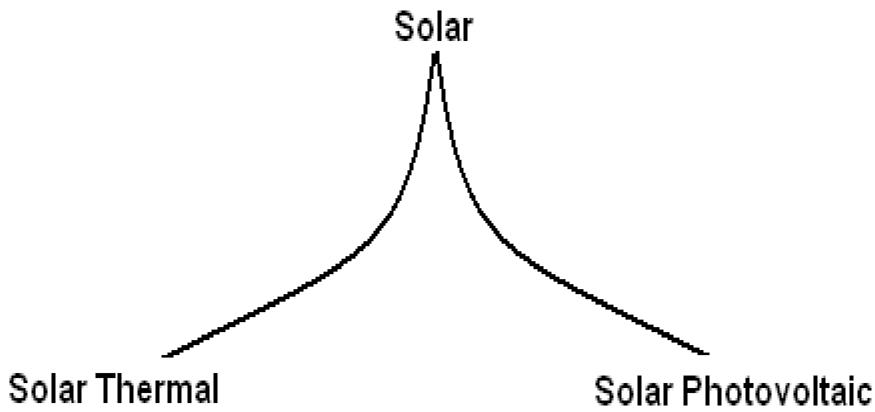


Figure 1.2: Ways of converting solar energy into electrical energy

- Solar thermal: The solar collectors concentrate sunlight to heat a heat transfer fluid to a high temperature. The hot heat transfer fluid is then used to generate steam that drives the power conversion subsystem, producing electricity. Thermal energy storage provides heat for operation during periods without adequate sunshine.

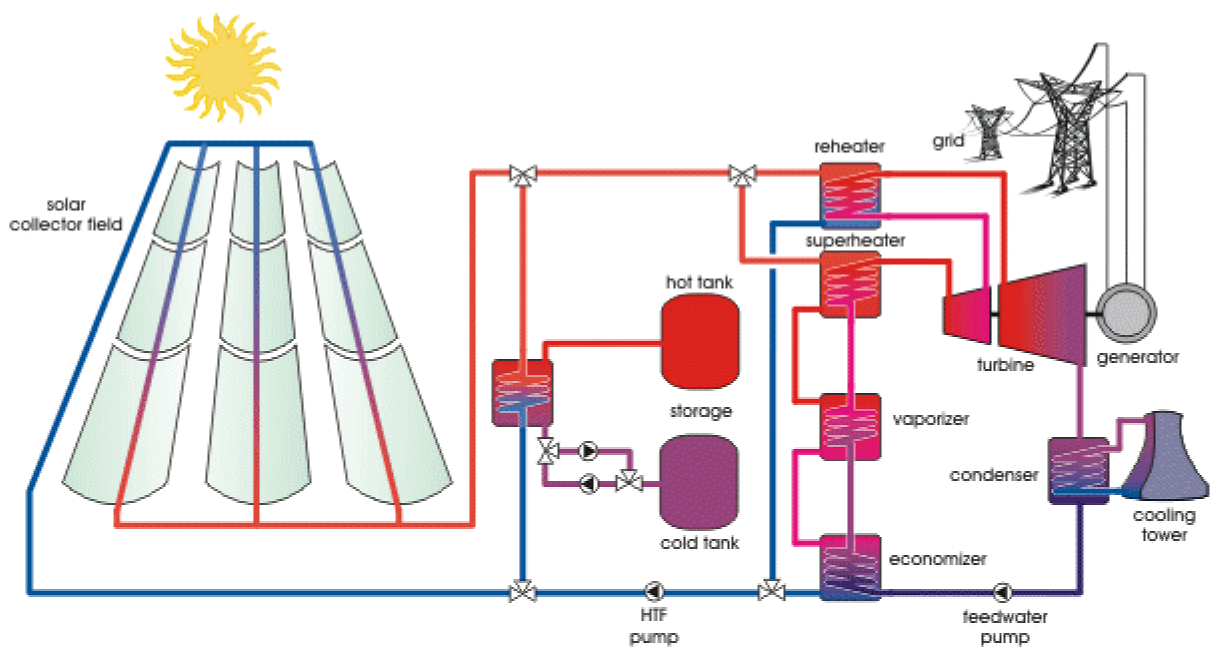


Figure 1.3: Solar thermal

- Solar Photovoltaic: Another way to generate electricity from solar energy is to use photovoltaic cells; magic slivers of silicon that converts the solar energy falling on them directly into electricity. Large scale applications of photovoltaic for power generation, either on the rooftops of houses or in large fields connected to the utility grid are promising as well to provide clean, safe and strategically sound alternatives to current methods of electricity generation.

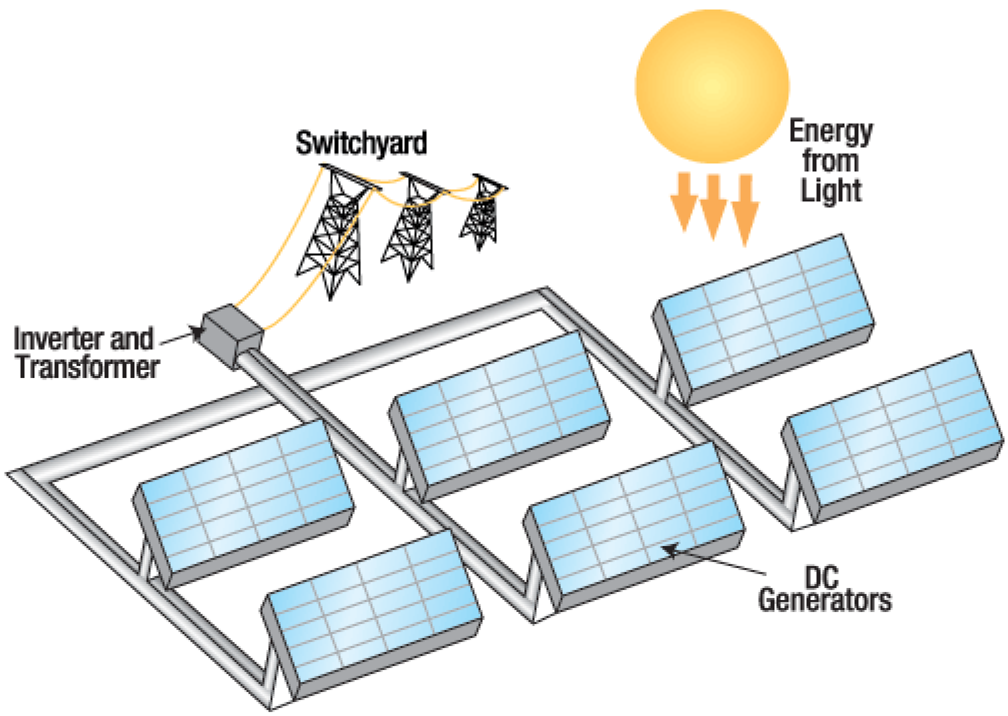


Figure 1.4: Solar Photovoltaic

1.8 COMPARISE BETWEEN SOLAR PHOTOVOLTAIC PLANT AND SOLAR THERMAL POWER PLANT

Many people associate solar energy directly with photovoltaic and not with solar thermal power generation. In contrast to photovoltaic's plants, solar thermal power plants are not based on the photo effect, but generate electricity from the heat produced by sunlight. A fossil burner can drive the water-steam cycle during periods of bad weather or at night. In contrast to photovoltaic's systems, solar thermal power plants can guarantee capacity. Due to their modularity, photovoltaic operation covers a wide range from less than one Watt to several megawatts and solar thermal power plants are small units in the kilowatt range. On the other hand, Global solar irradiance consists of direct and diffuse irradiance. When skies are overcast, only diffuse irradiance is available. While solar thermal power plants can only use direct irradiance for power generation, photovoltaic systems can convert the diffuse irradiance as well. That means, they can produce some electricity even with cloud-covered skies. From economical point of view market introduction of photovoltaic systems is much more aggressive than that of solar thermal power plants, cost reduction can be expected to be faster for photovoltaic systems. But even if there is a 50% cost reduction in photovoltaic systems and no cost reduction at all in solar thermal power plants. Thus we conclude that solar PV power plant is better than solar thermal power plant. In the next chapter we study about solar photovoltaic technology.

SOLAR PHOTOVOLTAIC TECHNOLOGY

Chapter 02

Photovoltaic's offer consumers the ability to generate electricity in a clean, quiet and reliable way. Photovoltaic systems are comprised of photovoltaic cells, devices that convert light energy directly into electricity. Because the source of light is usually the sun, they are often called solar cells. The word photovoltaic comes from "photo" meaning light and "voltaic" which refers to producing electricity. Therefore, the photovoltaic process is "producing electricity directly from sunlight. Photovoltaic are often referred to as PV.

2.1 BRIEF HISTORY

In 1839 Edmond Becquerel accidentally discovered photovoltaic effect when he was working on solid-state physics. In 1878 Adam and Day presented a paper on photovoltaic effect. In 1883 Fxitz fabricated the first thin film solar cell. In 1941 Ohl fabricated silicon PV cell but that was very inefficient. In 1954 Bell labs Chopin, Fuller, Pearson fabricated PV cell with efficiency of 6%. In 1958 PV cell was used as a backup power source in satellite Vanguard-1. This extended the life of satellite for about 6 years [24].

2.2 PHOTOVOLTAIC CELL

A device that produces an electric reaction to light, producing electricity. PV cells do not use the sun's heat to produce electricity. They produce electricity directly when sunlight interacts with semiconductor materials in the PV cells.

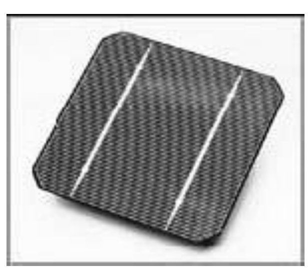


Figure 2.1: Photovoltaic cell

“A typical PV cell made of crystalline silicon is 12 centimeters in diameter and 0.25 millimeters thick. In full sunlight, it generates 4 amperes of direct current at 0.5 volts or 2 watts of electrical power [25].

2.2.1 Basic theory of photovoltaic cell

Photovoltaic cells are made of silicon or other semi conductive materials that are also used in LSIs and transistors for electronic equipment. Photovoltaic cells use two types of semiconductors, one is P-type and other is N-type to generate electricity [27].

- When sunlight strikes a semiconductor, it generate pairs of electrons (-) and protons (+).

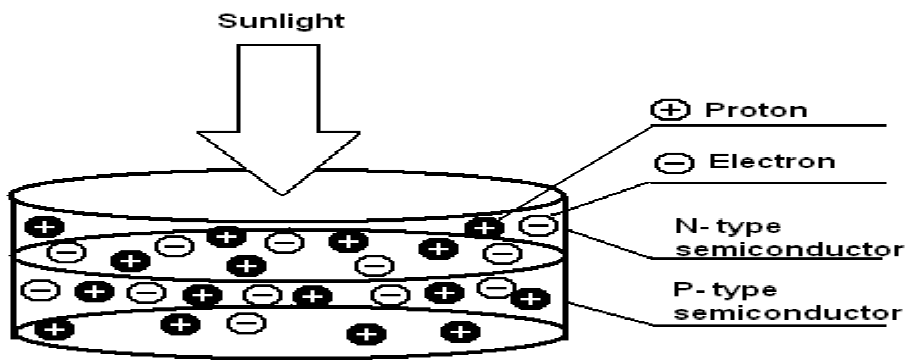


Figure 2.2: Basic theory of photovoltaic cell 1

- When an electron (-) and a proton (+) reach the joint surface between the two types of semiconductors, the former is attracted to N-type and the latter to the P-type semiconductor. Since the joint surface supports only one way traffic, they are not able to rejoin once they are drawn apart and separated.

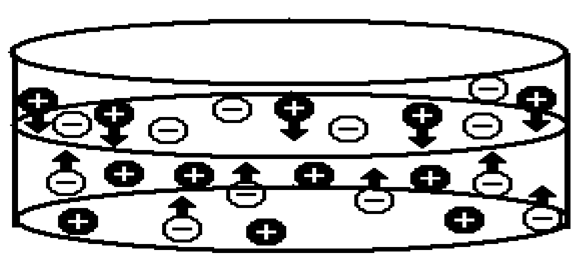


Figure 2.3: Basic theory of photovoltaic cell 2

- Since the N-type semiconductor now contains an electron (-), and P-type semiconductor contains a proton (+), an electromotive (voltage) force is generated. Connect both electrodes with conductors and the electrons runs from N- type to P-type semiconductors, and the proton from P-type to N-type semiconductors to make an electrical current.

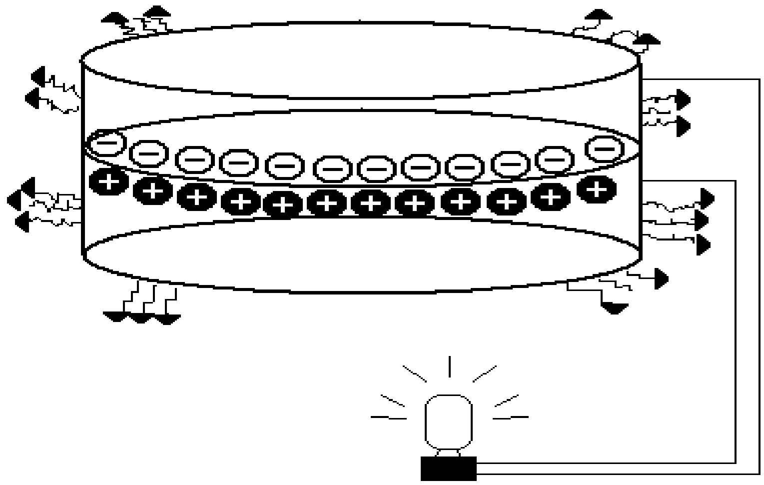


Figure 2.4: Basic theory of photovoltaic cell 3

2.2.2 Series and parallel connection of PV cells

Solar cells can be thought of as solar batteries. If solar cells are connected in series, then the current stays the same and the voltage increases [27].

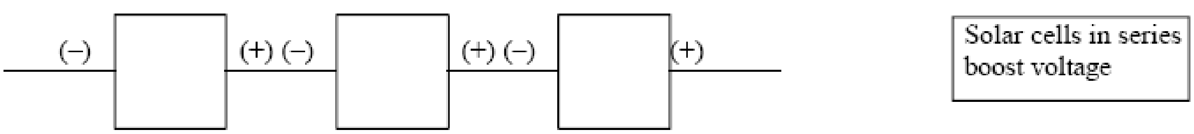


Figure 2.5: Series connection of cells

If solar cells are connected in parallel, the voltage stays the same, but the current increases.

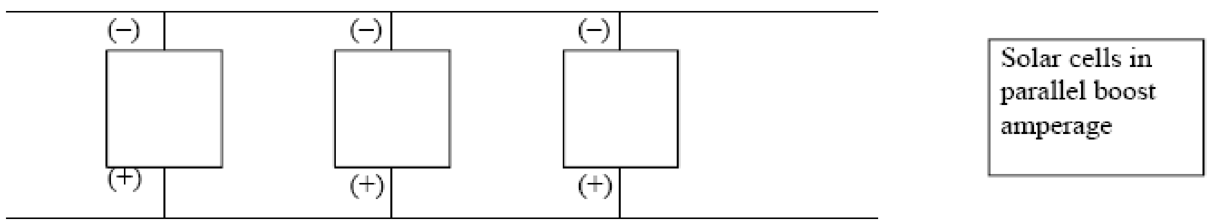


Figure 2.6: Parallel connection of cells

As we know those Solar cells are combined to form a 'module' to obtain the voltage and current (and therefore power) desired.

2.2.3 Types of Photovoltaic's cells

There are essentially two types of PV technology, crystalline and thin-film. Crystalline can again be broken down into two types:

- Monocrystalline Cells - These are made using cells cut from a single cylindrical crystal of silicon. While monocrystalline cells offer the highest efficiency (approximately 18% conversion of incident sunlight), their complex manufacturing process makes them slightly more expensive.

- Polycrystalline Cells - These are made by cutting micro-fine wafers from ingots of molten and recrystallized silicon. Polycrystalline cells are cheaper to produce, but there is a slight compromise on efficiency (approximately 14% conversion of incident sunlight).

Thin film PV is made by depositing an ultra thin layer of photovoltaic material onto a substrate. The most common type of thin-film PV is made from the material a-Si (amorphous silicon), but numerous other materials such as CIGS (copper indium/gallium diselenide) CIS (copper indium selenide), CdTe (Cadmium Teluride), dye-sensitized cells and organic solar cells are also possible.

2.3 PHOTOVOLAIC MODULES

PV cells are the basic building blocks of PV modules. For almost all applications, the one-half volt produced by a single cell is inadequate. Therefore, cells are connected together in series to increase the voltage. Several of these series strings of cells may be connected together in parallel to increase the current as well.

These interconnected cells and their electrical connections are then sandwiched between a top layer of glass or clear plastic and a lower level of plastic or plastic and metal. An outer frame is attached to increase mechanical strength, and to provide a way to mount the unit. This package is called a "module" or "panel". Typically, a module is the basic building block of photovoltaic systems. PV modules consist of PV cells connected in series (to increase the voltage) and in parallel (to increase the current), so that the output of a PV system can match the requirements of the load to be powered. The PV cells in a module can be wired to any desired voltage and current.

The amount of current produced is directly proportional to the cell's size, conversion efficiency, and the intensity of light. Groups of 36 series connected PV cells are packaged together into standard modules that provide a nominal 12 volt (or 18 volts @ peak power). PV modules were originally configured in this manner to charge 12-volt batteries.

