CHAPTER 1: INTRODUCTION

1.1 Introduction to Energy

Energy plays a very important role in our daily activities. The degree of development of any country is measured by amount of use of energy by the country. Energy demand is increasing day by day due to population and increasing technology utilization. The world's fossil fuel i.e. petroleum, coal and natural gas will be depleted in coming years. Also rate of energy consumption is increasing exponentially and to fulfil this demand we have to switch over to permanent energy resources i.e. solar, wind, geothermal, and other renewable resources [1].

We can divide energy resources into two categories:

1.1.1. Non-Renewable Energy Resources

These energy resources had been formed over millions of years of geological processes that include coal, petroleum and natural gas. We currently depend on non-renewable energy resources for meeting most of our energy demands.

Coal: A combustible sedimentary rock with constituents of carbon and hydrocarbon. It is most abundant fuel worldwide and used in most of electricity production but it emits as many as 3 times of CO_2 as the amount of coal combusted.

Natural Gas: A natural gas is mainly made of methane and found in other near fossil fuels, like coal etc. Whencombusted,natural gas produces only half of greenhouse gases emissions as coal

Petroleum: A liquid fuel occurring in beneath of geological earth surfaces. Majority of it is used for fuel of automobiles and engines. Crude oil mainly consists of different types of hydrocarbons.

1.1.2 Renewable Energy Resources

These energy resources are those which can be replenished are Available in abundance. The renewable energy resources include wind, solar, biomass, hydropower and tidal energy.

These energy sources are cleaner and offer sustainable supply of energy throughout.

Wind Energy: Wind power is use of air flow through wind turbines to mechanically power generators for electricity. This energy is plentiful, widely distributed, clean and produces no greenhouse gases while operation.

Solar Energy: Solar energy is radiant light and heat coming from sun and can be harnessed in form of solar heating, photovoltaic, solar thermal energy etc.it is said that solar energy is future energy source.

The solar PV system is a power system designed to supply power through photovoltaic. Demand of solar photovoltaic energy is growing exponentially all over the world due to following reasons:

1) Social awareness about environment.
2) Comparative price of solar energy with other conventional coal energy.
3) Clean and inexhaustible source of energy.
4) High global solar insolation for counties like India, etc.
5) Better energy policies by Ministry of New and Renewable Energy (MNRE) of Government of India to promote renewable energy.

Geothermal Energy: This thermal energy is generated and stored in earth crust. Earths internal heat energy can be harnessed in driving turbines to draw electricity from it.

1.2 World Energy Scenario

To meet world energy demands reliable, secure and affordable energy supply is basic requirement to global economic growth and development. In today's world where new technologies are flourishing, demand of electricity is also booming. The current renewable energy resources also made a significant jump in energy share and it also fulfils pledge of sustainable development. The pressure and challenges to further robust development and transform the energy system more towards renewable is immense. To make these things happen business leaders and policymakers have to take critical decisions on our future energy infrastructure. Here we have presented a comparative analysis of electricity consumption between 1973 and 2013.

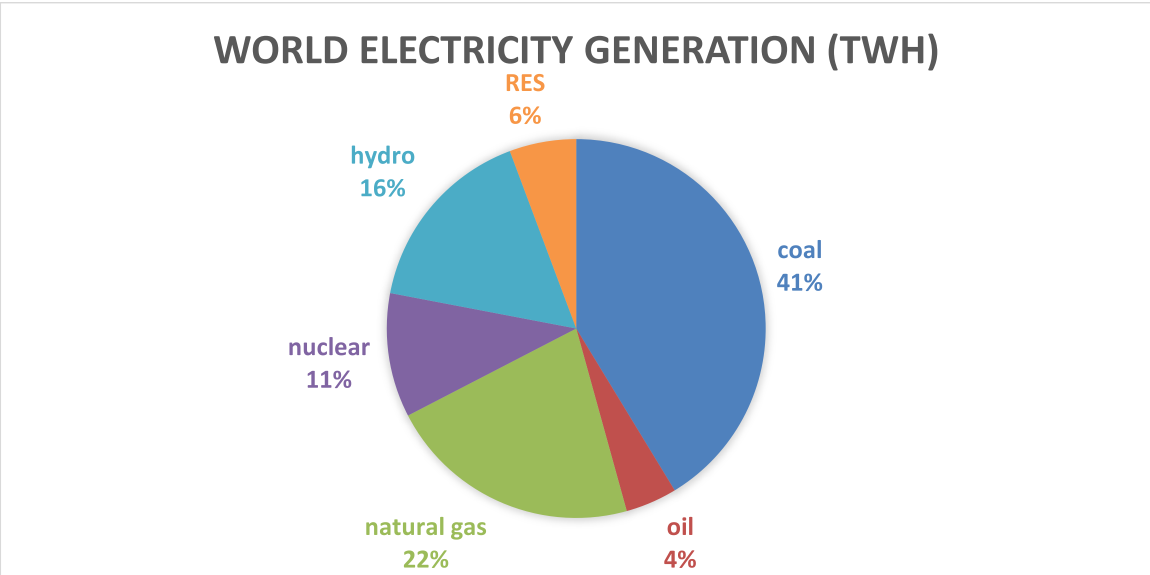


Fig1.1: Electricity generation by various resources in 2013[2]

Table1.1: comparative electricity consumption between 1973 to 2013 [2]

Fuel Source	**1973**		**2013**	
	Amount of Elect.(Twh)	**% Share in Total**	**Amount of Elect.(Twh)**	**% Share in Total**
Coal	2348	38.3	9632	41.3
Oil	1520	24.8	1026	4.4
Natural gas	742	12.1	5061	21.7
Nuclear	202	3.3	2472	10.6
Hydro	1282	20.9	3802	16.3
RES	37	0.6	1329	5.7
Total	6131	100	23322	100

1.3 Indian Energy Scenario

India is one of the fastest growing economies of the world. Economic growth is desirable of all developing countries and energy plays a vital role for economic growth. For e.g. under present 6% increase in India's gross domestic product (GDP) would increase demand of 9% increase on its energy sector. At present total installed capacity of electricity in our country is 2,98,060 MW as on 1 April 2016.It has been reported that India's primary energy absolute consumption is only 1/29th to that of the world. If we compare with other economies of world, we consume power 1/7th to that of USA and 1/1.6th to that of Japan.

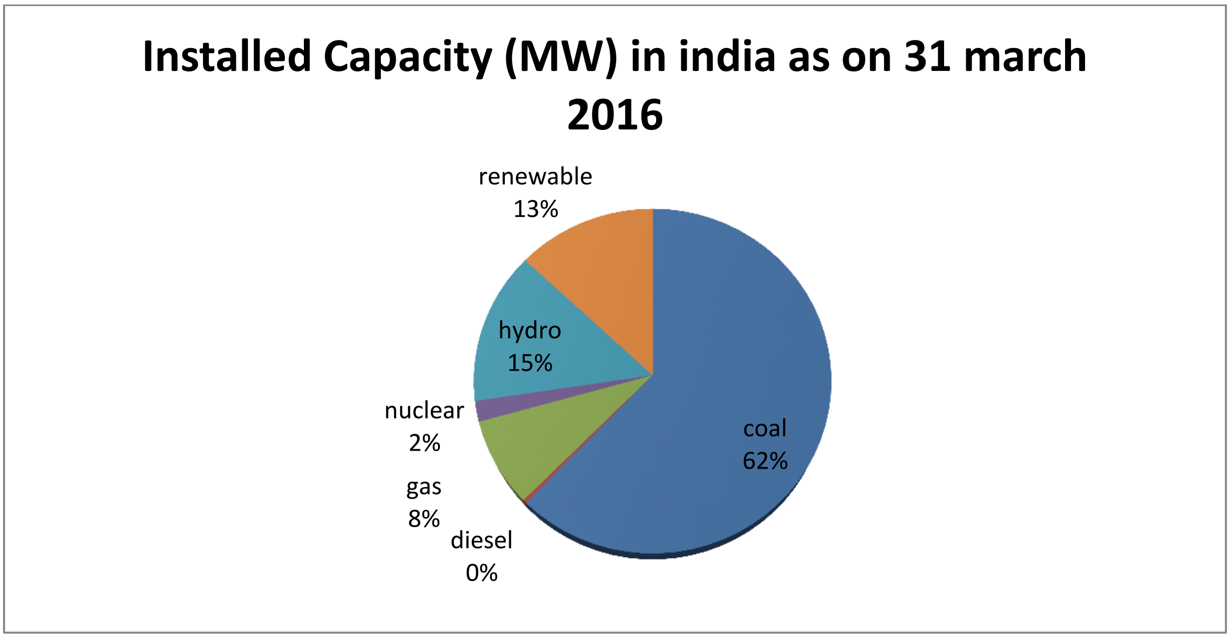
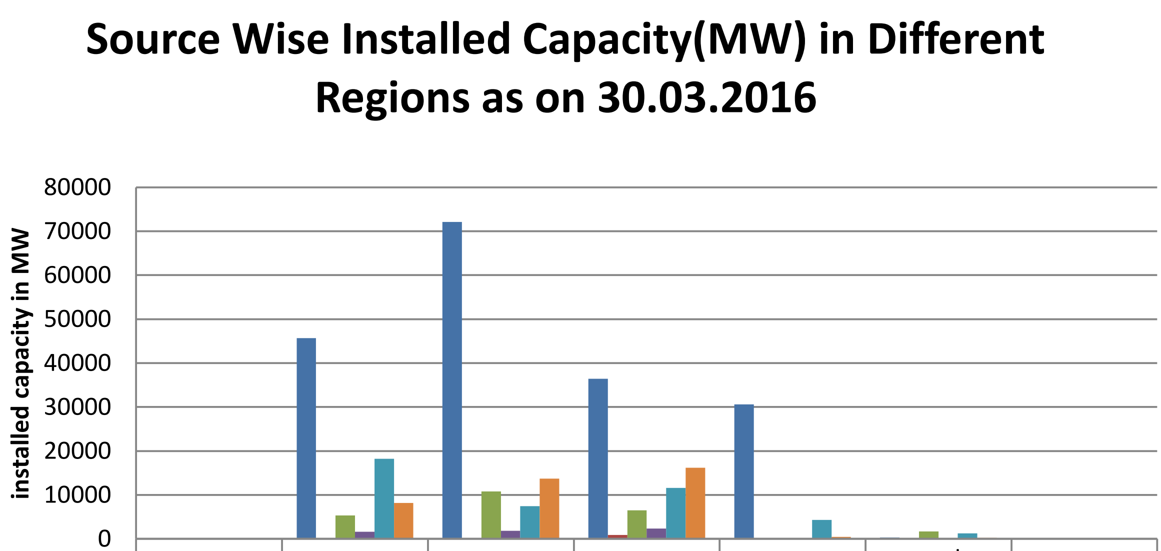


Fig1.2: Installed Capacity (MW) in India source wise as on 31 march 2016 [3]

Table1.2: Installed Capacity (MW) in India as on 31 march 2016[3]

Sources of electricity generation	**Installed capacity in MW as on 31 march 2016**	**% share in total energy**
Coal	185172.9	62.12 %
Gas	24508.63	8.22 %
Diesel	993.53	0.33 %
Total thermal	210675.1	70.68 %
Nuclear	5780	1.9 %
Hydro	42783.42	14.35 %
RES	38821.51	13.02 %
Grand total	**2,98,060 MW**	**100%**



	northern	western	southern	eastern	north eastern	islands
coal	45644.5	72153.01	36442.5	30622.87	310	0
diesel	0	0	917.48	0	36	40.05
gas	5331.26	10815.41	6473.66	190	1698.3	0
nuclear	1620	1840	2320	0	0	0
hydro	18246.77	7447.5	11558.03	4289.12	1242	0
RES	8166.92	13698.15	16213.18	469.54	262.62	11.1

Fig1.3: Source wise installed capacity (MW) in different regions as on 30.03.2016 [3]

1.4 Renewable Energy Progress in India

With the increasing threat of pollution and global warming we have to switch over to environment friendly options like renewable energy resources. There has been a rapid growth in renewable energy which is clean and inexhaustible and our country has shown rapid deployment of RES projects. Today India is major world leader in extensive renewable energy programmes. Renewable energy sources include solar energy, wind power, hydropower, biomass etc. India is one of country where largest wind power capacity. With success of Jawaharlal Nehru solar mission, India stands as world leader in decentralised solar energy projects. In India there are 300 sunny days in a year and receives 5 to 7 kWh/m^2/day. As on 01 march 2016 India has grid connected installed renewable capacity is 42752 MW in which solar power includes 6763 MW installed capacity which accounts for

16% of installed grid connected renewable energy. The Indian solar photovoltaic industry is growing at a pace of 25%.ministry of new and renewable energy India has also started to expertise renewable energy projects in other countries for its commitment towards sustainable development.