2.4 DESCRIBING PHOTOVOLTAIC MODULE PERFORMANCE

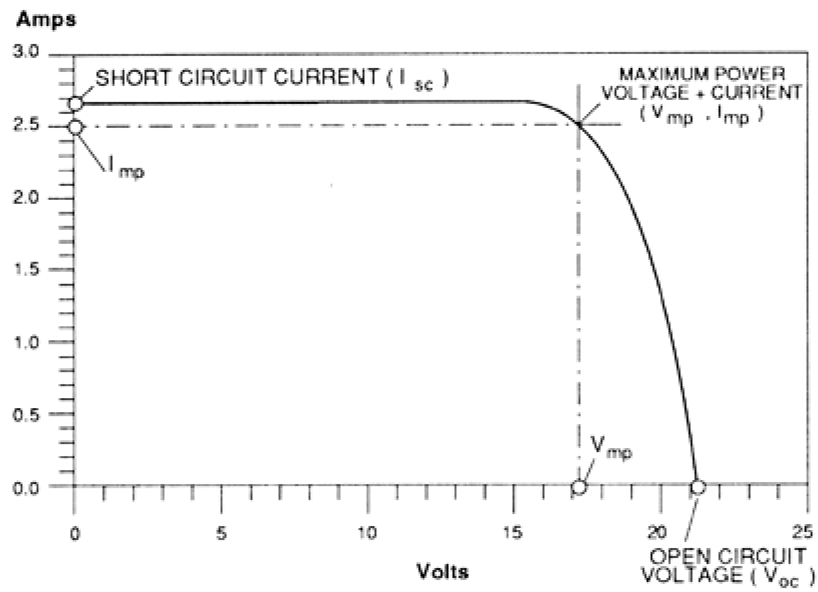
To insure compatibility with storage batteries or loads, it is necessary to know the electrical characteristics of photovoltaic modules. As a reminder, "I" is the abbreviation for current, expressed in amps. "V" is used for voltage in volts, and "R" is used for resistance in ohms.

2.4.1 The standard V-I characteristic curve of Photovoltaic Module

A photovoltaic module will produce its maximum current when there is essentially no resistance in the circuit. This would be a short circuit between its positive and negative terminals. This maximum current is called the short circuit current, abbreviated I(sc). When the module is shorted, the voltage in the circuit is zero.

Conversely, the maximum voltage is produced when there is a break in the circuit. This is called the open circuit voltage, abbreviated V(oc). Under this condition the resistance is infinitely high and there is no current, since the circuit is incomplete [28].

These two extremes in load resistance, and the whole range of conditions in between them, are depicted on a graph called a I-V (current-voltage) curve. Current, expressed in amps, is on the vertical Y-axis. Voltage, in volts, is on the horizontal X-axis as in Figure.



Graph 2.1: The standard V-I characteristic curve of Photovoltaic Module

As you can see in above Figure, the short circuit current occurs on a point on the curve where the voltage is zero. The open circuit voltage occurs where the current is zero. The power available from a photovoltaic module at any point along the curve is expressed in watts. Watts are calculated by multiplying the voltage times the current (watts = volts × amps, or W = VA).

At the short circuit current point, the power output is zero, since the voltage is zero.

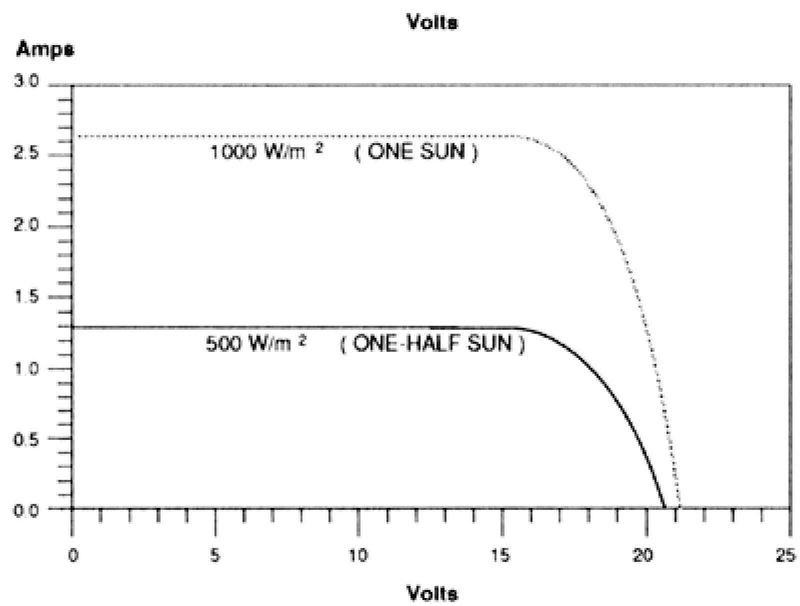
At the open circuit voltage point, the power output is also zero, but this time it is because the current is zero.

There is a point on the "knee" of the curve where the maximum power output is located. This point on our example curve is where the voltage is 17 volts, and the current is 2.5 amps. Therefore the maximum power in watts is 17 volts times 2.5 amps, equaling 42.5 watts.

The power, expressed in watts, at the maximum power point is described as peak, maximum, or ideal, among other terms. Maximum power is generally abbreviated as "I (mp)." Various manufacturers call it maximum output power, output, peak power, rated power, or other terms. The current-voltage (I-V) curve is based on the module being under standard conditions of sunlight and module temperature. It assumes there is no shading on the module.

2.4.2 Impact of solar radiation on V-I characteristic curve of Photovoltaic Module

Standard sunlight conditions on a clear day are assumed to be 1000 watts of solar energy per square meter (1000 W/m2). This is sometimes called "one sun," or a "peak sun." Less than one sun will reduce the current output of the module by a proportional amount. For example, if only one-half sun (500 W/m2) is available, the amount of output current is roughly cut in half.

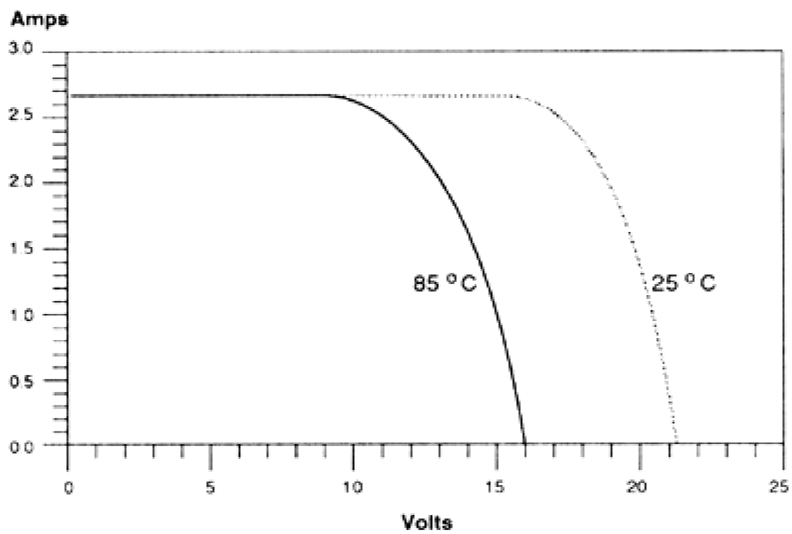


Graph 2.2: Change in Photovoltaic module voltage and current on change in solar radiation

For maximum output, the face of the photovoltaic modules should be pointed as straight toward the sun as possible.

2.4.3 Impact of temperature on V-I characteristic curve of Photovoltaic Module

Module temperature affects the output voltage inversely. Higher module temperatures will reduce the voltage by 0.04 to 0.1 volts for every one Celsius degree rise in temperature (0.04V/0C to 0.1V/0C). In Fahrenheit degrees, the voltage loss is from 0.022 to 0.056 volts per degree of temperature rise.

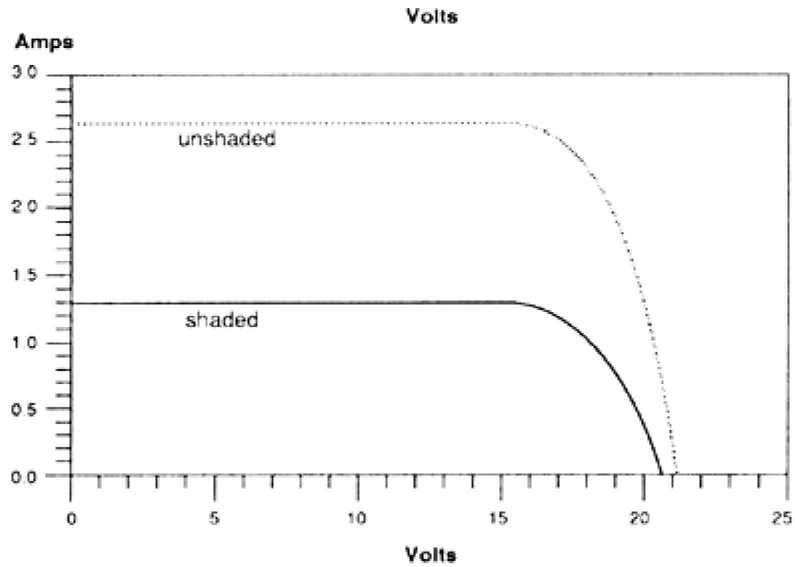


Graph 2.3: A Typical Current-Voltage Curve for a Module at 25°C (77°F) and 85°C (185°F)

This is why modules should not be installed flush against a surface. Air should be allowed to circulate behind the back of each module so it's temperature does not rise and reducing its output. An air space of 4-6 inches is usually required to provide proper ventilation.

2.4.4 Impact of shading effect on V-I characteristic curve of Photovoltaic Module

Because photovoltaic cells are electrical semiconductors, partial shading of the module will cause the shaded cells to heat up. They are now acting as inefficient conductors instead of electrical generators. Partial shading may ruin shaded cells. Partial module shading has a serious effect on module power output. For a typical module, completely shading only one cell can reduce the module output by as much as 80%. One or more damaged cells in a module can have the same effect as shading.



Graph 2.4: A Typical Current-Voltage Curve for an Unshaded Module and for a Module with One Shaded Cell

This is why modules should be completely unshaded during operation. A shadow across a module can almost stop electricity production. Thin film modules are not as affected by this problem, but they should still be unshaded.

2.5 PHOTOVOLAIC ARRAY

Desired power, voltage, and current can be obtained by connecting individual PV modules in series and parallel combinations in much the same way as batteries. When modules are fixed together in a single mount they are called a panel and when two or more panels are used together, they are called an array. Single panels are also called arrays. When circuits are wired in series (positive to negative), the voltage of each panel is added together but the amperage remains the same. When circuits are wired in parallel (positive to positive, negative to negative), the voltage of each panel remains the same and the amperage of each panel is added. This wiring principle is used to build photovoltaic (PV) modules. Photovoltaic modules can then be wired together to create PV arrays.

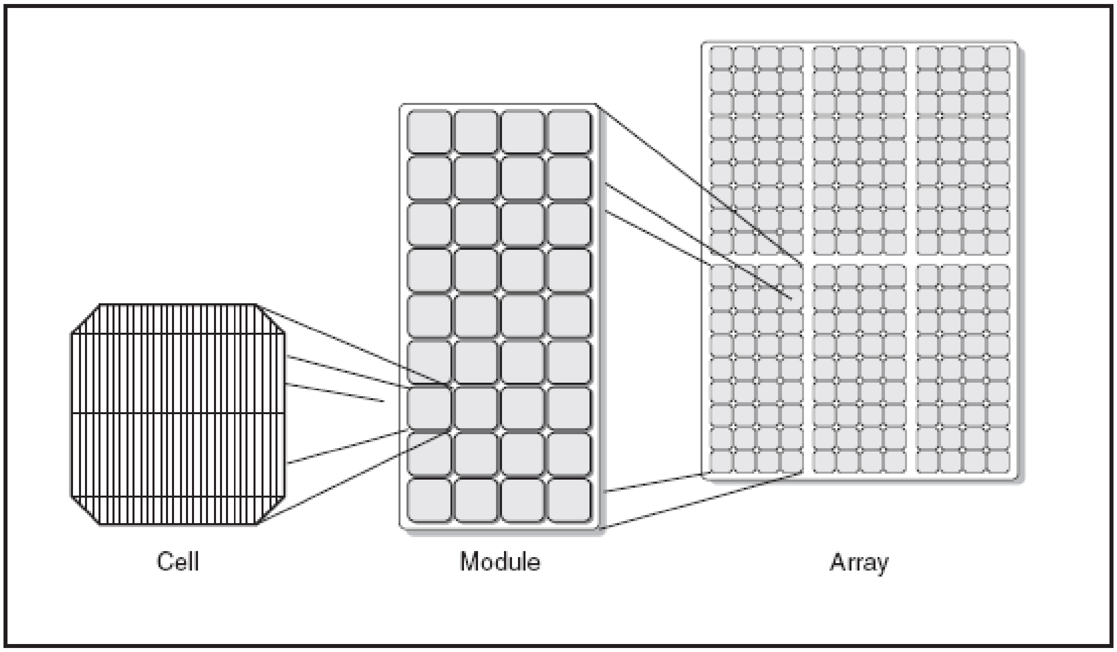


Figure 2.7: PV cells are combined to create PV modules, which are linked to create PV arrays

2.6 ELEMENTS INCLUDED IN A SYSTEM OF PHOTOVOLTAIC CONVERSION

The main elements that can be included in a system of photovoltaic conversion are [4]: Batteries, Photovoltaic Modules, Loads DC and AC, Load Regulators, Invertors, Converters...

- **Batteries**: Normally they have been considered as a simple element of storage of electrical energy. Batteries are often sold with a PV system. The primary purpose is to store the electricity not immediately used, which could be used at some later time. With net metering, the value of batteries is less because the utility grid basically acts as a storage facility. For a reliable generation system that can function independent of the utility grid, however, batteries may be a viable component to the total system. Back-up generators may be included in a system to provide power when the PV system is not operating, and are generally included when systems are not grid connected. Neither batteries nor generators are eligible for rebate money.
- **Solar panel:** The solar panel is the power source of all photovoltaic installation. It is the result of a set of photovoltaic cells in series and parallel. Solar panel gives power to battery or inverter through charge controller (Regulator).

- **Regulator:** It is the element to protect the battery against to risking situations as overloads and over discharges. The theoretical formulation of the model can be simple, although it is necessary to consider the peculiar discontinuities of the model and the inter performance with the rest of the analyzed models.
- **Inverter:** The inverter allows transforming the DC current to AC. A photovoltaic installation that incorporates an inverter can belong to two different situations, based on the characteristics of the alternating network. In first an isolated system, where the inverter is the element of the network and has to feed the set of loads and in second situation the inverter is connected to the public network, to which it sends the energy generated by the system.
- **Converter:** The positioning of a converter between the panels and the batteries will improve the whole photovoltaic installation, allowing different controls from the system. Depending on the applied regulation, the panels will contribute to the maximum energy given to the system or the optimal energy for their operation, assuring an efficient charge of the battery.
- **Load:** It is the component responsible to absorb this energy and transform it into work.

2.7 TYPES OF PHOTOVOLTAIC SYSTEM

PV technology was first applied in space, by providing electricity to satellites. Today, PV systems can be used to power just about anything on Earth. On the basis working operation PV systems operate in four basic forms [29].

- **Grid Connected PV Systems -** These systems are connected to a broader electricity network. The PV system is connected to the utility grid using a high quality inverter, which converts DC power from the solar array into AC power that conforms to the grid's electrical requirements. During the day, the solar electricity generated by the system is either used immediately or sold off to electricity supply companies. In the evening, when the system is unable to supply immediate power, electricity can be bought back from the network.

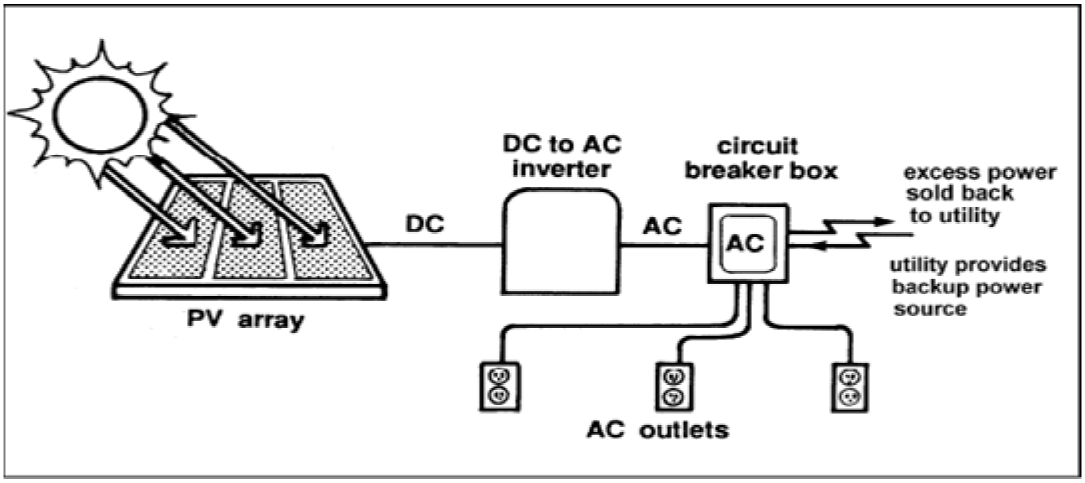


Figure 2.8: Grid Connected PV Systems

- **Standalone Systems:** PV systems not connected to the electric utility grid are known as Off Grid PV Systems and also called 'stand-alone systems.' Direct systems use the PV power immediately as it is produced, while battery storage systems can store energy to be used at a later time, either at night or during cloudy weather. These systems are used in isolation of electricity grids, and may be used to power radio repeater stations, telephone booths and street lighting. PV systems also provide invaluable and affordable electricity in developing countries like India, where conventional electricity grids are unreliable or non-existent.