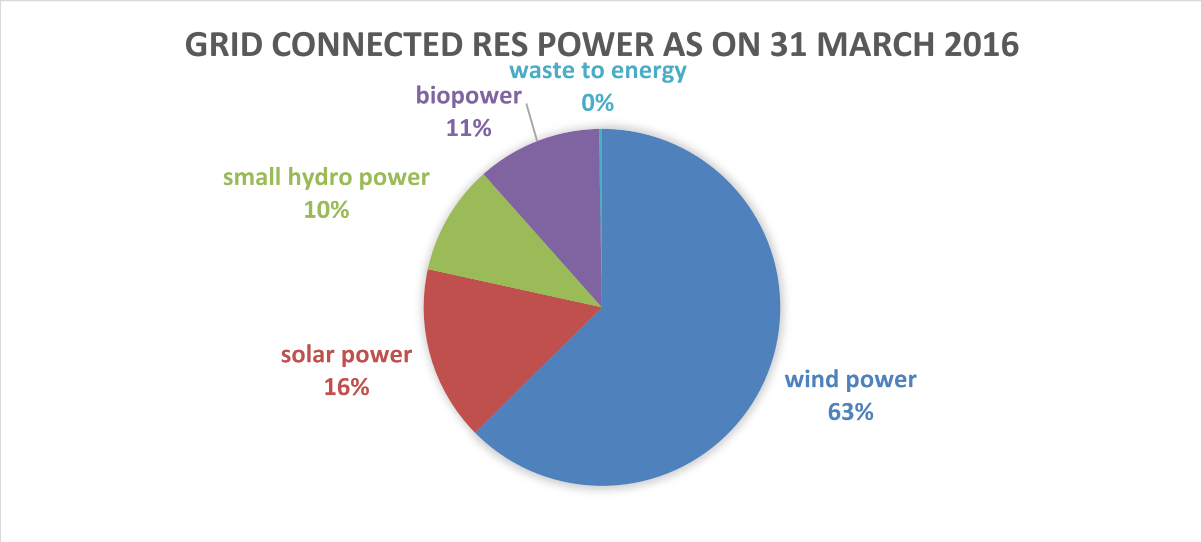


Fig1.4: Grid connected renewable power production as on 31.03.16 [4]

Table 1.3: Grid connected renewable power production as on 31.03.16 [4]

Source of RES	**Installed capacity**	**% share in total**
Wind power	26796	62.67
Small hydro	4274	10
Waste to energy	115	0.27
Biomass power	4831	11.3
Solar power	6763	15.8
Total	42752	100

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

As solar energy is growing its wings with time, parallel research is going to make this technology more feasible and cheaper than conventional energy resources. A large amount of literature is there on solar energy systems, PV grid connected systems. So by studying different research paper, attending courses on subject, read books, journals, and papers, I have understand and visualize the concept and its development.

2.2 Review of Earlier Work

M.H albadi et al. [5] have presented a paper on design of 50 KW solar rooftop system. In paper they introduce idea of installing photovoltaic system, along with components (design array size, choosing inverter rating, charge controller rating etc.).Economic analysis is also done to find payback period, net present value and savings over the years. In the work RETSCREEN soft ware were used to provide data regarding financial and cost analysis and determined annual energy produced and amount of green house gas reduction by using PV system instead of thermal power plants. Solar insolation data utilized to estimate annual energy production as well cost per KWh of generated electricity from specific PV system using RETSCREEN software. This paper was presented keeping in mind of popularity of renewable energy nowadays.

M .Chegaar et al. [6] presented a paper in 2013 on 'effects of solar illumination intensity on solar cells parameters. In this paper effect of irradiance intensity on different parameters (ideal factor, saturation current, series and shunt resistance) of polycrystalline silicon solar cells is accessed. I-V characteristics of these cells plotted at room temperature and modelled by using single diode model. Here it is found that short circuit current, photocurrent and ideal factor increases linearly with irradiance intensity while open circuit voltage and efficiency increases logarithmically. The fill factor increases a bit for low intensities and then decreases with higher intensities. The saturation current increases exponentially and others parameters have similar effect on this. The results showed importance of kind of application of different solar cells under low and high illumination intensities.

Tinton DwiAtmaja [7] presented a paper on facade and rooftop PV installation strategies for building integrated photo voltaic application. Paper showed a strategic review on optimum PV module installation to produce electricity. The facades and rooftops would be an entity of building envelope to deposit wit specific characteristic installation of photovoltaic

module. Facade installation is affected by geographical position of site, so a certain directions will execute a higher electric energy generation. In façade installation, direction of array facing and inclination angles will affect solar radiation input. In north path of earth, PV modules will generate higher electricity when facing southeast or southwest.
The inclination angle that will achieve optimum solar insulation are 60° horizontal inclination or smaller than 15 ° vertical inclination. The more the D/L ratio, greater is solar insulation on panels. For rooftop installation, curved rooftop has higher yield due to intrinsic characteristics of thin film amorphous silicon. While comparing with flat PV installation, curved PV has lower overall performance. However in summer season, Curved PV performs better than flat PV up until 15% in peak hours.

S Chander et al. [8] carried out a study on photovoltaic parameters of mono-crystalline silicon solar with cell temperature. In this study cell temperature effect on PV parameters of mono crystalline Si-cell is studied. The experiment carried out for cell temperature range of 25-60 ℃ at light intensity of 215-515 w/m².the results were laid out to show that temperature affects performance of solar cell significantly. The open circuit voltage, maximum power, efficiency and fill factor decreases with increase in cell temperature. There will be slight increase in reverse saturation current. The results are in line with available literature. The experiment was carried out employing cell simulator with cell temperature in range of 25-60 ℃. The results were quite important to understand various parameters relation with temperature.

Souvik Ganguly & Sunanda Sinha [9] presented a paper on estimation of grid quality solar PV power generation potential and its cost estimation in some places of west Bengal. The aim of their research was to estimate potential of grid connected solar PV plants in some selected places in west Bengal (Burdwan, Brigham, Hooghly, Kolkata and Howrah) .They carried out study of selected places solar radiation potential and finally developed solar PV systems .The equipment specifications were provided based on system developed and in end cost analysis of proposed systems were carried out.

Brig. M.R. Narayaoan , D.V Gupta , R.C Gupta& R.S Gupta [10] presented a paper on design develop and installation of 100 KW grid connected solar photovoltaic plants for Indian rural applications. The paper describes features on 'building block philosophy' with 25 KW system as basic unit. It included indigenous design and development for a grid connected system with high emphasize on safety for rural people. Tile paper concluded with lesions both on technical and logistics point of view. Since rural people are not that much aware about technology so safety is most important requisite while developing PV system.

B. Maion, J. Adelstein, K.Boyle et al. [11] presented a paper on performance parameters of grid connected PV systems. The performance parameters used to define performance of system are PV system output, reference yield and performance ratio PR. By using DC power PV output and PR can be calculated. The PV output is primary measure of performance and is expressed in KWh/kW. It gives a relative measure of energy produced and can analyze comparison between different systems with different sizes and different technology. And comparisons are also made for different time periods. To evaluate long term changes in performance, a dimensionless quantity to indicate overall effect of losses, Performance ratio may be used to identify the performance of system.

V.Dixit et al. [12] presented a paper on study of comparison of SPV and CPV in context with Indian climate. They carried out study on two PV systems with dual axis tracking. In study it was showed that in India where diffused part of solar insolation is more, it is more advantageous to adopt solar PV rather than CPV. They also concluded that dual axis tracking of SPV system gives better results as compared to that of CPV, especially in tropical regions where direct normal irradiance is low. CPV system with high concentration ratio fails to perform at their rated power. Output further reduces if the system modules are not cleaned regularly.