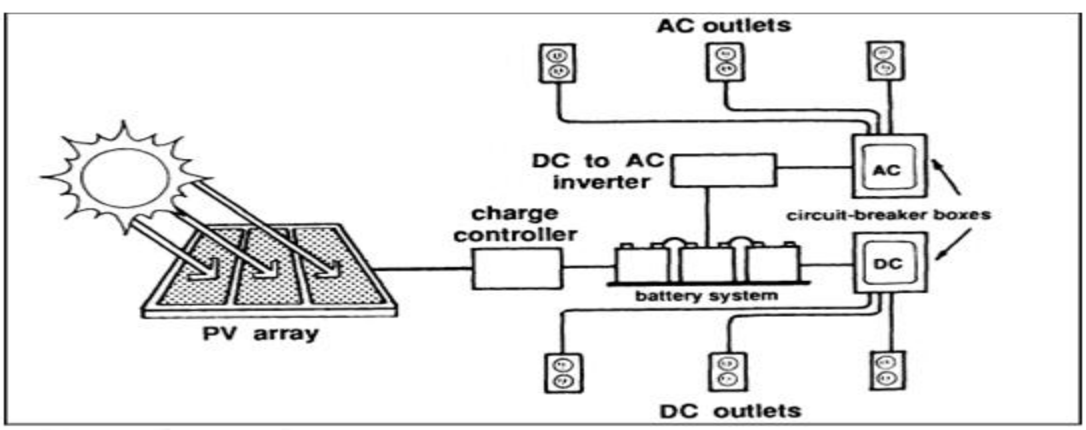


Figure 2.9: Off Grid PV Systems

➢ **Hybrid System**: A hybrid system combines PV with other forms of power generation, usually a diesel generator. Biogas is also used. The other form of power generation is usually a type which is able to modulate power output as a function of demand. However more than one form of renewable energy may be used e.g. wind and solar. The photovoltaic power generation serves to reduce the consumption of non renewable fuel.

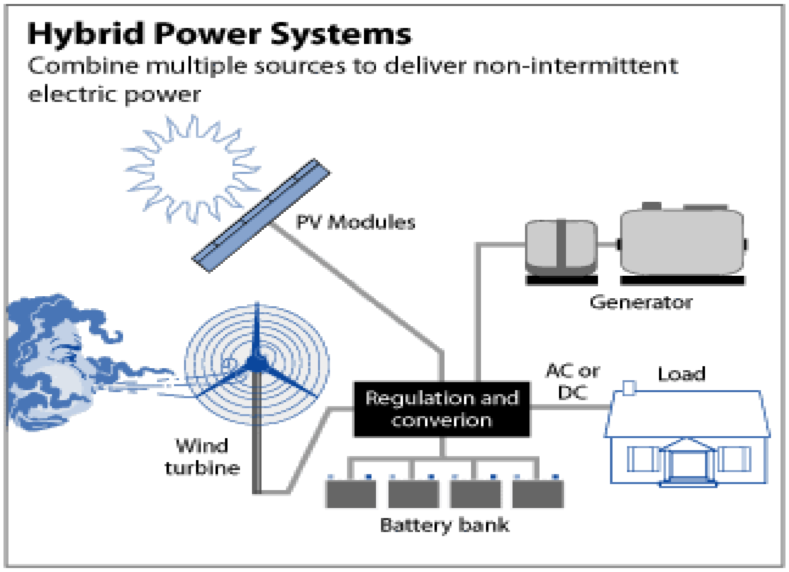


Figure 2.10: Hybrid System

➢ **Grid Tied with Battery Backup PV system:** Solar energy stored in batteries can be used at nighttime. Using net metering, unused solar power can be sold back to the grid. With this system, you will have power even if your neighborhood has lost power.

2.8 WE PREFER GRID CONNECTED PV SYSTEM

Because as day by day the demand of electricity is increased and that much demand cannot be meeting up by the conventional power plants. And also these plants create pollution. So if we go for the renewable energy it will be better but throughout the year the generation of all renewable energy power plants. Grid tied PV system is more reliable than other PV system. No use of battery reduces its capital cost so we go for the grid connected topology. If generated solar energy is integrated to the conventional grid, it can supply the demand from morning to afternoon (total 6 hours mainly in sunny days) that is the particular time range when the SPV system can fed to grid. As no battery backup is there, that means the utility will continue supply to the rest of the time period. Grid-connected systems have demonstrated an advantage in natural disasters by providing emergency power capabilities when utility power was interrupted. Although PV power is generally more expensive than utility-provided power, the use of grid connected systems is increasing. In the 5^{th} chapter we study about grid connected solar photovoltaic system in detail.

REVIEW OF EARLIER WORKS

Chapter 03

3.1 INTRODUCTION

It is important to state that the amount of literature on solar energy, the solar energy system and PV grid connected systems is enormous. So much study is needed to design a grid connected PV system without battery backup accurately from first principles. The author of this thesis has attended courses on the subject, read books, journals and papers. This chapter will cover just a little portion of that enormous amount of literature.

3.2 REVIEW OF EARLIER WORKS

Several works are going on solar photovoltaic systems. Some of these are discussed below:

Prakasit Sritakaew, Anawach Sangswang, and Krissanapong Kirtikara [1] presented a paper about On the Reliability Improvement of Distribution Systems Using PV Grid-Connected Systems. The purpose of their paper was to examine issues related to the distribution system reliability improvement using photovoltaic (PV) grid-connected systems. The output characteristics of a PV system were experimentally measured. The measured data were used to investigate the effects of PV system installation to improve the distribution system's reliability. The system constraints such as, recovered real power, and loading reduction of the tie line/switch after the installation of PV grid-connected systems are concentrated. Simulation results show that with the action of a tie switch, system losses and loading level of the tie switch can be reduced with proper installation location.

Allen M. Barnett [2] presented a paper about solar electrical power for a better tomorrow. The promise of solar electricity based on the photovoltaic (PV) effect is well known. Why don’t we see these systems all over the world? Consumers in the United States are well-known for their attraction to new technology. Why aren’t PV systems appearing on roof-tops in the U.S.?

The answer may be that grid-connected roof top systems are Too difficult to acquire, Too difficult to integrate with the grid, Too difficult to measure the energy and Too expensive .It is essential that we make PV systems user friendly, while reducing the component and system costs. Our elegant technology must be reduced to practical systems that can be used by the average person - everywhere.

R. Ramkumar & J. E. Bigger [3] presented a paper of photovoltaic systems including a discussion of major U.S. and international activities. After a brief review of system types and output characteristics, various system configurations were discussed and a classification based on photovoltaic (PV) system rating was provided. Modeling, design, and economic Considerations were briefly discussed. The worldwide status of PV system technology was discussed with a view to making an assessment of the future. The assessment presented includes some specific areas for further research and development. Although no major technical barriers are evident the entry of PV, as the level of penetration increases, several key issues identified in this paper will need further consideration. Photovoltaic's is still evolving and has not reached its full potential. It is likely to grow for decades to come; however, the rate of growth may depend on several exogenous factors such as cost of conventional energy sources and the people's desire to improve the global environment.

G. Ofualagba [4] in his paper first explained the reasons for the mounting interest in photovoltaic technology and has provided a quick synopsis of the operation of these technology and their applications and markets. Photovoltaic technology have received increasing attention over the last decade as one response to the challenges of global warming, increasing demand for energy, high fuel costs, and local pollution. This paper describes photovoltaic systems (PV modules, batteries, power conditioning, generators, and pumps) and discusses the photovoltaic markets including on-grid, off grid and water pumping applications

N. Jenkins [5] presented a paper about Photovoltaic systems for small-scale remote power supplies. In his article, he considers the technical aspects of using photovoltaic systems for small power supplies where a connection from a main electricity distribution network is not appropriate. The technology of the various components of a photovoltaic system is discussed and the overall system design considered. Typical applications of photovoltaic systems are described.

Souvik Ganguli & Sunanda Sinha [6] presented a paper about Estimation of Grid Quality Solar Photovoltaic Power Generation Potential and its Cost Analysis in Some Districts of West Bengal. The objective of their work was to estimate the potential of grid quality solar photovoltaic power in some districts of West Bengal (Birbhum, Burdwan, Hooghly, Howrah and Kolkata), study the solar radiation level and potential of the above mentioned districts and finally develop a system corresponding to the potential. Equipment specifications were provided based on the system developed and finally cost analysis was also carried out.

Brig.M.R.Narayaoan, D.V.Gupta, R.C.Gupta & R.S.Gupta [7] presented a paper about Design, Development and Installation of 100 kW utility grid connected solar PV plants for rural application- an Indian experience. This paper briefly describes tile features of the two power plants, the developmental approach adopted based on "Building Block Philosophy" With 25 KW System as the basic unit with the attendant advantages. It includes the indigenous design and development effort made for grid connected operation and most importantly the special design features incorporated to ensure a very high degree of safety and protection so necessary in the rural areas with predominantly non-literate users. Tile paper is concluded with some important lessons learnt from both the technical and logistics point of view for guiding installation of similar such plants in the remote rural areas in India and other developing countries in the future.

Wang Jianqiang & Li Jingxin [8] researched two grid connected photovoltaic power systems. One is 10kW located in Beijing, the other is 100kW located in north of Shan’xi province of China. Inverter and its different operation of modes for both the photovoltaic power system were discussed. For 10kW Photovoltaic power system, the single phase transformers less grid-connecting inverters are applied to this system. The inverters have two-stage structure, DC-DC and DC-AC, but they often operates only with last DC-AC stage according to the panel string output voltage. For 100kW photovoltaic power system, 3 phase transformer less grid-connecting inverters are used. But they concluded that although all the inverters in two systems have two stage structures, only single stage were designed to work during most of time. Because the system efficiency can be increased availably. So large photovoltaic power system should adopt series-wound panels for high operating voltage and less loss. The research shows the correlation. The output power quality of one inverter of 10kW systems was analyzed, too.

B. Marion,J. Adelstein,K. Boyle and fellows [9] presented a paper about performance parameters for Grid-Connected PV systems. Three performance parameters may be used to define the performance of grid-connected PV systems: final PV system yield Y_f, reference yield Y_r, and performance ratio PR. The Y_f and PR are determined using the nameplate d.c. power rating. The Y_f is the primary measure of performance and is expressed in units of kWh/kW. It provides a relative measure of the energy produced and permits comparisons of PV systems of different size, design, or technology. If comparisons are made for different time periods or locations, it should be recognized that year-to-year variations in the solar resource will influence Y_f. The PR factors out solar resource variations by dividing Y_f by the solar radiation resource, Y_r. This provides a dimensionless quantity that indicates the overall effect of losses and may be used to identify when operational problems occur or to evaluate long-term changes in performance. As part of an operational and maintenance program, the PR may be used to identify the existence of performance issues.

Chang Ying-Pin & Shen Chung-Huang [10] presented a paper about Effects of the Solar Module Installing Angles on the Output Power. In their paper they discussed that the output power increment of photovoltaic cells is mainly based on two factors. One is decreasing the cell modular temperature and the other is increasing the cells received solar illumination intensity. The former can be simply achieved by maintaining a proper radiating space between the modules and the ground. The later is more complicated. One needs to consider the installation of cell modules and then the maximum power output which can be derived. This paper was theoretically calculated the solar orbit and position at any time and any location. With the estimation of their model on the variation of solar illumination intensity, they can derive the output power of the solar modular cell at any tilt angle and orientation. The simulated results could be utilized in large scale photovoltaic power generation systems when considering placement for optimal installation. It also provides a useful evaluation for the output power of photovoltaic cells mounted on roofs and out walls of buildings.

Several grid connected photovoltaic system topologies are used in existing installations. D.Picault, B. Raison , and S. Bacha [11] presented a paper about proposes evaluation criteria for comparing and choosing topologies compatible with the user's demands. After presenting an overview of current architectures used in grid connected systems, five key points for comparison based on topology upgradeability, performance under shaded conditions, degraded mode operation, investment costs and ancillary service participation were discussed. The proposed method can be adapted to the user's particular needs and expectations of the photovoltaic plant. These evaluation guidelines may assist grid-tied PV system users to choose the most convenient topology for their application by weighting the evaluation criteria

Jinhui Xue , Zhongdong Yin , Qipeng Song, and Renzhong Shan [12] presented a paper about analyze and research of the inverter for Grid connecting photovoltaic system. In their paper the described the Topology of main circuit, control methods, design of passive filter. The important point of their paper was control methods for grid-connecting, PFC, control methods of power direction. Based on the analyzing of SPWM (sinusoidal pulse-width-modulated) technique control method in detail, this paper improves the control means. This paper proposes a neoteric grid-connecting inverter, which synchronizes a sinusoidal AC output current with a utility line voltage, and control the power generation of each photovoltaic battery cell.

Phil Bolduc, David Lehmicke & Joseph Smith [13] presented a paper about performance of a grid –connected PV system with energy storage. One kilowatt amorphous photovoltaic system has been operated in a grid-connected mode with energy storage. The purpose of the system development and performance experiment is to investigate the additional value a grid-connected system garners with dispatchable battery energy storage. These values are then weighed against the added cost of the system and inefficiencies incurred in the charging and discharging of the battery.

Eduardo Román, Ricardo Alonso & Pedro Ibañez [14] presented the paper about the intelligent PVmodule concept, a low-cost high-efficiency dc–dc converter with maximum power point tracking (MPPT) functions,control, and power line communications (PLC). In addition, they analyzed the alternativesfor the architecture of grid connected PV systems: centralized, string, and modular topologies. The proposed system, i.e., the intelligent PV module, fits within this last group. Its principles of operation, as well as the topology of boost dc–dc converter, are analyzed. Besides, a comparison of MPPT methods is performed, which shows the best results for the incremental conductance method. Regarding communications, PLC in every PV module and its feasibility for grid-connected PV plants are considered and analyzed in this paper. After developing an intelligent PV module (with dc–dc converter) prototype, its optimal performance has been experimentally confirmed by means of the PV system test platform. This paper describes this powerful tool especially designed to evaluate all kinds of PV systems.

Grid-connected PV plants, aimed at delivering energy to the grid. However, the cost/kWh of PV energy is still quite high. V. Lughi , A. Massi Pavan , S. Quaia , and G. Sulligoi [15] reported some of the most promising research approaches currently in progress on new PV materials and devices , focusing on the reduction of PV generation cost expected from the technological implementation of such research. Their paper reported the main features and the expected economical effect of two of these researches: the first regards the use of cadmium telluride thin films, the second concerns the development of novel nanostructured PV materials. Large size industrial PV plants could have different characteristics compared to the small ones that, with few exceptions, have been realized until now. The analysis performed in this paper suggests to recommend centralized power electronic conditioning systems together with the use of proper simulation-aided design tools.

Kosuke Kurokawa, Kazuhiko Kato , Masakazu Ito', Keiichi Komoto, Tetsuo Kichim, & Hiroyuki Sugihara [16] presented paper about the cost analysis of very large scale PV system on the world desert. a 100 MW very large scale photovoltaic power generation (VLS-PV) system was estimated assuming that it is installed on the would deserts, which are Sahara, Negev, Thar, Sonora, Great Sandy and Gobi desert. PV array was dimensioned in detail in terms of array layout, support, foundation, wiring and so on. Then generation Cost of the system was estimated based on the methodology of Life-Cycle Cost (LCC). As a result of the estimation, the generation cost was calculated.

M. C. Cavalcanti, G. M. S. Azevedo and fellows [17] presented paper which introduces a comparative study of efficiency for topologies in photovoltaic energy conversion systems. In special, a study of losses was presented and the methodology was used to compare different topologies for grid connected photovoltaic systems in such a way that can be chosen the option of best efficiency. The systems were also tested with photovoltaic generation as well as current harmonic and reactive power compensation simultaneously. Using the loss models, it is possible to estimate efficiency and to make a comparative study of different conversion systems.

M.J. de Wild-Scholten, E.A. Alsema, E.W. ter Horst & V.M. Fthenakis [18] presented a paper about a cost and environmental impact comparison of grid connected rooftop and ground-based PV systems. The environmental impact and total system costs have been investigated for roof-top and ground-based crystalline silicon PV systems by using environmental and cost life cycle assessment. Greenhouse gas emissions and other environmental impacts from Balance-Of-System components are relatively small, in comparison with present-day modules. Frameless laminates are largely preferred from an environmental point of view; the extra impacts from a somewhat heavier mounting structure are more than compensated by the avoided impacts of the frames. In-roof systems clearly have a lower environmental impact of the Balance-of-System components in comparison to on-roof and ground-based systems.

Evert Nieuwlaar & Erik Alsema [19] gives us idea about environmental aspects of PV power systems. During normal operation, photovoltaic (PV) power systems do not emit substances that may threaten human health or the environment. In fact, through the savings in conventional electricity production they can lead to significant emission reductions. There are, however, several indirect environmental impacts related to PV power systems that require further consideration. The production of present generation PV power systems is relatively energy intensive, involves the use of large quantities of bulk materials and (smaller) quantities of substances that are scarce and/or toxic. During operation, damaged modules or a fire may lead to the release of hazardous substances. Finally, at the end of their useful life time PV power systems have to be decommissioned, and resulting waste flows have to be managed.

José L. Bernal-Agustí & Rodolfo Dufo-López [20] presented a paper about Economical and Environmental Analysis of Grid Connected Photovoltaic Systems in Spain. In this article an economic and environmental study was carried out on PV solar energy installations connected to the Spanish electrical grid system. First fall, an economical study was performed, proposing different scenarios where different values of interest rate and energy tariffs were considered. The following parameters were used to determine the profitability of a PV installation. The Net Present Value and the Pay-Back Period. Furthermore, the environmental benefits of PV systems connected to the grid have been evaluated. This has been accomplished using the Life Cycle Analysis theory of the systems, calculating the recuperation time of the invested energy, the contamination or emissions avoided and the externality costs.

Hironobu lgarashi and Shoichi Suenaga [21] presented a paper about Electromagnetic Noise from Solar Cells. Recent advances in semiconductor technology have seen growing efforts to improve the efficiency and reduce the size/weight of power conditioners. The power conditioner is an indispensable component of a photovoltaic power generation system. On the other hand, power conditioners do have a serious problem: they generate electromagnetic noise. To make matters worse, the electromagnetic noise that is generated at power conversion is transmitted to the solar cells through electric wires, the solar cells serving as an antenna to radiate the electromagnetic noise. The radiated electromagnetic noise may cause operation and communication failures in other electronic equipment.

3.3 OBJECTIVE OF WORK

It is seen from various earlier works that application of renewable energy will be forecast more and more in near future due to presence of Global Warming and clean renewable energy will reduce unacceptable air pollution and mainly to meet up the heavy energy demand. Grid connected system is well used in various parts of world, and many types of technology used is discussed as earlier work review.

The objective of this work is to estimate the potential of grid quality solar photovoltaic power in Patiala district of Punjab and finally develop a system based on the potential estimations made for a chosen area of 100 m^2. Equipment specifications are provided based on the availability of the components in India. In the last cost estimation of grid connected SPV power plant to show whether it is economically viable or not. So if we prefer Grid connected SPV system for our site, we have to analyses so many factors.

ESTIMATION OF GRID CONNECTED SOLAR PHOTOVOLTIAC POTENTIAL OF PATIALA DISTRICT

Chapter 04

4.1 INTRODUCTION

It is anticipated that photovoltaic (PV) systems will experience an enormous increase in the decades to come. However, a successful integration of solar energy technologies into the existing energy structure depends also on a detailed knowledge of the solar resource. Therefore solar radiation is a key factor determining electricity produced by photovoltaic (PV) systems which is usually obtained using Geographical Information System (GIS). A case study of solar radiation database was prepared in Europe as was reported in [30].

Using Photovoltaic Geographic Information System (PVGIS) another study was made in the 25 European Union member states and 5 candidate countries. The calculation of electricity generation potential by contemporary PV technology is a basic step in analyzing scenarios for the future energy supply and for a rational implementation of legal and financial frameworks to support the developing industrial production of PV. Three aspects were explored -the expected average annual electricity generation of a 'standard' 1 kW_p grid-connected PV system, the theoretical potential of PV electricity generation and determination of required installed capacity for each country to supply 1% of the national electricity consumption from PV. The analysis shows that PV can already provide a significant contribution to a mixed renewable energy portfolio in the present and future European Union [31].

In [32], a GIS based analysis of the theoretical PV potential to be installed on noise barriers along Italian national roads has been carried out. Thus we find that almost all the previous literatures involve the use of GIS systems to obtain the solar photovoltaic potential estimation. The method reported in this paper suggests a unique way of assessing the PV potential and estimate the possible plant capacity based on the available area, chosen as 100 m^2 in this work**.**

4.2 SOLAR RADIATION

Incoming solar radiation (insolation) originates from the sun, is modified as it travels through the atmosphere, is further modified by topography and surface features, and is intercepted at the earth's surface as direct, diffuse, and reflected components. Direct radiation is intercepted unimpeded, in a direct line from the sun. Diffuse radiation is scattered by atmospheric constituents, such as clouds and dust. Reflected radiation is reflected from surface features. The sum of the direct, diffuse, and reflected radiation is called total or global.

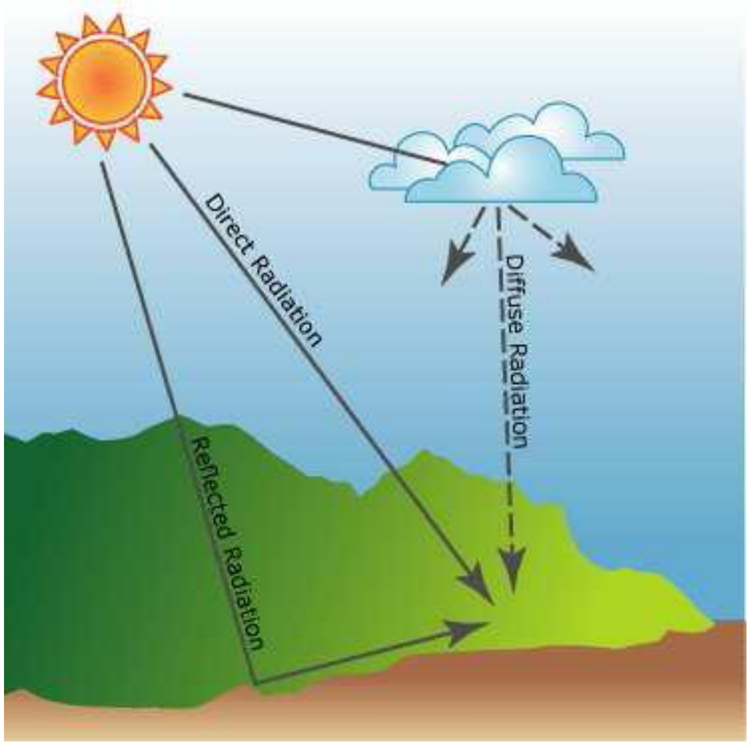


Figure 4.1: Path of solar radiation

4.3 METHODOLOGY

To find out the solar potential available at Patiala district of PUNJAB, the solar radiation over different months measured. Then the diurnal variations, average monthly output, yearly output are find out and related graphs are plot for showing the variation in different season and time.

We started our project work from September month. So we measured value of solar radiation from September to April month after that we calculated the diurnal variations, average monthly output for eight months (Sep 2009 to April 2010). Thus from these data we can estimate the rating of solar PV power plant for Patiala.

4.3.1 How We Measured Solar Radiation Reading

First of fall for the estimation of solar potential we need reading of solar radiation for our site. So we take these readings from whether station which is available in the civil department of Thapar University campus. This system has ability to measure air temperature (°C), humidity (%), wind speed (m/sec), wind direction (degree), rain fall (millimeters), evaporation (millimeters) and solar radiation (Watts/mtr^2) with in a small duration of time interval. Best thing about this system is that it has ability to store all those data which it measure in previous three month. So we take solar radiation readings from there. For the better understanding of the methodology, the measured radiation data sheet of Patiala district for the month of April 2010 has been given as a sample. In the same way the solar radiation data are collected and calculated the SPV potential for all the remaining months. The diurnal variation for eight months & are plotted. From that the monthly output and yearly output are calculated. Also observing the peak value in different days, the monthly average peak is calculated and variation of the monthly peak is plotted for a year and the average annual peak is calculated. Input solar radiation means how much amount of solar radiation is coming from sun and Output solar radiation means how much amount of solar radiation we can utilize to generate electricity which is depends upon the efficiency of the PV module. For calculating the output the efficiency of the PV module is taken as 14.3%. Chosen area for the estimated plant capacity is considered as 100 m^2.

4.3.2 Tables Shows Average Solar Radiation at Different Time Interval For April Month

Here the given tables show us day by day input average solar radiation Watts/mtr² at different time interval for April month at Patiala.

- **TIME :- 09:00 AM**

DATE	INPUT SOLAR RADIATION	EFFICIENCY	OUTPUT	TOTAL SOLAR RADIATION	AVG SOLAR RADIATION
	Watts/mtr²		Watts/mtr²	Watts/mtr²	Watts/mtr²
1/04/2010	481.25		68.81875		
2/04/2010	498.125		71.231875		
3/04/2010	505		72.215		
4/04/2010	480.625		68.729375		
5/04/2010	499.375		71.410625		
6/04/2010	528.75		75.61125		
7/04/2010	575.625		82.314375		
8/04/2010	413.75		59.16625		
9/04/2010	509.375		72.840625		
10/04/2010	511.875		73.198125		
11/04/2010	499.375		71.410625		
12/04/2010	444.375		63.545625		
13/04/ 2010	551.25		78.82875		
14/04/ 2010	555		79.365		
15/04/ 2010	569.375	14.3%	81.420625	2034.443125	67.81477083
16/04/ 2010	514.375		73.555625		
17/04/ 2010	501.25		71.67875		
18/04/ 2010	343.75		49.15625		
19/04/ 2010	239.375		34.230625		
20/04/ 2010	479.375		68.550625		
21/04/ 2010	432.5		61.8475		
22/04/ 2010	450.625		64.439375		
23/04/ 2010	483.75		69.17625		
24/04/ 2010	316.875		45.313125		
25/04/ 2010	565.625		80.884375		
26/04/ 2010	531.25		75.96875		
27/04/ 2010	451.25		64.52875		
28/04/ 2010	479.375		68.550625		
29/04/ 2010	511.875		73.198125		
30/04/ 2010	302.5		43.2575		

Table 4.1

- **TIME :- 10:00 AM**

DATE	INPUT SOLAR RADIATION	EFFICIENCY	OUTPUT	TOTAL SOLAR RADIATION	AVG SOLAR RADIATION
	Watts/mtr²		Watts/mtr²	Watts/mtr²	Watts/mtr²
1/04/2010	672.5		96.1675		
2/04/2010	693.75		99.20625		
3/04/2010	685.625		98.044375		
4/04/2010	651.875		93.218125		
5/04/2010	721.875		103.228125		
6/04/2010	719.375		102.870625		
7/04/2010	772.5		110.4675		
8/04/2010	660.625		94.469375		
9/04/2010	644.375		92.145625		
10/04/2010	724.375		103.585625		
11/04/2010	679.375		97.150625		
12/04/2010	612.5		87.5875		
13/04/ 2010	733.75		104.92625		
14/04/ 2010	721.25		103.13875		
15/04/ 2010	752.5	14.3%	107.6075	2778.221875	92.60739583
16/04/ 2010	678.75		97.06125		
17/04/ 2010	678.125		96.971875		
18/04/ 2010	291.875		41.738125		
19/04/ 2010	601.875		86.068125		
20/04/ 2010	627.5		89.7325		
21/04/ 2010	343.75		49.15625		
22/04/ 2010	605.625		86.604375		
23/04/ 2010	668.125		95.541875		
24/04/ 2010	613.75		87.76625		
25/04/ 2010	728.75		104.21125		
26/04/ 2010	684.375		97.865625		
27/04/ 2010	646.25		92.41375		
28/04/ 2010	616.25		88.12375		
29/04/ 2010	670		95.81		
30/04/ 2010	526.875		75.343125		

Table 4.2

- **TIME :- 11:00 AM**

DATE	INPUT SOLAR RADIATION	EFFICIENCY	OUTPUT	TOTAL SOLAR RADIATION	AVG SOLAR RADIATION
	Watts/mtr²		Watts/mtr²	Watts/mtr²	Watts/mtr²
1/04/2010	808.75		115.65125		
2/04/2010	808.75		115.65125		
3/04/2010	801.25		114.57875		
4/04/2010	770.625		110.199375		
5/04/2010	861.25		123.15875		
6/04/2010	857.5		122.6225		
7/04/2010	913.75		130.66625		
8/04/2010	809.375		115.740625		
9/04/2010	820		117.26		
10/04/2010	862.5		123.3375		
11/04/2010	819.375		117.170625		
12/04/2010	733.125		104.836875		
13/04/ 2010	866.25		123.87375		
14/04/ 2010	881.875		126.108125		
15/04/ 2010	866.875	14.3%	123.963125	3333.776875	111.1258958
16/04/ 2010	791.875		113.238125		
17/04/ 2010	803.75		114.93625		
18/04/ 2010	543.75		77.75625		
19/04/ 2010	589.375		84.280625		
20/04/ 2010	737.5		105.4625		
21/04/ 2010	642.5		91.8775		
22/04/ 2010	710.625		101.619375		
23/04/ 2010	786.25		112.43375		
24/04/ 2010	830		118.69		
25/04/ 2010	876.875		125.393125		
26/04/ 2010	825.625		118.064375		
27/04/ 2010	765.625		109.484375		
28/04/ 2010	683.75		97.77625		
29/04/ 2010	780		111.54		
30/04/ 2010	464.375		66.405625		

Table 4.3

- **TIME :- 12:00 PM**

DATE	INPUT SOLAR RADIATION	EFFICIENCY	OUTPUT	TOTAL SOLAR RADIATION	AVG SOLAR RADIATION
	Watts/mtr²		Watts/mtr²	Watts/mtr²	Watts/mtr²
1/04/2010	840		120.12		
2/04/2010	860.625		123.069375		
3/04/2010	866.875		123.963125		
4/04/2010	846.25		121.01375		
5/04/2010	928.125		132.721875		
6/04/2010	927.5		132.6325		
7/04/2010	961.875		137.548125		
8/04/2010	838.125		119.851875		
9/04/2010	845.625		120.924375		
10/04/2010	798.75		114.22125		
11/04/2010	871.875		124.678125		
12/04/2010	811.25		116.00875		
13/04/ 2010	921.25		131.73875		
14/04/ 2010	920		131.56		
15/04/ 2010	940.625	14.3%	134.509375	3517.531875	117.2510625
16/04/ 2010	856.875		122.533125		
17/04/ 2010	842.5		120.4775		
18/04/ 2010	528.75		75.61125		
19/04/ 2010	571.25		81.68875		
20/04/ 2010	778.75		111.36125		
21/04/ 2010	452.5		64.7075		
22/04/ 2010	735		105.105		
23/04/ 2010	866.875		123.963125		
24/04/ 2010	866.875		123.963125		
25/04/ 2010	923.125		132.006875		
26/04/ 2010	880		125.84		
27/04/ 2010	795.625		113.774375		
28/04/ 2010	708.75		101.35125		
29/04/ 2010	828.125		118.421875		
30/04/ 2010	784.375		112.165625		

Table 4.4

➢ **TIME :- 1:00 PM**

DATE	INPUT SOLAR RADIATION	EFFICIENCY	OUTPUT	TOTAL SOLAR RADIATION	AVG SOLAR RADIATION
	Watts/mtr²		Watts/mtr²	Watts/mtr²	Watts/mtr²
1/04/2010	865.625		123.784375		
2/04/2010	839.375		120.030625		
3/04/2010	857.5		122.6225		
4/04/2010	817.5		116.9025		
5/04/2010	914.375		130.755625		
6/04/2010	883.75		126.37625		
7/04/2010	907.5		129.7725		
8/04/2010	806.25		115.29375		
9/04/2010	881.25		126.01875		
10/04/2010	780.625		111.629375		
11/04/2010	829.375		118.600625		
12/04/2010	793.75		113.50625		
13/04/ 2010	897.5		128.3425		
14/04/ 2010	892.5		127.6275		
15/04/ 2010	883.125	14.3%	126.286875	3451.036875	115.0345625
16/04/ 2010	851.25		121.72875		
17/04/ 2010	843.75		120.65625		
18/04/ 2010	543.125		77.666875		
19/04/ 2010	551.25		78.82875		
20/04/ 2010	746.25		106.71375		
21/04/ 2010	534.375		76.415625		
22/04/ 2010	687.5		98.3125		
23/04/ 2010	900		128.7		
24/04/ 2010	857.5		122.6225		
25/04/ 2010	905		129.415		
26/04/ 2010	854.375		122.175625		
27/04/ 2010	775.625		110.914375		
28/04/ 2010	720		102.96		
29/04/ 2010	779.375		111.450625		
30/04/ 2010	733.75		104.92625		

Table 4.5

- **TIME :- 2:00 PM**

DATE	INPUT SOLAR RADIATION	EFFICIENCY	OUTPUT	TOTAL SOLAR RADIATION	AVG SOLAR RADIATION
	Watts/mtr²		Watts/mtr²	Watts/mtr²	Watts/mtr²
1/04/2010	780		111.54		
2/04/2010	702.5		100.4575		
3/04/2010	753.75		107.78625		
4/04/2010	740.625		105.909375		
5/04/2010	731.25		104.56875		
6/04/2010	798.125		114.131875		
7/04/2010	816.25		116.72375		
8/04/2010	678.75		97.06125		
9/04/2010	800.625		114.489375		
10/04/2010	625.625		89.464375		
11/04/2010	736.25		105.28375		
12/04/2010	746.875		106.803125		
13/04/ 2010	805		115.115		
14/04/ 2010	781.875		111.808125		
15/04/ 2010	783.125	14.3%	111.986875	3087.37	102.9123333
16/04/ 2010	741.25		105.99875		
17/04/ 2010	746.25		106.71375		
18/04/ 2010	704.375		100.725625		
19/04/ 2010	598.125		85.531875		
20/04/ 2010	634.375		90.715625		
21/04/ 2010	450.625		64.439375		
22/04/ 2010	626.875		89.643125		
23/04/ 2010	818.125		116.991875		
24/04/ 2010	750		107.25		
25/04/ 2010	785.625		112.344375		
26/04/ 2010	755.625		108.054375		
27/04/ 2010	685.625		98.044375		
28/04/ 2010	665		95.095		
29/04/ 2010	695.625		99.474375		
30/04/ 2010	651.875		93.218125		