Amit jain [13] studied the accountability of solar energy resources in India. He studied and noted down the GHI and DNI of various places in India and advocated the organization of solar data houses for easy analysis. He concluded that solar energy generating cost is reducing day by day due to decreasing module prices and their technology advancement. So having access to solar data of metrological stations spread across the country will enable reliable design and development of solar photovoltaic systems. He also noted that encouraging government policies on SPV can further add to its demand in near future.

J. P. Kesri et al. [14] states that India is fastest growing economy of world today and annual GDP growth rate is 8.6%.the government of India recognizes that in order to sustain this growth rate and to strengthen its energy supply and national competitiveness, solar energy research and innovations will play a critical role for country's advancement. The government of India's solar mission is a visionary and inspiring policy maker to harness solar energy and set an example before the world. Harnessing the solar energy potential for the benefit of rural areas of India will enlighten the hearts and minds of rural population. Research on all aspects of solar energy including science, technology, engineering, economics and management will engage diverse body of faculty and students in a team environment. This can energize India's population lives in rural as well in rural areas and the quality of life will positively improve by innovative use of solar energy.

P.Natarajan and G.S. Nalini [15] presented a paper to bring to our notice that according to World Bank 300 million people are not connected to national grid electricity. Globally 1.3 billion people are cut from electricity out of which around 84% are in rural areas. India is fifth largest renewable energy rich country in world. People who have grid connection do not have access to electricity for a long time of day because of non availability of power supply. To make country self sufficient in energy sector, various alternative energy should be promoted. The available renewable energies are either seasonal or time or place bound. Among the non conventional energy solar is perpetual source which ensures sustainable energy stock for country. The government should scrutinize the implementation process to enhance the viability of solar power and government has to propose a subsidy and tariff model exclusively for vulnerable people living in poverty.

Sthita Pajna Mishra [16] presented a paper in which she has studied a model design of hybrid system comprising of solar and wind technology for a small locality rural area and proposed a design for standalone hybrid system by using HOMER software to calculate exact load with the money and cost estimation of project. This paper consists of simulation data of each component used in project as well as cost effectiveness of project during working and while setting it up. This is called as hybrid optimization model for electric renewable. In this both PV and wind setup has been taken care for balanced load sharing and to feed the local home connectivity system. It includes that it has been concluded that rural electrification presents different load patterns in relation to that of urban loads in terms of daily variation expected and yearly variation rural patterns are smoother. In case of remote areas that have small incomes (common features for most rural areas), the extension of utility grids is not feasible and total dependence on imported fossil fuels is economically unreasonable, fuel transport costs becomes exorbitant.

Pawan Sharma et al. [17] presented a paper on economic analysis of grid connected 40 kW solar photovoltaic system at administration building, DTU. Study shows that 61920 units will be generated annually and the payback period comes out to be 5.08 years. As plant life is around 25 years, next 20 years energy output will be free of cost for DTU. After successfully implementing of this technology, this model needs to be replicated on all Institutions buildings of Delhi which will have MWs of potential and help Delhi to become Smart city and Green capital of India. This also makes hand in fulfilling 100 GW solar PV target by 2022 Under MNRE national solar mission.

2.3 Case Studies of Grid Connected SPV System in India

2.3.1 India's largest Grid Connected Rooftop SPV project at Amritsar [31].

The state of Punjab, a land of green revolution in agriculture, has accomplished another green revolution in the country. This time green revolution pertains to green electricity generation from grid connected solar rooftop PV power project on a single roof in campus of Radha Soami Satsang Beas (RSSB) in Amritsar district.

Radha Soami Satsang Beas (RSSB)

The RSSB is a philosophical organization based on spiritual teachings of all religion and dedicated to a process of inner development under the guidance of a spiritual teacher. It is registered not-for-profit society with no affiliation to any political or commercial organizations.

The Largest Project in India

This solar PV power project, spread over 24 acres of rooftop on a single roof is undoubtedly the largest plant in India. Germany also possesses such grid connected rooftop plants but not of this size on a single roof. The RSSB project has around 30,096 PV modules of 250 Wp each ,11.5 km walkway,14 central type inverters of 500 kWp each, seven transformers,140 junction boxes, and 44,000 of J-bolts used for module mounting structure and walkway. The project has been commissioned by Larsen &Toubro limited, a reputed engineering organization of our country.

Solar Electricity Generation

The project generated over 1 million kWh of electricity per month during april-june 2014.in the months of July, August, September and October, the generation ranged between 0.72-0.99 million kWh per month depending upon the weather conditions and availability of sunshine hours. The plant generated highest electricity of 44,200 kWh in May 2014.

Project Cost

The total cost of project is about s 48 Crore which includes the cost of transmission network, substation, and transformer installations. It also claims to have a simple payback period of around six years.

Future Plans

By 2016, The RSSB plans to set up a total of 27 MWp capacity peak grid connected rooftop plant. Out of this, 5 MWp capacity will be added soon to make the total capacity up to 12.524 MWp. The campus has an estimated potential of further addition of about 45 MWp grid connected rooftop plants in approximately 200 acres of land.

Fig 2.1: Rooftop installation of solar rooftop PV project of 7.524 MWp capacity at RSSB [31].

Table 2.1: Statistics of solar rooftop PV project of 7.524 MWp capacity [31]

Items	Values
Number of PV modules	30,096
Walkway length on rooftop	11.5 km
Number of J-bolts used for module mounting structure and walkway	44,000
Junction boxes	140
Number of modules in each string	24
Number of strings in each junction box	9
Number of inverters	14
Number of transformers	7

Table 2.2: Solar power generation of SPV project of 7.524 MWp capacity at RSSB [31]

Items	Values
Maximum peak power of the day	6,844 MW(on 6 july,2014 at 11.28 am)
Maximum global solar irradiance on july 6,2014	1151.51 W/m²
Highest energy generation of day	44,200 kWh (on 20 april 2014)
Maximum energy of month	10,60,604 kWh in may 2014
Maximum average temperature of the day	45.89 °C as on june 8,2014 at 14.01 pm

Table 2.3: Technical details and specifications SPV project of 7.524 MWp capacity at RSSB [31]

Technical details	Specifications
Project capacity	7.52 MWp
Location	Beas(Amritsar district)
Latitude	31.54 ° N
Longitude	75.32° E
Altitude	234 m
Area covered	24 acres of rooftop
Module types	Poly crystalline
Module wattage	250Wp
Inverter rating	500 kW (central type)
String voltage	720 V dc
String current	8.3 A dc
Inverter rating	500 kw
Inverter output	320 V ac 3Ø
Transformer output	11 kV

2.3.2 25 kW Grid Connected Rooftop Solar Power Plant at CEA, New Delhi

It houses the head office of Central Electricity Authority, central water commission, Bureau of energy efficiency, Registrar office of census and sub offices of CPWD. It is situated in west block area at R.K.Puram in New Delhi.