Table 4.6

- **TIME :- 3:00 PM**

DATE	INPUT SOLAR RADIATION	EFFICIENCY	OUTPUT	TOTAL SOLAR RADIATION	AVG SOLAR RADIATION
	Watts/mtr²		Watts/mtr²	Watts/mtr²	Watts/mtr²
1/04/2010	609.375		87.140625		
2/04/2010	491.25		70.24875		
3/04/2010	578.125		82.671875		
4/04/2010	576.25		82.40375		
5/04/2010	566.25		80.97375		
6/04/2010	620.625		88.749375		
7/04/2010	639.375		91.430625		
8/04/2010	540		77.22		
9/04/2010	610		87.23		
10/04/2010	405		57.915		
11/04/2010	563.75		80.61625		
12/04/2010	555.625		79.454375		
13/04/ 2010	626.875		89.643125		
14/04/ 2010	615		87.945		
15/04/ 2010	623.125	14.3%	89.106875	2301.2275	76.70758333
16/04/ 2010	526.875		75.343125		
17/04/ 2010	583.125		83.386875		
18/04/ 2010	573.75		82.04625		
19/04/ 2010	450		64.35		
20/04/ 2010	488.75		69.89125		
21/04/ 2010	340		48.62		
22/04/ 2010	466.875		66.763125		
23/04/ 2010	631.25		90.26875		
24/04/ 2010	588.125		84.101875		
25/04/ 2010	611.25		87.40875		
26/04/ 2010	583.125		83.386875		
27/04/ 2010	416.875		59.613125		
28/04/ 2010	511.25		73.10875		
29/04/ 2010	371.875		53.178125		
30/04/ 2010	328.75		47.01125		

Table 4.7

- **TIME :- 4:00 PM**

DATE	INPUT SOLAR RADIATION	EFFICIENCY	OUTPUT	TOTAL SOLAR RADIATION	AVG SOLAR RADIATION
	Watts/mtr²		Watts/mtr²	Watts/mtr²	Watts/mtr²
1/04/2010	383.75		54.87625		
2/04/2010	215.625		30.834375		
3/04/2010	378.125		54.071875		
4/04/2010	373.125		53.356875		
5/04/2010	367.5		52.5525		
6/04/2010	396.875		56.753125		
7/04/2010	430		61.49		
8/04/2010	223.125		31.906875		
9/04/2010	395.625		56.574375		
10/04/2010	361.875		51.748125		
11/04/2010	366.25		52.37375		
12/04/2010	367.5		52.5525		
13/04/ 2010	418.125		59.791875		
14/04/ 2010	393.125		56.216875		
15/04/ 2010	411.25	14.3%	58.80875	1380.933125	46.03110417
16/04/ 2010	335.625		47.994375		
17/04/ 2010	310.625		44.419375		
18/04/ 2010	295		42.185		
19/04/ 2010	253.75		36.28625		
20/04/ 2010	334.375		47.815625		
21/04/ 2010	221.25		31.63875		
22/04/ 2010	276.25		39.50375		
23/04/ 2010	422.5		60.4175		
24/04/ 2010	390.625		55.859375		
25/04/ 2010	397.5		56.8425		
26/04/ 2010	383.75		54.87625		
27/04/ 2010	120		17.16		
28/04/ 2010	258.125		36.911875		
29/04/ 2010	172.5		24.6675		
30/04/ 2010	3.125		0.446875		

Table 4.8

4.3.3 Diurnal Variations for April Month 2010

The below table shows us the diurnal variation for April month. In the second coulomb of table shows the average solar radiation available for whole month at different time interval of day. From this data we calculated the average solar radiation in Watts-hour per mtr². Watt-Hour per meter² (Watts-h/mtr²) means number of watts acting on one mtr² area over a period of 1 hour. The daily energy output also calculated by adding average output solar radiation for different time interval of day. Monthly energy output is calculated by multiplying the number of days of month with the daily energy output.

TIME	AVG O/P SOLAR RADIATION	AVG OUTPUT SOLAR RADIATION IN HOUR	DAILY ENERGY OUTPUT	MONTHLY ENERGY OUTPUT
	Watts/mtr²	Watts-h/mtr²	Watts-h/mtr²	Watts-h/mtr²
9:00AM	67.81477083	67.81477083		
10:00AM	92.60739583	92.60739583		
11:00AM	111.1258958	111.1258958		
12:00PM	117.2510625	117.2510625	729.4847083	21884.54125
1:00PM	115.0345625	115.0345625		
2:00PM	102.9123333	102.9123333		
3:00PM	76.70758333	76.70758333		
4:00PM	46.03110417	46.03110417		

Table 4.9

4.3.4 Diurnal Variations Tables (Sep 2009 to March 2010)

The below table shows us the diurnal variation for September month.

TIME	AVG O/P SOLAR RADIATION	AVG OUTPUT SOLAR RADIATION IN HOUR	DAILY ENERGY OUTPUT	MONTHLY ENERGY OUTPUT
	Watts/mtr²	Watts-h/mtr²	Watts-h/mtr²	Watts-h/mtr²
9:00AM	64.63798611	64.63798611		
10:00AM	83.43321759	83.43321759		
11:00AM	99.66967593	99.66967593		
12:00PM	102.9467593	102.9467593	664.3905787	19931.71736
1:00PM	102.1125926	102.1125926		
2:00PM	93.65506944	93.65506944		
3:00PM	73.63506944	73.63506944		
4:00PM	44.30020833	44.30020833		

Table 4.10

The below table shows us the diurnal variation for October month.

TIME	AVG O/P SOLAR RADIATION	AVG OUTPUT SOLAR RADIATION IN HOUR	DAILY ENERGY OUTPUT	MONTHLY ENERGY OUTPUT
	Watts/mtr²	Watts-h/mtr²	Watts-h/mtr²	Watts-h/mtr²
9:00AM	61.15236111	61.15236111		
10:00AM	84.37662037	84.37662037		
11:00AM	98.17016204	98.17016204	544.2209259	16326.62778
12:00PM	97.15724537	97.15724537		
1:00PM	88.33229167	88.33229167		
2:00PM	70.52018519	70.52018519		
3:00PM	44.51206019	44.51206019		

Table 4.11

The below table shows us the diurnal variation for November month.

TIME	AVG O/P SOLAR RADIATION	AVG OUTPUT SOLAR RADIATION IN HOUR	DAILY ENERGY OUTPUT	MONTHLY ENERGY OUTPUT
	Watts/mtr²	Watts-h/mtr²	Watts-h/mtr²	Watts-h/mtr²
9:00AM	40.351025	40.351025		
10:00AM	57.217875	57.217875		
11:00AM	71.46425	71.46425	371.274475	11138.23425
12:00PM	68.64	68.64		
1:00PM	61.450675	61.450675		
2:00PM	46.5036	46.5036		
3:00PM	25.64705	25.64705		

Table 4.12

The below table shows us the diurnal variation for December month.

TIME	AVG O/P SOLAR RADIATION	AVG OUTPUT SOLAR RADIATION IN HOUR	DAILY ENERGY OUTPUT	MONTHLY ENERGY OUTPUT
	Watts/mtr²	Watts-h/mtr²	Watts-h/mtr²	Watts-h/mtr²
9:00AM	13.34566	13.34566		
10:00AM	27.248675	27.248675		
11:00AM	43.546284	43.546284		
12:00PM	54.6438759	54.6438759	284.6676219	8824.696279
1:00PM	56.93546	56.93546		
2:00PM	46.46283	46.46283		
3:00PM	30.648437	30.648437		
4:00PM	11.8364	11.8364		

Table 4.13

The below table shows us the diurnal variation for January month.

TIME	AVG O/P SOLAR RADIATION	AVG OUTPUT SOLAR RADIATION IN HOUR	DAILY ENERGY OUTPUT	MONTHLY ENERGY OUTPUT
	Watts/mtr²	Watts-h/mtr²	Watts-h/mtr²	Watts-h/mtr²
9:00AM	18.84025	18.84025		
10:00AM	32.2465	32.2465		
11:00AM	50.232325	50.232325		
12:00PM	59.48085	59.48085	329.40765	9882.2295
1:00PM	60.228025	60.228025		
2:00PM	53.242475	53.242475		
3:00PM	37.77345	37.77345		
4:00PM	17.363775	17.363775		

Table 4.14

The below table shows us the diurnal variation for February month.

TIME	AVG O/P SOLAR RADIATION	AVG OUTPUT SOLAR RADIATION IN HOUR	DAILY ENERGY OUTPUT	MONTHLY ENERGY OUTPUT
	Watts/mtr²	Watts-h/mtr²	Watts-h/mtr²	Watts-h/mtr²
9:00AM	42.2296875	42.2296875		
10:00AM	67.98245536	67.98245536		
11:00AM	89.09410714	89.09410714		
12:00PM	96.72928571	96.72928571	569.1495759	15936.18813
1:00PM	94.36404018	94.36404018		
2:00PM	81.1525	81.1525		
3:00PM	63.188125	63.188125		
4:00PM	34.409375	34.409375		

Table 4.15

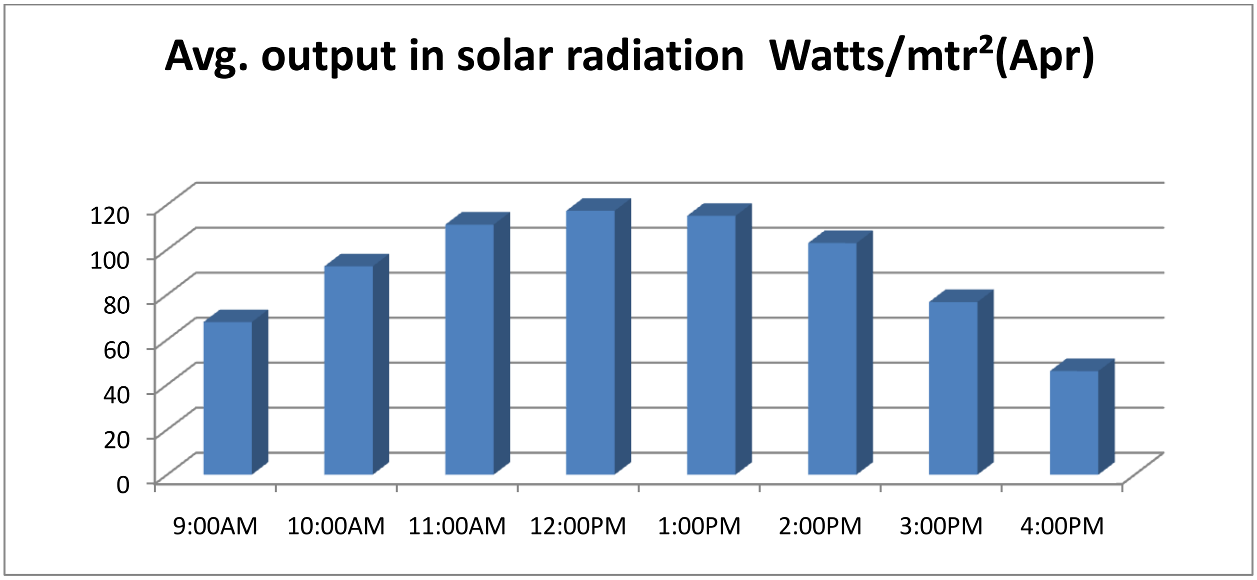
The below table shows us the diurnal variation for March month.

TIME	AVG O/P SOLAR RADIATION	AVG OUTPUT SOLAR RADIATION IN HOUR	DAILY ENERGY OUTPUT	MONTHLY ENERGY OUTPUT
	Watts/mtr²	Watts-h/mtr²	Watts-h/mtr²	Watts-h/mtr²
9:00AM	58.5896371	58.5896371		
10:00AM	85.24933468	85.24933468		
11:00AM	105.5432258	105.5432258		
12:00PM	115.8357661	115.8357661	700.3972782	21011.91835
1:00PM	114.3798185	114.3798185		
2:00PM	97.3783871	97.3783871		
3:00PM	74.66560484	74.66560484		
4:00PM	48.75550403	48.75550403		

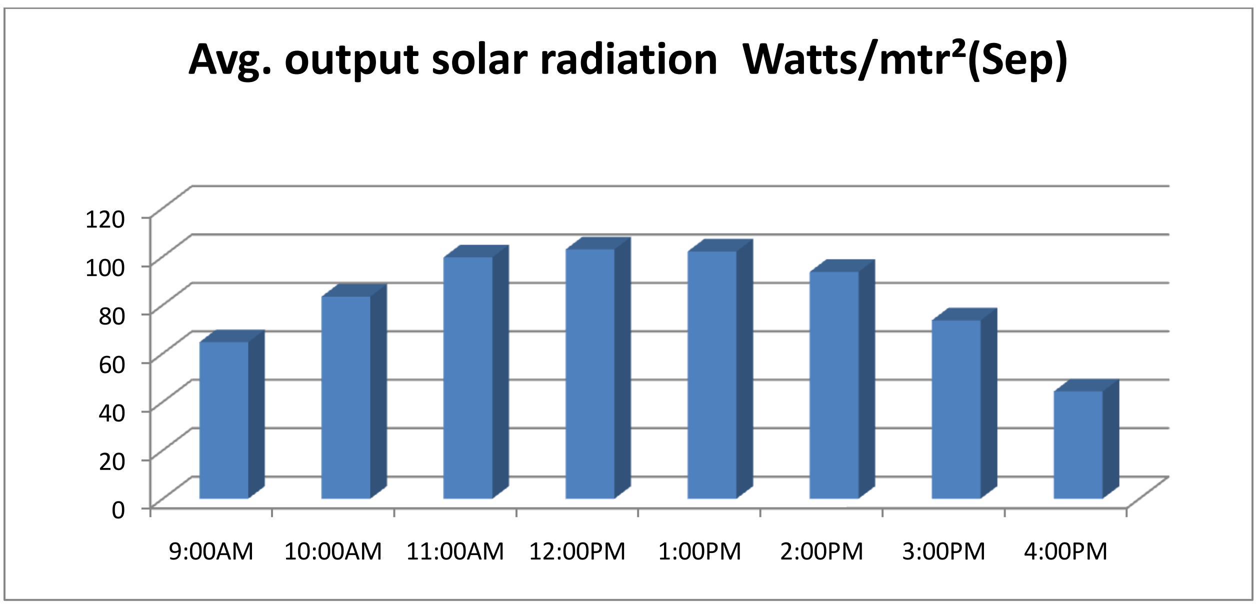
Table 4.16

4.3.5 Graphs for Diurnal Variations (Sep 2009 to April 2010)

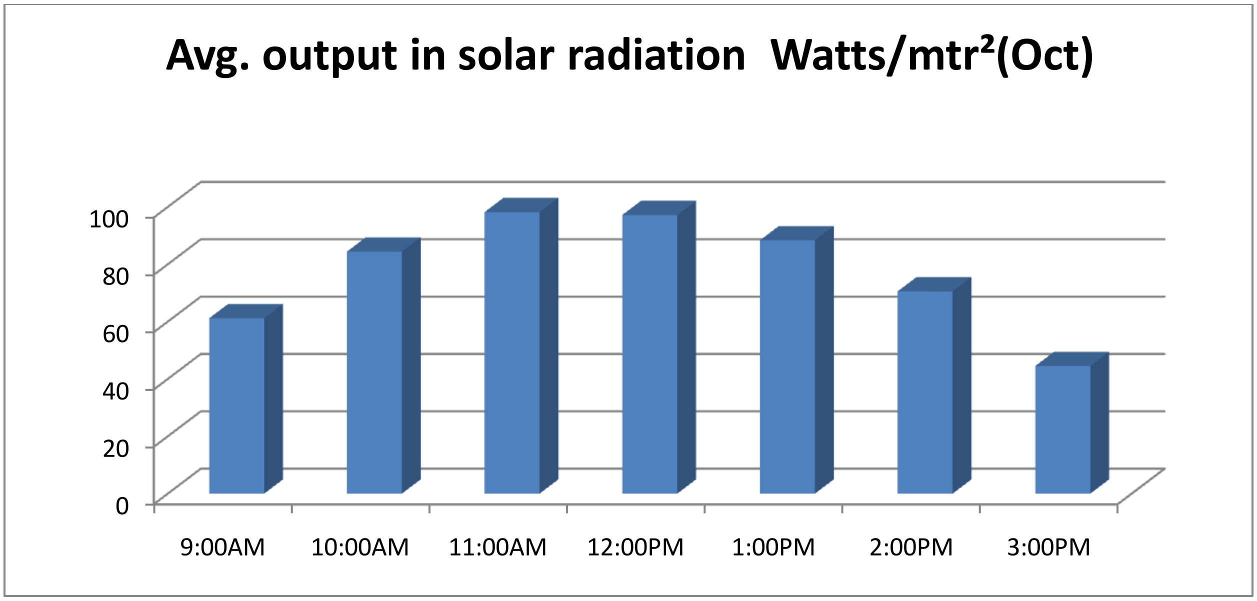
Graph is plotted between average solar radiation available in Watts/mtr² and different time interval of day for different months.



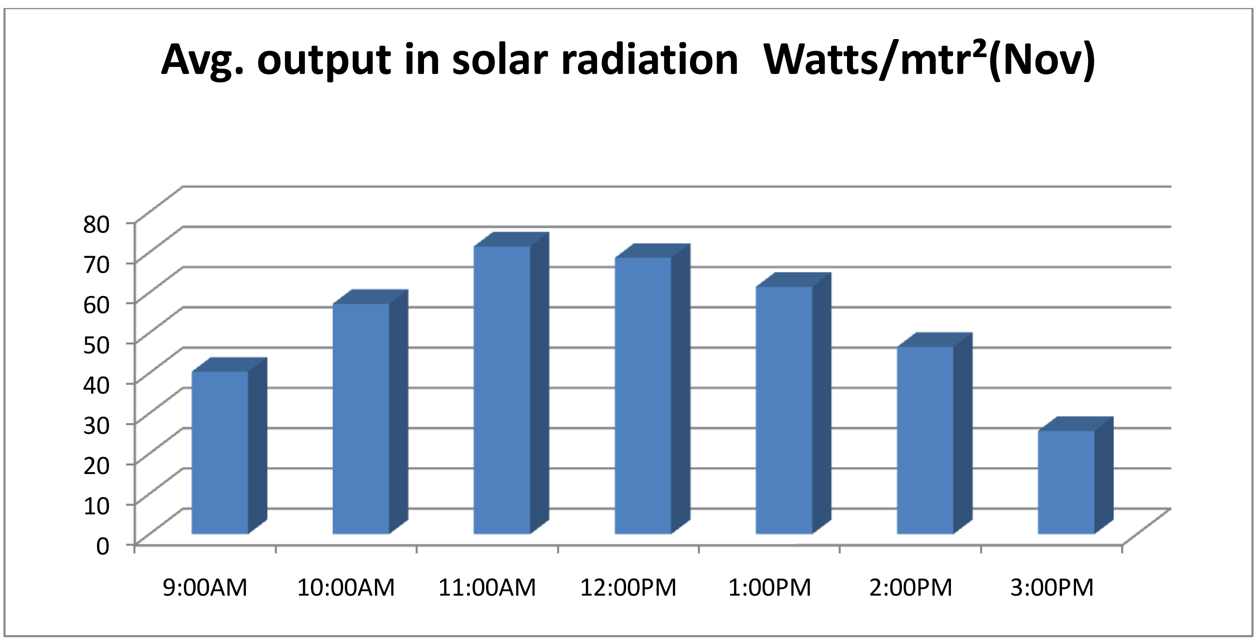
Graph 4.1



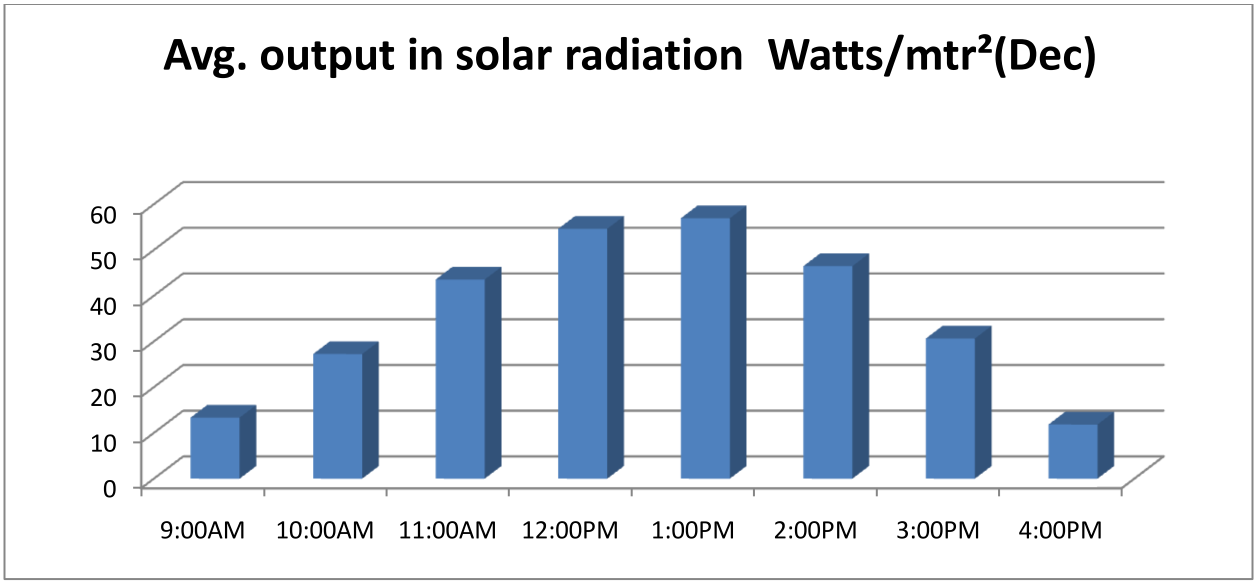
Graph 4.2



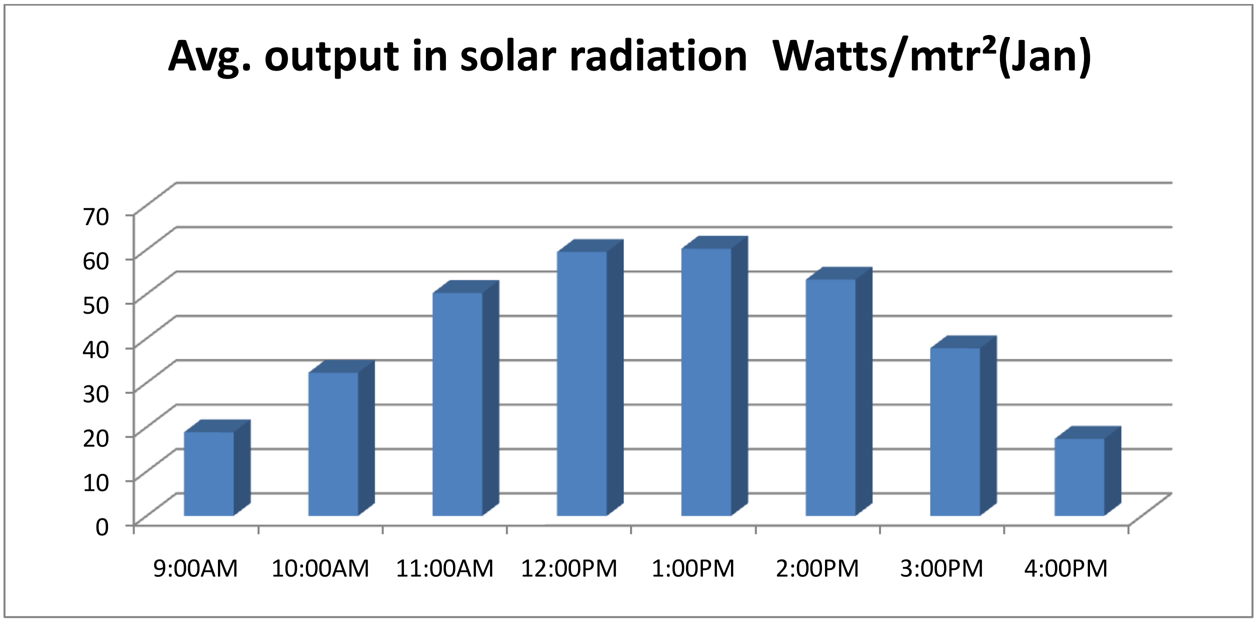
Graph 4.3



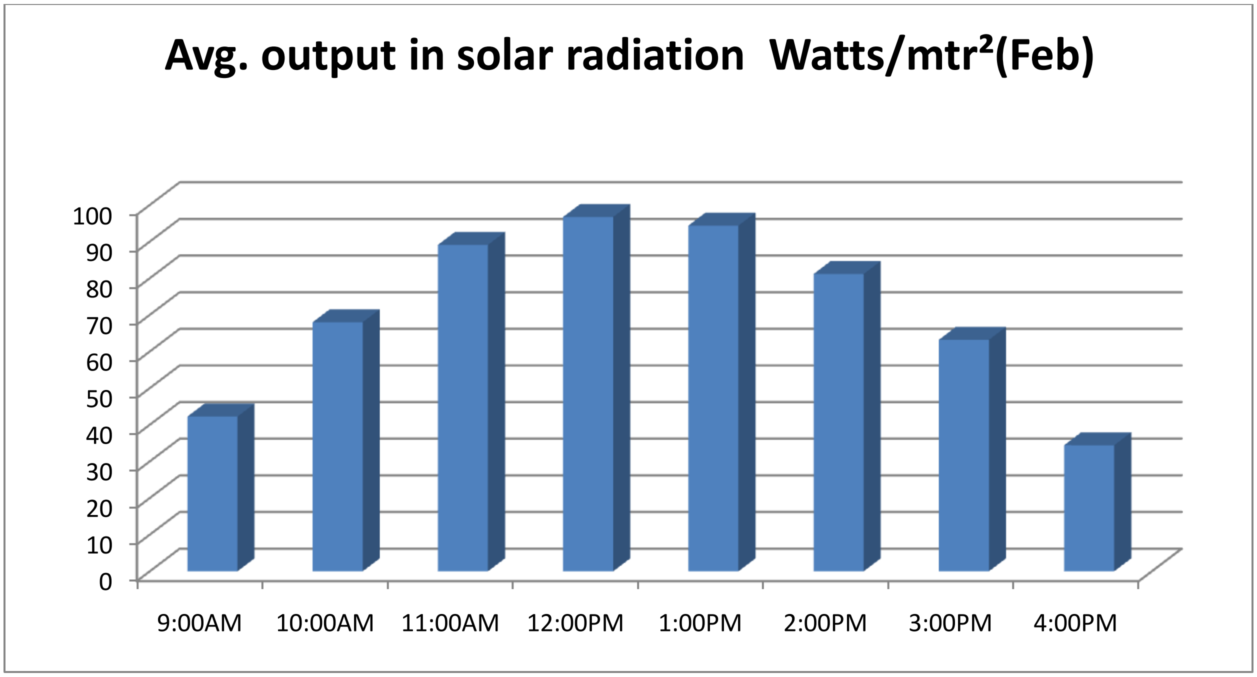
Graph 4.4



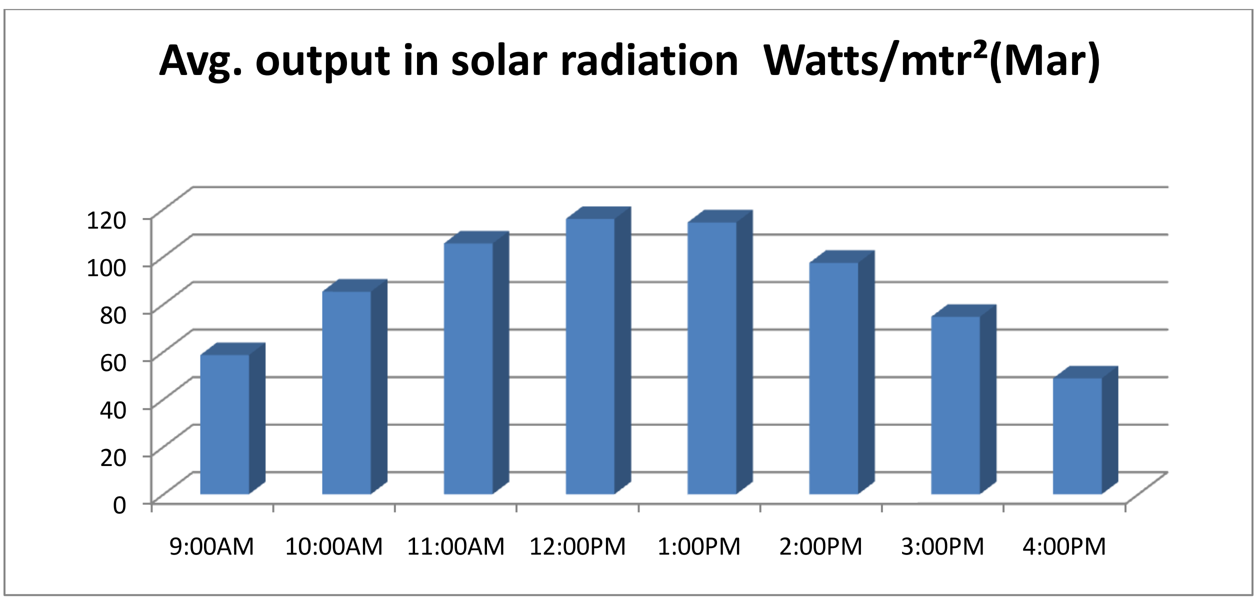
Graph 4.5



Graph 4.6



Graph 4.7



Graph 4.8

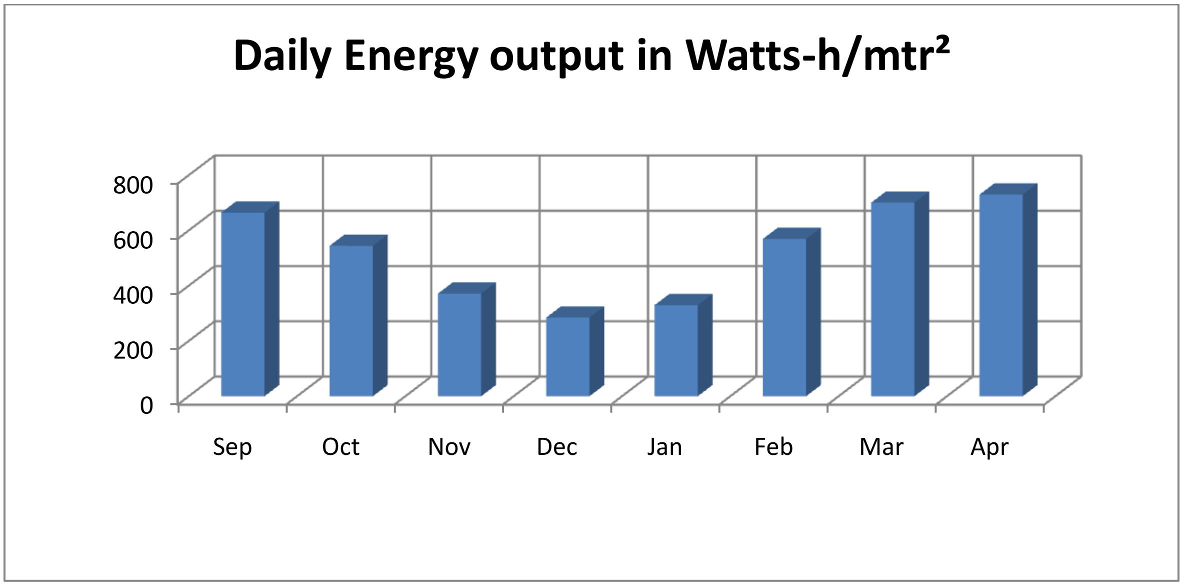
4.4 TOTAL OUTPUT

Here the average yearly energy output is calculated by multiplying average monthly energy output with total number of month12. The daily energy output also calculated for various months shown in 2^{nd} coulomb. Monthly energy output is calculated by multiplying the number of days of month with the daily energy output shown in 3^{rd} coulomb for various months. Kilowatt-Hour (kWh) means 1,000 thousand watts acting over a period of 1 hour. The kWh is a unit of energy. 1 kWh=3600 kJ.

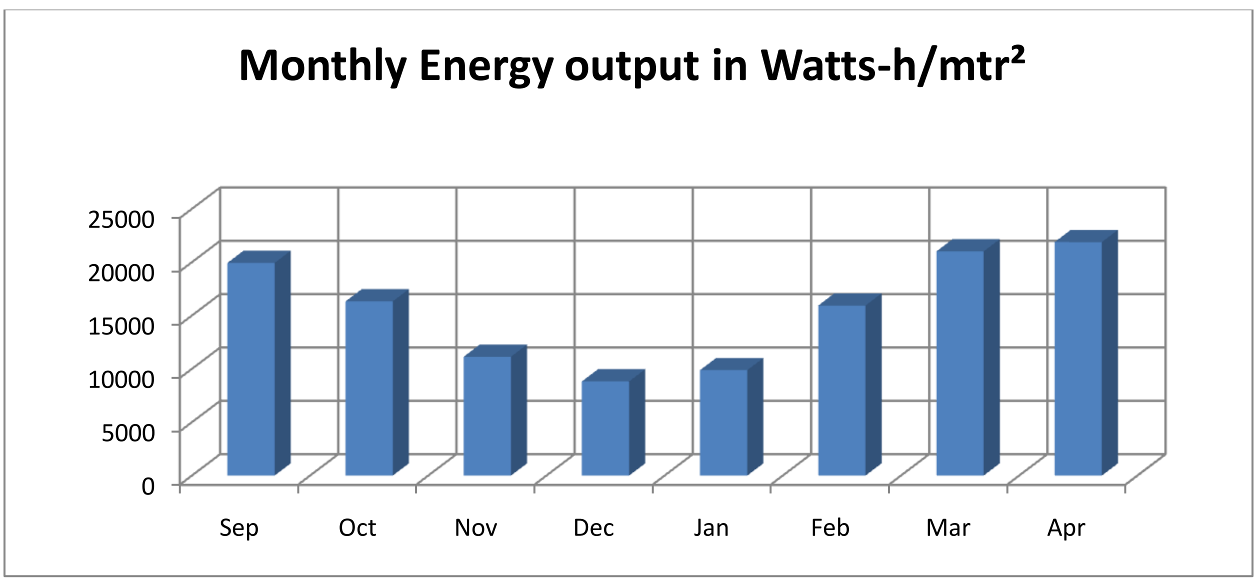
MONTHS	DAILY ENERGY O/P	MONTHLY ENERGY O/P	AVG MONTHLY ENERGY O/P	AVG YEARLY ENERGY O/P
	Watts-h/mtr²	Watts-h/mtr²	Watts-h/mtr²	Watts-h/mtr²
Sep	664.3905787	19931.71736		
Oct	544.2209259	16326.62778		
Nov	371.274475	11138.23425		
Dec	284.6676219	8824.696279	15617.01911	187404.2293
Jan	329.40765	9882.2295		
Feb	569.1495759	15936.18813		
Mar	700.3972782	21011.91835		
Apr	729.4847083	21884.54125		

Table 4.17

4.4.1 Graph for Daily & Monthly Energy Outputs (Watt/ mtr²-hr)



Graph 4.9



Graph 4.10

4.5 PEAK VARIATION AND POSSIBLE PLANT RATING

Table shows the peak value of solar potential for the different months.