It had been proposed to set up a 25kWp grid connected solar photovoltaic power plant on the rooftop terrace of north wing of Sewa Bhawan a. the 25 kWp SPV system at rooftop of SewaBhavan, is estimated to afford annual energy generation of 42 MWh and operate at a capacity factor of 19% [32].

Fig 7.2: Actual installed photograph of 25 kW SPV system at Sewa Bhawan,New Delhi.

Table 2.4: System specifications of 25 kW SPV system at Sewa Bhawan [32]

Item	Specification
System size	25 kWp
Module technology	Poly crystalline
Modules	150
Area covered	331.5 sq.Mts
Rooftop angle	28.32 degrees south
Inverter	27 kWp(no.=1)
Output	440 V,50 Hz,3ph
Annual generation	42000 kWh
Capacity factor	19 %
Installation cost	Rs 42.5 lakhs

2.4 Research Gap Identified

By going through literature review it has been found that many researchers have proposed procedure for designing of solar Photovoltaic power plant. But the performance plays a very important role in power plant installation, which i had seen missing in many of research papers. By providing data of plant location and plant capacity, expected energy production can be found out in some softwares such as SAM(system adviser model), PV WATT CALCULATOR ,SOLARIUS –PV etc. when we compare actual performance with expected energy production from outcome of software ,we can actually judge plant performance ratio and can estimate energy output in coming months .

Since PV module and other equipment cost is decreasing day by day due to exponentially increasing demand so to find payback period in current situation there is need to do economic analysis of an installed solar photovoltaic plant.

The actual performance results also encourages other institutions and other corporates to install solar photovoltaic system in a very positive way.

2.5 Objective of Work

The growing energy demand and more awareness about environment by seeing disastrous effects of global warming have triggered to switch over to renewable energy resources. solar energy is abundant and freely available, so more technologies are coming in this field to harness this energy. In series of it grid connected solar photovoltaic is gaining popularity day by day to connect the solar power plant with the grid and utilise the generated energy even at far locations. In my work have studied 40 KW grid connected solar photovoltaic system which is installed at administrative building at Delhi Technological University, New Delhi.

The following objectives and related parameters are envisaged for present research work

- Study of global and Indian energy scenario at present.
- Detailed literature review.
- Study of solar insolation of India.
- Study of solar photovoltaic technologies.
- Study about grid connected SPV systems.
- Design of 40 KW solar photovoltaic System at DTU.
- Performance analysis of 40 KW solar photovoltaic System at DTU.
- Economic analysis of 40 KW solar photovoltaic System at DTU.

Chapter 3: Solar Radiation Potential and SPV Growth in India

3.1 Introduction

Solar is the principal source of inexhaustible energy available to us. India is one of the sun's favoured nations, blessed with about 5000 TWh of solar power every year. Renewable energy has potential to achieve energy independence and to energize India's economy by generating millions of jobs and to realize its target to become a green nation. It is said that solar photovoltaic will become one of the main source of energy in future. For a successful design and implementation of solar PV systems and solar thermal system we should have sufficient knowledge of solar insolation of past years. Based on solar irradiance data of past years, we can predict input solar energy that will be available to our systems. Solar radiation database have been assembled up by NREL and MNRE.

Our country have potential of over 226000 MW of grid connected solar power generation and in wind energy sector to reach to over 100000 MW by 2030.The calculation of solar insolation potential is a basic step for design of solar photovoltaic system.

3.2 Solar Radiation

A solar radiation is the radiant energy radiated by the sun in the form of electromagnetic waves. The sun emits very vast amount of solar energy nut our earth catches only a fraction of it. The earth is the only planet in solar system which receives optimum amount of solar radiation that makes life sustainable on planet. Solar spectrum resembles to that of a black body at approx 5800K temperature. 98 % of total emitted energy by sun lies in spectrum of wavelength 250nm to 300nm. Nearly half of radiations are in visible range. Rest half is mostly in infrared and some in ultraviolet part of solar spectrum.

The solar radiation having wavelength less than 0.286 nm(known as ultraviolet spectrum) is absorbed by ozone layer in stratosphere. The UV rays are responsible for change of colour of skin pigments known as skin cancer. The radiation which travels further in atmosphere is subjected to scattering, reflection, and absorption by clouds, air molecules etc. the radiation budget is the balance between incoming energy and outgoing energy (long wave thermal waves) and reflected short wavelength radiations. Sunlight of 1367 W/m^2 of power incidence above the earth surface, this value is known as solar constant. Solar constant is defined as amount of solar energy received per unit area perpendicularly by earth's atmosphere.

Earth receives 1.8 $\times 10^{17}$W of solar radiations at top of atmosphere. Out of which only half of it reaches to earth's surface. Many factors such as scattering, absorption and reflection of light affects while passing through the atmosphere.

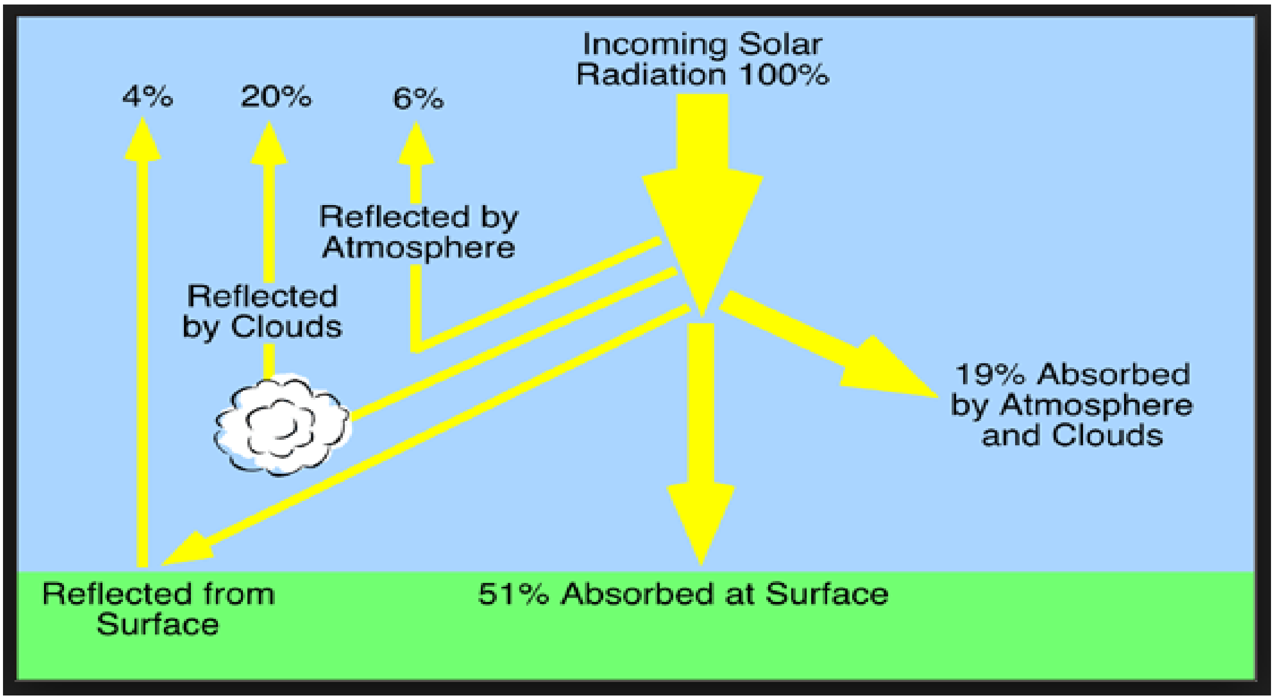


Fig 3.1: Solar energy radiation budget [21]