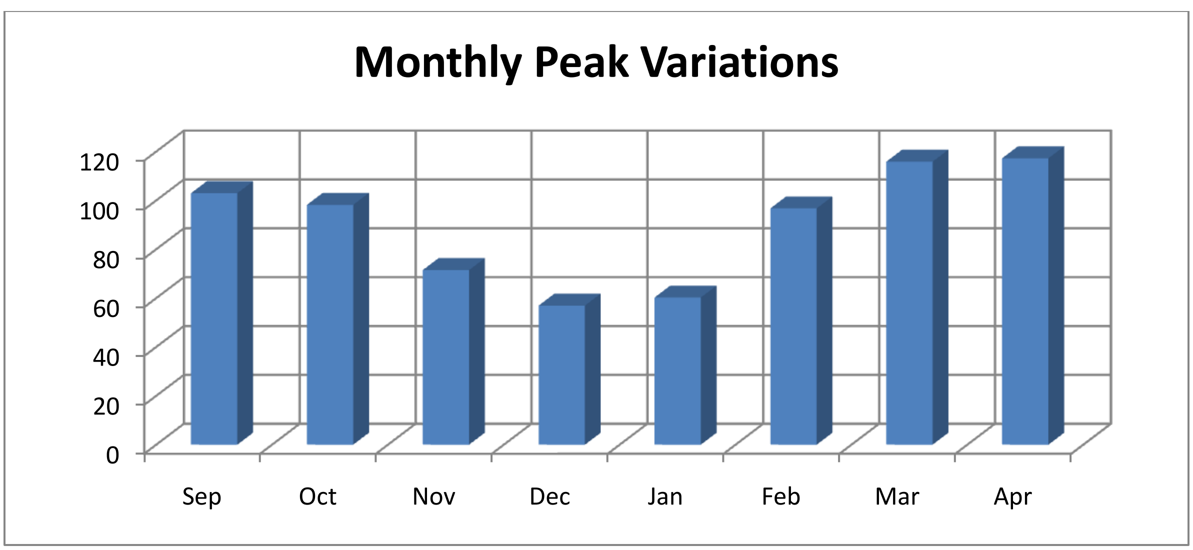
MONTHS	PEAK OUTPUT	AVG PEAK OUTPUT	AVG PEAK PER 100 mtr² AREA	POSSIBLE PLANT CAPACITY
	Watts/mtr²	Watts/mtr²	Watts	Kilowatts
Sep	102.9467593			
Oct	98.17016204			
Nov	71.46425			
Dec	56.93546	94.66075866	9466.075866	9
Jan	60.228025			
Feb	96.72928571			
Mar	115.8357661			
Apr	117.2510625			

Table No. 4.18

Average peak solar radiation for the months is 9.466075866Watts/mtr².We assume that 100 mtr² areas are available for installation of solar power plant. Above we calculated the average peak solar radiation for the different months. So the possible plant rating can be calculated by multiplying average peak solar radiation value 94.66075866 Watts/mtr² with available area 100 mtr², we get 9466.075866Watts.

So predicted plant rating in megawatt is 09 Kilowatt.

4.5.1 Graph for Monthly Peak Variations in Patiala



Graph No. 4.11

4.6 CONCLUSION

The April months gives the maximum monthly energy output out of eight months. Solar photovoltaic generation potential during the period September 2009-April 2010 is assessed for Patiala district of Punjab. It is found that the month of December produced the lowest solar radiation. Monthly and yearly outputs were calculated on the basis of 100 m^2 area. Considering the monthly peaks, the average peak output is calculated from where an estimate of the possible plant rating is made. The methodology adopted seems satisfactory for determining the possible plant capacity for an arbitrarily chosen area.

GRID CONNECTED SOLAR PHOTOVOLTAIC SYSTEMS

Chapter 05

5.1 INTRODUCTION

Grid interconnection of photovoltaic (PV) power generation system has the advantage of more effective utilization of generated power. However, the technical requirements from both the utility power system grid side and the PV system side need to be satisfied to ensure the safety of the PV installer and the reliability of the utility grid. Clarifying the technical requirements for grid interconnection and solving the problems are therefore very important issues for widespread application of PV systems.

Grid interconnection of PV systems is accomplished through the inverter, which convert DC power generated from PV modules to AC power used for ordinary power supply for electrical equipments. Inverter system is therefore very important for grid connected PV systems.

Inverter technology is very important to have reliable and safety grid interconnection operation of PV system. It is also required to generate high quality power to AC utility system with reasonable cost. To meet with these requirements, up to date technologies of power electronics are applied for PV inverters. By means of high frequency switching of semiconductor devices with PWM (Pulse Width Modulation) technologies, high efficiency conversion with high power factor and low harmonic distortion power can be generated. Reduction of inverter system cost is to be accomplished.

The greatest influence on system cost is the amount of PV modules installed. Other factors include maximum power demand, location, type and quality of equipment, extent of automatic controls and metering, provision of suitable accommodation for equipment and the amount of wiring needed. The cost of grid connected PV systems varies considerably.

As day by day the demand of electricity is increased and that much demand cannot be meeting up by the conventional power plants. And also these plants create pollution. If we look at the nature of load demand curve it is found that demand is increased from morning for different causes like opening the shops, markets, schools, colleges, offices etc. and that increased demand remains up to around 5 pm. And from the study of PV system it is found that, it is very much ideal to meet that increased energy demand by using Grid Connected Photovoltaic System. That's why we go for grid connected topology.

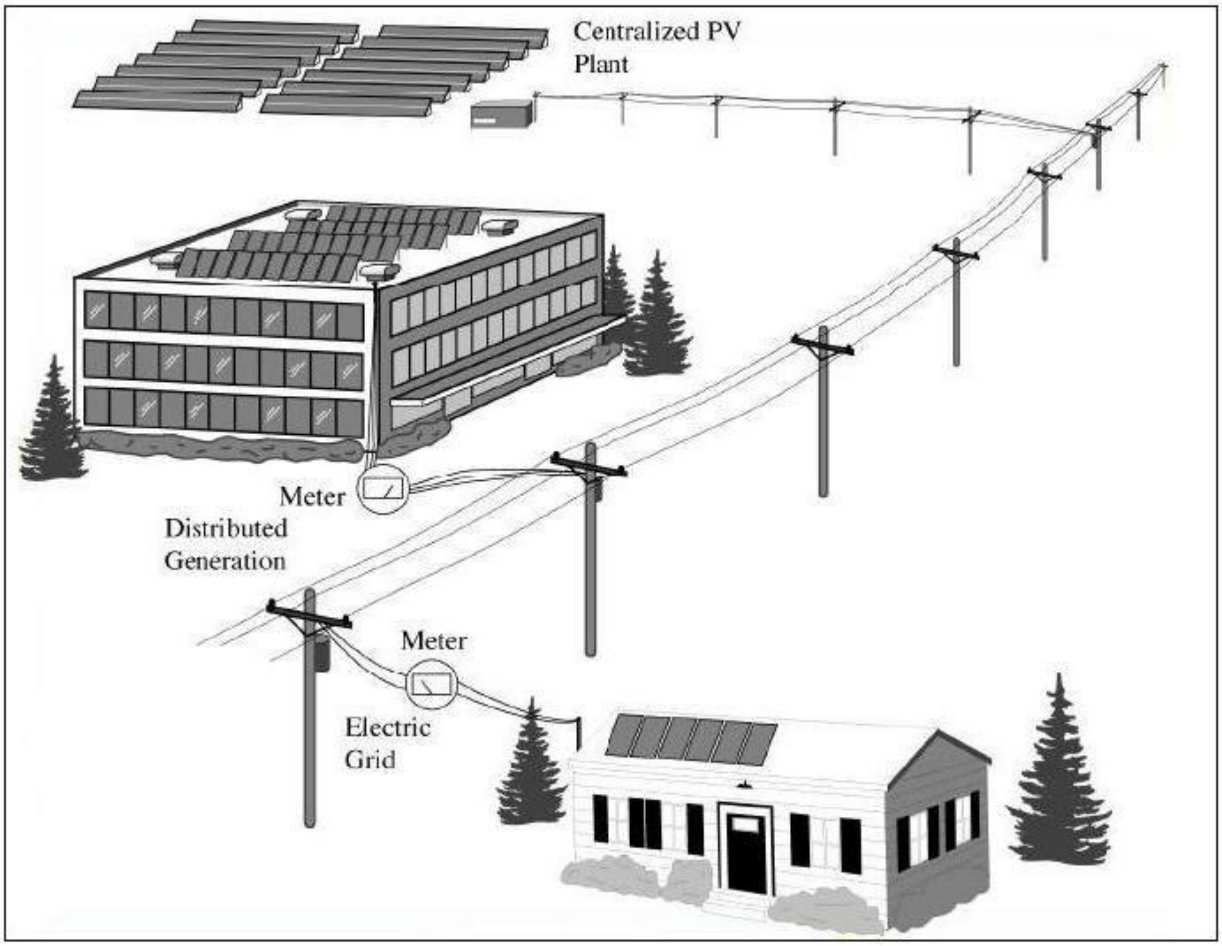


Figure 5.1: Grid connected PV system

5.2 BASIC COMPONENTS OF GRID CONNECTED PV SYSTEM

The basic Grid Connected PV system design has the following components:

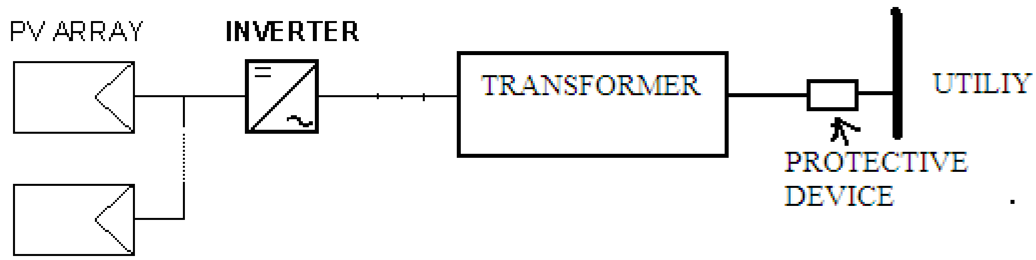


Figure 5.2: Block diagram Grid Connected System

- **PV ARRAY**: A number of PV panels connected in series and/or in parallel giving a DC output out of the incident irradiance. Orientation and tilt of these panels are important design parameters, as well as shading from surrounding obstructions.
- **INVERTER**: A power converter that 'inverts' the DC power from the panels into AC power. The characteristics of the output signal should match the voltage, frequency and power quality limits in the supply network.
- **TRANSFORMER**: A transformer can boost up the ac output voltage from inverter when needed. Otherwise transformer less design is also acceptable.
- **LOAD**: Stands for the network connected appliances that are fed from the inverter, or, alternatively, from the grid.
- **METERS**: They account for the energy being drawn from or fed into the local supply network.
- **PROTECTIVE DEVICES**: Some protective devices is also installed, like under voltage relay, circuit breakers etc for resisting power flow from utility to SPV system.
- **OTHER DEVICES:** Other devices like dc-dc boost converter, ac filter can also be used for better performance.

5.3 WORKING PRINCIPLE OF GRID CONNECTED PHOTOVOLTAIC SYSTEM

Electricity is produced by the PV array most efficiently during sunny periods. At night or during cloudy periods, independent power systems use storage batteries to supply electricity needs. With grid interactive systems, the grid acts as the battery, supplying electricity when the PV array cannot. During the day, the power produced by the PV array supplies loads. An inverter converts direct current (DC) produced by the PV array to alternating current (AC) and transformer stepped up the voltage level as need for export to the grid. Grid interactive PV systems can vary substantially in size. However all consist of solar arrays, inverters, electrical metering and components necessary for wiring and mounting.

5.4 CONDITIONS FOR GRID INTER FACING

There are some conditions to be satisfied for interfacing or synchronizing the SPV system with grid or utility. If proper synchronizing is not done then SPV potential cannot be fed to the grid. The conditions for proper interfacing between two systems are discussed below:

- **Phase sequence matching:** Phase sequence of SPV system with conventional grid should be matched otherwise synchronization is not possible. For a three phase system three phases should be 120 deg phase apart from each other for both the system.

- **Frequency matching:** Frequency of the SPV system should be same as grid. Generally grid is of 50 Hz frequency capacity, now if SPV systems frequency is slightly higher than grid frequency (0.1 to 0.5) synchronization is possible but SPV system frequency should not be less than grid frequency.

- **Voltage matching**: One of the vital point is voltage matching. Voltage level of both the system should same, otherwise synchronization is not possible.

5.5 ADVANTAGES OF SMALL UNITS INSTEAD OF SINGLE LARGE UNIT

The design for a grid connected photovoltaic system can be done in various ways like it can be made by small numbers of single phase units instead of single large three phase unit. Because this type of designing have some advantages over a large system design. The advantages are given below:

- **Efficiency of Operation:** It is logical to operate a small unit delivering rated output when the load demand is light. Then as load increases another unit is connected with the one already in operation. This keeps the plant loaded up to their rated capacity and increases efficiency of operation.

- **Reliability or Continuity of service**: Several smaller units are more reliable than a large single unit, since if one unit fails the continuity of supply can be maintained by remaining units. On the other hand if the power stations consisted only of a single large unit, in the event of breakdown, there will be complete shutdown (failure of supply).

- **Maintenance and repair:** It is considered necessary to carry out regular inspection and maintenance so as to avoid possibility of failure. This is possible only when the unit is out of service which means that the remaining units should be capable to take care of load .Repairing of a unit is also more convenient and economical if there are several smaller units in the power station.

- **Additions to power plant:** The additional unit can be installed as and when required with the growth of load on power station.

5.6 CALCULATIONS ABOUT AMOUNT OF ENERGY IS FED TO THE GRID FROM SOLAR POWER

There are two meters connected one is called import meter another is export meter. Now from these we can conclude.

Export meter reading – Import meter reading = power fed to the grid

From SPV power plant

So now we can determine what amount of energy is fed to the grid from solar power. That much of tariff will differ from conventional power tariff.

5.7 GRID CONNECTED PV POWER GENERATION ALL OVER THE WORLD

The first large sized (1MW) grid interactive PV power plant was installed in Lugo in California, USA. The second and largest (6.5 MW) plant was installed in Carissa Plains, California, USA. Also some other large sized plant are operating in various countries and many other proposed in Italy, Switzerland, Germany, Australia, Spain and Japan. Several small capacity systems in the range of 25 KW – 200 KW are being experimentally tried out in Africa, Asia and Latin America. In India, 33 SPV, grid connected plants with total installed capacity of 2.54 MW have been installed so far, and another 550 KW aggregate installed capacity plants are undergoing installation process. A 200 KW grid interactive SPV plant installed recently at village Khatkarkalan, Dt- Nawanshahr of Punjab. Also a large no of small rooftop grid interactive systems are successfully being operated at various parts of the world. In next chapter we study about grid connected photovoltaic system.

5.8 ABOUT GRID INTERACTIVE SPV PLANT INSTALLED RECENTLY AT NAWANSHAHR DISTRICT OF PUNJAB

Village Khatkar Kalan in District Nawanshahr [33] of the state of Punjab India is one of the thousands of Indian villages, which are facing electricity shortages due to gap between demand and supply of electricity. The village has grid connection but availability of electricity is erratic. The Ministry of Non conventional Energy Sources (MNES), Government of India in consultation with village Panchayat (the local governance body) identified the village for demonstration of grid connected solar photovoltaic power plant of 200kW capacity, which is the largest Photovoltaic plant in the country. The Power plant also supplies electricity to streetlights in the villages. The power plant of this size has not been installed in the country so far. This plant is one of the best examples of demonstration of technology as well as the concept of feeding the renewables electricity into the state grid.

5.8.1 Description of The Activity

The solar power plant is situated on the outskirts of the village. The plant is installed on the ground covering an area of 1.4 acres. The plant rated capacity is 200kWp. It consists of 2690 numbers of poly-crystalline silicon PV modules each of 75Wp capacity. The battery backup is provided to take care of street lighting load of 10 kW capacities. Total battery storage capacity is 120V, 850Ah.

The electrical circuits are divided in three sections, two each of 100kW p capacity for grid feeding and one 10kWp capacity for powering street lights in the night. The plant powers 100 streetlights for 12 hrs per day.

5.9 SYSTEM DESIGN

Grid connected PV system can be designed in various ways, like with battery, without battery, with or without transformer etc. Here without battery grid interconnected system is used, because of short life time, large replacement cost, and increased installation cost. A transformer is used for boosting the ac output voltage and feeding to grid. There are two meters connected-one is called the import meter, the other is called the export meter. Thus the difference between the two meter readings gives the power fed to the grid from solar photovoltaic power plant. So using these meters we can easily determine what amount of energy is fed to the grid from solar power.

From the results obtained, we find that a 9 kW_P solar photovoltaic power plant can be developed on 100 m^2 chosen area. Corresponding system sizing and specifications are provided along with the system design.

For the 9 kW_P plant required no. of PV modules = (9000 /180) =50.

Now to form a solar photovoltaic power plant 50 modules are connected in series-parallel combination.

10 modules are connected in series and there are 5 parallel paths of 10 modules each. It also supports the fact that these 50 PV modules can be accommodated within 100 m_2 available area.

Now each module produces 24 Volts. So total 10 series connected module will produce = 24×10 = 240Volts.