3.3 Solar Radiation Measurement:

The direct solar beam reaching directly at the earth's surface is called **direct solar radiation**. The total amount of solar radiation reaching on a horizontal surface (i.e. the direct solar beam + diffuse solar radiation on a horizontal surface) is termed as **global solar radiation**.

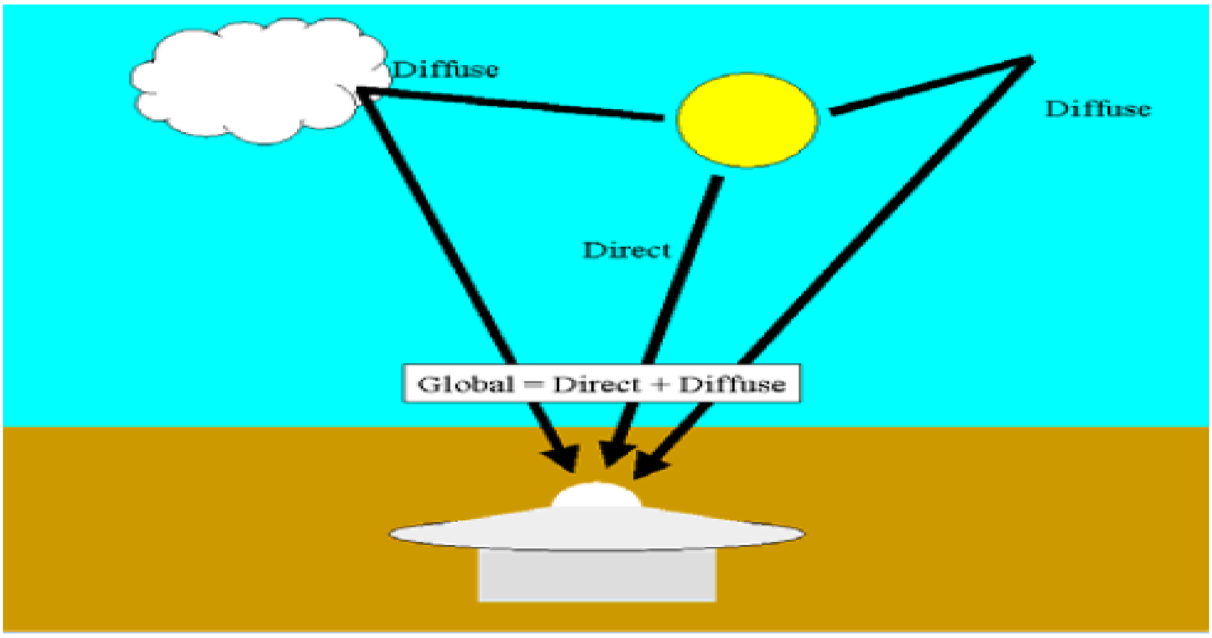


Fig 3.2: Various terminologies of solar radiation [22]

A **Pyrheliometer** is used to measure direct solar radiation from the sun and its marginal periphery. To measure direct solar radiation correctly, its receiving surface must be arranged to be normal to the solar direction. For this reason, the instrument is usually mounted on a sun-tracking device called an equatorial mount.

A **Pyranometer** is used to measure global solar radiation falling on a horizontal surface. Its sensor has a horizontal radiation-sensing surface that absorbs solar radiation energy from the whole sky (i.e. a solid angle of 2π sr) and transforms this energy into heat. Global solar radiation can be ascertained by measuring this heat energy. Most Pyranometers in general use are now the thermopile type, although bimetallic Pyranometers are occasionally found.

Fig 3.3: Different solar radiation measurement instruments. [22]

Table 3.1: Types of radiation measuring instruments [21]

Radiation measurement	
Parameter	**Instrument used**
Short wave (0.3μ -4.0 μ)	
Direct solar irradiance	Angstrom and thermoelectric Pyrheliometers.
Global solar irradiance	Thermoelectric Pyranometer
Diffuse solar irradiance	Thermoelectric Pyranometer with shading ring
Reflected solar irradiance	Inverted Pyranometer
Solar spectral irradiance and turbidity	Sunphotometer
Long wave (4μ-100μ)	
Net terrestrial radiation	Angstrom Pyrgeometer
Total (0.3μ-100μ)	
Upward or downward radiation	Pyradipometer
Net radiation	Net Pyradiomter

3.4 India's Solar Resource Map

The solar collectors which are flat in nature global horizontal irradiance (GHI) data is useful to design flat systems. While the solar concentrating systems such as Scheffler dishes or Arun dish requires data of direct normal irradiance (DNI).solar photovoltaic system which now a days are fixed type uses average global horizontal irradiance data of solar radiation over the years.

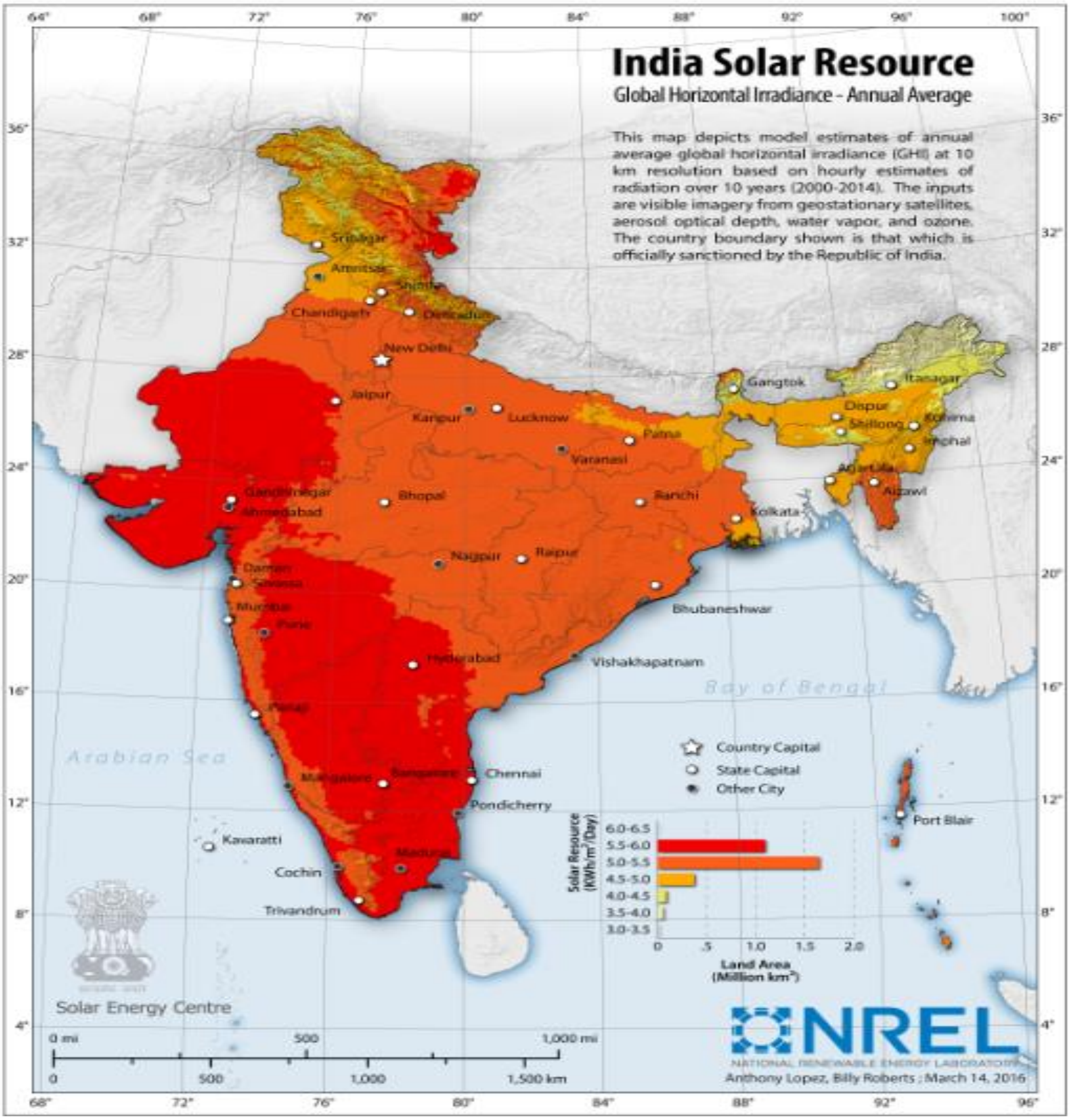


Fig 3.4: India solar resource map-GHI annual average (2000-2014) [23]

3.5 Solar Insolation of Delhi

Since solar PV systems are designed on global horizontal insolation values. By seeing latitude of location we can find out average GHI.

Latitude of New Delhi : 28.61° N

Longitude of New Delhi : 77.21°E

New Delhi last 14 years (2000-2014) average GHI value=5-5.5 kWh/m²/day

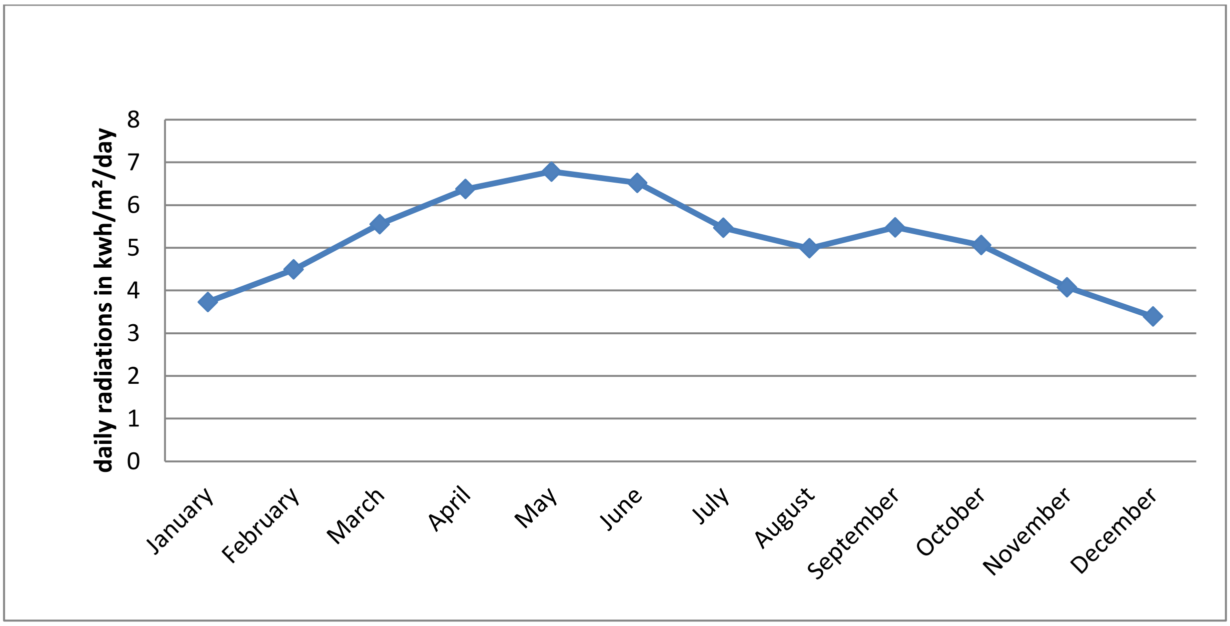


Fig 3.5: Monthly GHI solar radiation of New Delhi [24].

3.6 Solar Photovoltaic Installation in India

India is a country having so much land area and around 300 sunny days which suits for deployment of large solar PV systems. In last few years India has shown a tremendous growth in instalments of solar PV power plants across whole country.

3.6.1 State Wise Installed Capacity of Solar Power

Table 3.2: State wise installed capacity of solar power [18]

S.No.	State	Installed capacity as on 31 mar 2016 (in MW)	% share in total
1.	Rajasthan	1269.932	18.77
2.	Gujarat	1119.173	16.54
3.	Tamilnadu	1061.820	15.70
4.	Madhya Pradesh	776.370	11.47
5.	Andhra Pradesh	572.966	8.47
6.	Telangana	527.843	7.80
7.	Punjab	405.063	5.98
8.	Maharashtra	385.756	5.70
9.	Karnataka	145.462	2.15
10.	Uttar Pradesh	143.495	2.1
11.	Chhattisgarh	93.58	1.38
12.	others	261.397	3.86
	Total	6762.85	100