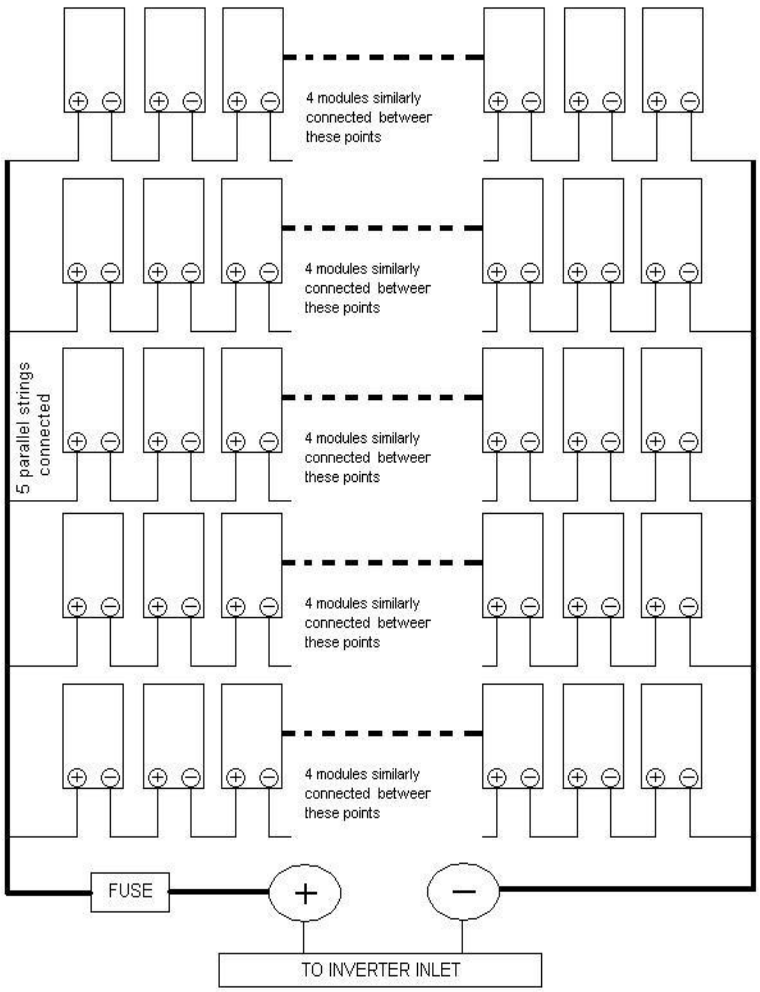


Figure 5.3: for Wiring diagram of PV array

So there are five 240 Volts combinations are connected in parallel. Therefore we know that when strings are connected in parallel the voltage remains same but current will be add so

Total output voltage is from solar photovoltaic structure = 240 Volts.

Total output current is from solar photovoltaic structure = 5 × 5 = 25 Amp.

This 240 Volts dc output from solar photovoltaic structure is the input of 3 phase inverter and it will convert the dc voltage into ac voltage. After the inverter a 3 phase transformer is connected this will boost up the ac voltage and feeds it to the grid. The design layout is shown in Figure.

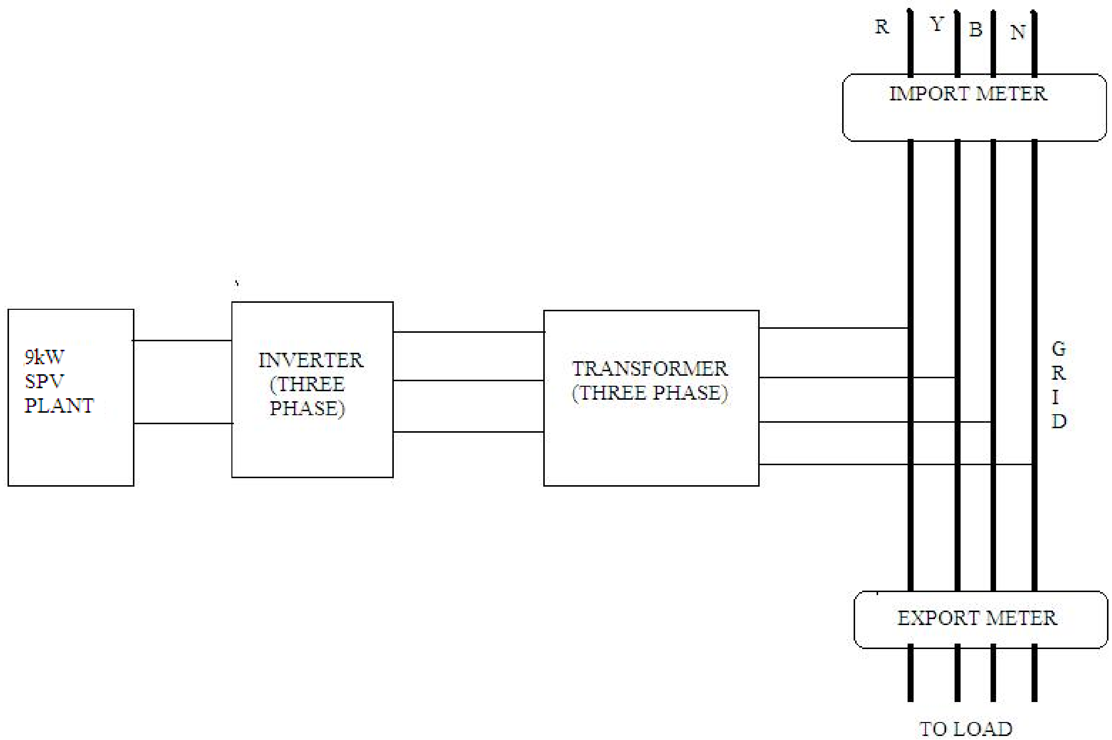


Figure 5.4: 9 KWp Grid Connected Solar Photovoltaic Power Plant

5.10 SYSTEM SIZING & SPECIFICATIONS

The system sizing and specifications for the 9 KW_P power plant unit is shown below:

Site Information:-

Proposal site for The Plant is Patiala district of Punjab, India. Its co-ordinates are:

Latitude : 30^o 7’ N

Longitude : 76^o 25’ E

One way to describe locations on Earth is by latitude and longitude. Latitude is a measure of how far north or south a place is from the Equator. Because the Equator is at the midpoint of Earth, its latitude is 0°. All other locations are measured starting from the Equator and moving north or south. To measure distance east or west you would use longitude lines. The starting point for measuring longitude is called the Prime Meridian. It goes through Greenwich, England. Similar to the Equator, its longitude is 0°. Longitude lines run between the geographic North and South Poles. To describe the position of a place on Earth you would use both latitude and longitude. By locating where a location's latitude and longitude intersect, you can easily find it on a map. Both latitude and longitude are measured in degrees.

Grid Specification:-

No. of Phases	3-φ
Voltage rating	400 Volts AC
Frequency	50 Hz.

Table 5.1

Solar Photovoltaic Power Plant Specification:-

Plant Capacity	9 KW
Voltage Output	400 Volts dc
Current Output	25 A dc
No. of Modules	50 nos.
Area	$100m^2$

Table 5.2

PWM inverters are used here for suppressing the harmonics produced after DC to AC conversion. The calculation for finding the output voltage of inverter is shown below:

Phase voltage= $V_{ph}= 0.4714 \times V_{dc} = 0.4714 \times 240 = 113.136$Volts.
Line voltage = $V_L = 0.779 \times V_{dc} = 0.779 \times 240 = 186.96$ Volts.

Inverter Specification:-

KVA rating	11.5 - 12 KVA
Input DC voltage	240 Volts DC
Input dc current	25 A
Output AC voltage	113.136 V ac (phase voltage) 186.96 V ac (line voltage)
No. of Phases	3-φ
Type	PWM (for suppressing 3rd harmonics)
Efficiency	Almost 90-93%
Total harmonic distortion	< 5%

Table 5.3

Transformer Specification:-

KVA rating	12 KVA
No of phases	3-φ
Frequency rating	50 Hz
Primary voltage rating	186.96 V
Secondary voltage rating	400 V
Primary current rating	64.18 A + (10-15% extra)
Secondary current rating	27.27 A + (10-15% extra)
Connections	Primary – delta (for suppressing Secondary – star 3rd harmonics) 10 to 25 taps in secondary
Efficiency	Almost 95 %
Extra features	Air cooled

Table 5.4

Solar Panel Specification:-

Watt	180 Watt
Voltage	24 Volts
Current	5 A
Type	polycrystalline
Efficiency	14.3%
Temperature	25 deg c
Dimensions (mm)	1593 × 790 × 50 Area of single panel = 1258470 (mm) Area of single panel = 1.259 $meter^2$
Tilt angle(slope) of PV Module	30^o 7’
Mounting	Fixed Type

Table 5.5

Tilt angle, which is the angle between the plane of module and the horizontal. The optimum array orientation will depend on the latitude of the site, prevailing weather conditions and the load to be met. It is generally accepted that, for low latitudes, the maximum annual output is obtained when the array tilt angle is roughly equal to the latitude angle and the array faces due south (in northern hemisphere) or due north (for the southern hemisphere).However, the best financial payback may be to optimize for summer (latitude + 15 in the northern hemisphere), To optimize for Winter, the simple tilt angle is latitude – 15.

Protection:-

Protective device	400 Volts under voltage relay

Table 5.6

Others: Junction boxes, meters, distribution boxes, wiring materials, mounting materials etc.

5.11 COST ANALYSIS FOR 9 KW GRID CONNECTED SOLAR PV PLANT

a. Cost of Solar panels: - Above we use the BP 7180 most powerful module manufactured by BP Solar [34], cost of solar panel is Rs.160 per watt. So cost of 180 watt panel is (180 × 160) Rs.28800.

   We use 50 numbers of panels so Cost estimate for total panels used (50 × 28800) Rs.1440000.

b. Cost of 3-φ Inverter: - Only one piece of 11.5 - 12 KVA or 10 KW of an inverter / Power Conditioning Unit is used, multiply the size of the inverter by Rs. 25 per rated watt.

   Cost estimate for Inverter (25 × 10000) Rs. 250000.

c. Cost of 3-φ step up Transformer: - Only one piece of 12 KVA or 10 KW of a step up Transformer is used, multiply the size of the Transformer by Rs. 20 per rated watt.

   Cost estimate for Inverter (20 × 10000) Rs. 200000.

   Subtotal: Rs.1890000.

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

   Cost Estimate for Balance of System: (1890000 × 0.2) Rs. 378000.

Total Estimated PV System Cost is Rs.2268000.

5.12 ANNUAL ENERGY GENERATION

The annual energy generation from the SPV power plant has been worked out based on the data on mean global solar radiant exposure over Punjab at district Patiala. The mean global solar radiant exposure varies from 1.99 kWh/m² /day in the month of December to 5.10 kWh/m²/day in the month of April. The month-wise mean global solar radiant exposure is given at table below .Considering the efficiency of PV module at 14.3%. Monthly Average energy export to Grid is 0.98MWh. The annual energy generation feed into the grid is estimated as 11.76 MWh.

This takes into consideration an efficiency of the Power Conditioning Unit (PCU) as 94% and losses in the DC and AC system as 3% each up to the point of interconnection. The month wise energy generation during the year is given at table and shown on next page [35].

5.12.1 Mean Global Solar Radiant Exposure Patiala, PUNJAB

Month	Daily solar radiation in kWh/m²/d
Sep	4.65
Oct	3.81
Nov	2.59
Dec	1.99
Jan	2.31
Feb	3.98
Mar	4.89
Apr	5.10
Monthly Average	3.67

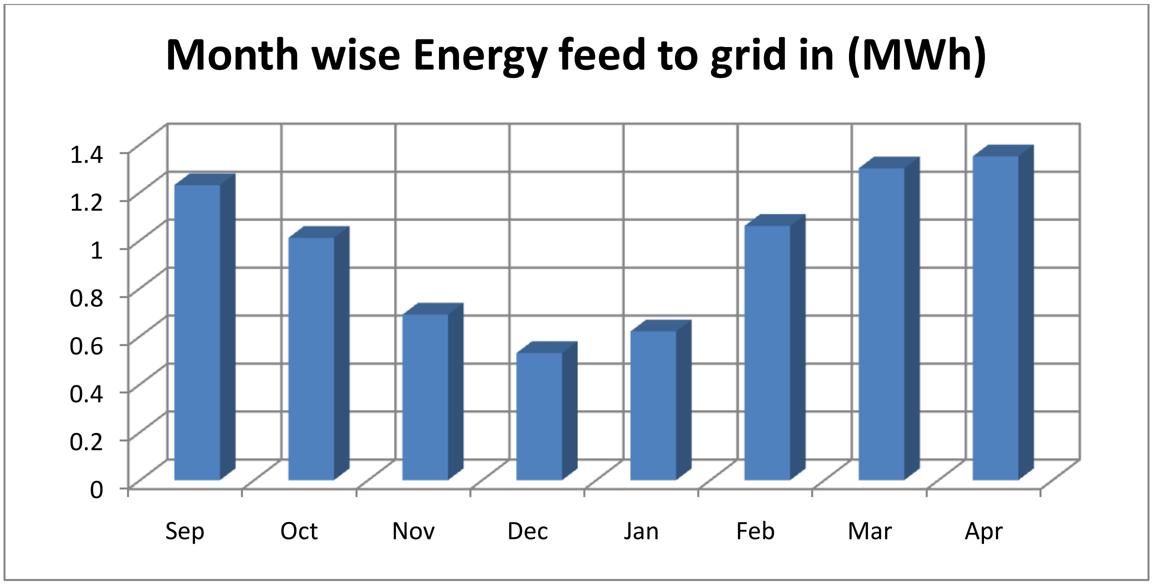
Table 5.7

5.12.2 Pattern of Energy Generation

Month	Export to Grid (MWh)
Sep	1.23
Oct	1.01
Nov	0.69
Dec	0.53
Jan	0.62
Feb	1.06
Mar	1.30
Apr	1.35
Monthly Average	0.98
Annual	11.76

Table 5.8

Assumption:- Losses in DC circuit 3%,Converter efficiency 92%,Lossess in AC circuit 3%



Graph 5.1: Month wise Variation in Energy feed to grid

The energy available from the Plant would vary from a minimum of 0.53 MWh during the month of December to a maximum of 1.35 MWh during the month of April. Due to the short time span four months of year are missed to analysis.

5.13 CONCLUSIONS

The design described is based on the potential measured. System sizing and specifications are provided based on the design made. Finally, cost analysis is carried out for the proposed design. Total Estimated PV System Cost is Rs.2268000.Annual energy generation is also calculated. The annual energy generation feed into the grid is approximately estimated as 11.76 MWh.

CONCLUSION AND WORK IN FUTURE

Chapter 06

6.1 CONCLUSION

It is expected that with present acceleration in the efforts on the part of manufacturers, designers, planners and utilities with adequate Governmental support, PV systems will within the next two decades occupy a place of pride in the country's power sector, ensuring optimum utilization of the energy directly from the sun around the year. It is clear that the Grid Connected SPV system can provide some relief towards future energy demands. Potential of grid connected photovoltaic system in Patiala district of PUNJAB is trying to find out. For which the radiation level measurements and analysis of various graphs from the solar radiation data is done in the fourth chapter. From the diurnal variation analysis of eight month we conclude that solar potential is maximum at noon. The April months gives the maximum monthly energy output out of eight months. Solar photovoltaic generation potential during the period September 2009-April 2010 is assessed for Patiala district of Punjab. It is found that the month of December produced the lowest solar radiation. Monthly and yearly outputs were calculated on the basis of 100 m^2 area. Considering the monthly peaks, the average peak output is calculated from where an estimate of the possible plant rating is made. The methodology adopted seems satisfactory for determining the possible plant capacity for an arbitrarily chosen area. The design described is based on the potential measured. System sizing and specifications are provided based on the design made. Finally, cost analysis is carried out for the proposed design. Total Estimated 9 KWp PV System Cost is Rs.2268000.Annual energy generation is also calculated. The annual energy generation feed into the grid is approximately estimated as 11.76 MWh.

6.2 WORK IN FUTURE

With in the short span of time allotted for the project work could not be extended to whole year, only eight months of year solar radiation reading is analysis, The April months gives the maximum monthly energy output out of eight months but as we all know summer session start from April. Solar radiation level goes on increasing till July so Jun or July may be the months will gives the maximum monthly energy output out of whole year at Patiala. Thus this will increase maximum plant rating for our site. So in future there is a need of solar radiation data for whole year.

A detailed Cost analysis can be conducted considering carbon credit to show whether it is economically viable or not. Since the performance of PV system is strongly dependent on loss factors such as shading, PCS losses, mismatch, PV array temperature rise, etc. There is a necessity for reviewing these loss factors to evaluate and analyze accurately the performance of PV system.

This system can be designed with also some another electrical appliances like DC- DC booster for boosting up the voltage wherever is necessary, filter for suppressing the ripples etc. Another transformer less design also can be done. DC –DC choppers with variable duty cycle can be used along with filters. For direct application of DC that kind of system can be designed.

Intelligent devices like microprocessors, PLC (programmable logic controller) may be added to the system to keep the operating point (maximum power point) for maximum efficiency. To taken care of the uncertainty in the insolation level, use of fuzzy control can be done. Use of feedback path for automatic control-position control servo for changing the transformation ratio of variac can be used. A detailed performance analysis of the present system can be carried out to show its reliability as a future work.

Solar PV is a technology that offers a solution for a number of problems associated with fossil fuels. It is clean decentralized, indigenous and does not need continuous import of a resource. On top of that, India has among the highest Solar irradiance in the world which makes Solar PV all the more attractive for India. The state of Orissa and Andhra Pradesh also houses some of the best quality reserves of silica. India has a large number of cells and modules manufacturers. In spite of all above advantages Indian Photo Voltaic programme is still in the infancy stage. One of the reasons could be absence of simple, action oriented and aggressive PV policy of the country both in the state and central level. More quickly we do it with the professionals more we protect our future energy security.

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