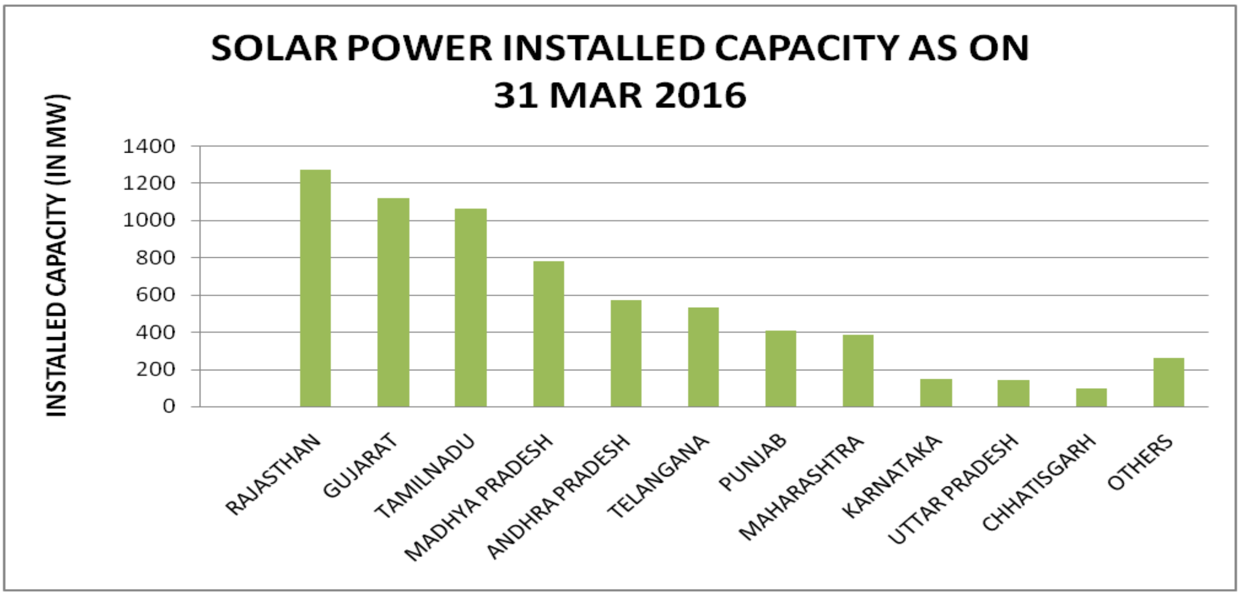


Fig 3.6: State wise installed capacity of solar power as on 31 march 2016 [18]

3.6.2 India’s Largest Solar Photovoltaic Plants

Table 3.3: India’s largest solar photovoltaic plants [19]

s.no.	Name of plant	DC peak power(MW)	Commissioned on
1.	Charanka Solar Park, Gujarat.	221	April 2012
2.	Welspun Solar Project, Neemuch (M.P)	151	Feb 2014
3.	Sakri Solar Plant, Maharashtra.	125	March 2013
4.	Welspun Solar Project, Rajasthan.	50	March 2013
5.	GEDCOL Solar Power Plant, Odisha.	50	Feb 2014
6.	NTPC’S Solar Power Project ,M.P.	50	March 2013
7.	GEDCOL Solar Power Plant, Odisha.	48	May 2014
8.	Bitta Solar Power Plant, Adani Power, Gujarat.	40	Jan 2012
9.	DhirubahiAmbani Solar Plant, Rajasthan.	40	April 2012
10	Welspun Solar Plant, Bathind, Punjab.	34	August 2015

3.7 SPV Technology Growth in Recent Years

Today PV technology is being increasingly recognised as part of solution to meet sustainable energy demands. Jawaharlal Nehru National Solar Mission is one of the key global initiatives in advancement of solar energy technologies, announced by the Government of India under National Action Plan on Climate Change. Mission aims to attain grid tariff parity by 2022 through the comprehensive utilization and rapid transmission and deployment of solar technologies across the country at a scale which primes to cost reduction and promotes the research and development commotion to local manufacturing and infrastructural support.

3.7.1 Cost Reduction of Silicon PV Cells in $/Watt Over the Years

Government provides subsidies for the development of PV panels, in which there will bedrop in the market price and this can tip to more usage of solar power in India. In the previous three years, solar-generation costs have dropped from around Rs 18 a kWh to about Rs 7 a kWh, whereas power from trade in coal and domestically-produced natural gas presently costs around Rs 4.5 a kWh and it is increasing with time. Authorities believe that ultra-mega solar power plants like the forthcoming world’s largest 4,000 MW UMPP in Rajasthan would be able to produce power for around Rs 5 a kWh.

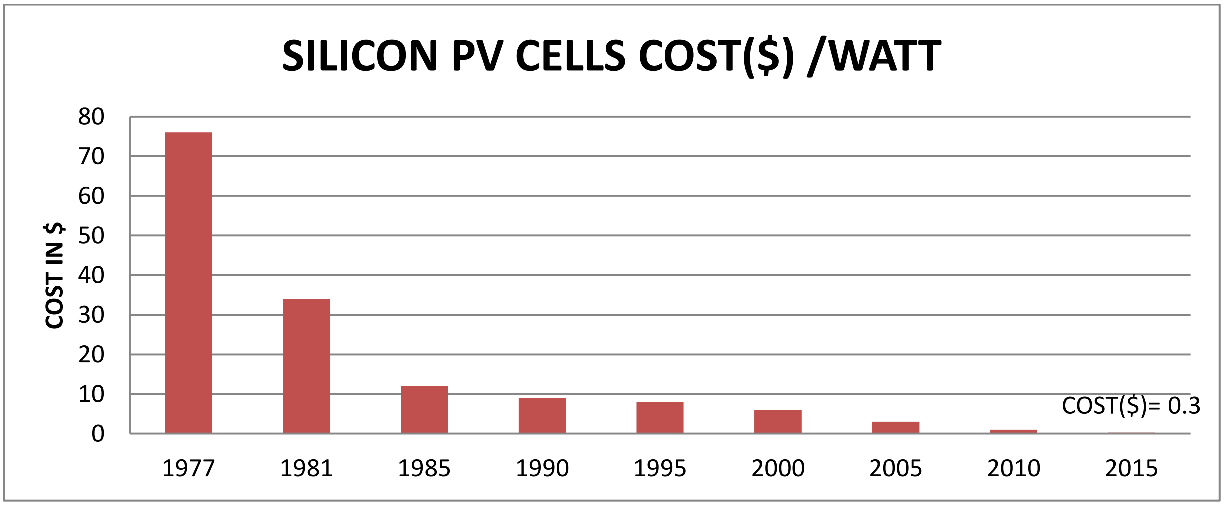


Fig 3.7: Cost reduction of silicon PV cells in $/watt over the years[20]

3.7.2 Increase in Solar PV Installed Capacity Year Wise

On 16 May 2011, India had installed first 5 MW of solar power project under the Clean Development Mechanism at Sivagangai Village, Sivaganga district, Tamil Nadu.In January 2015, the Indian government significantly expanded its solar plans, aiming US$100 billion of investment and 100 GW of installed solar capacity by 2022**.**India expects to set up an additional 10,000 MW by 2017, and a overall100, 000 MW by 2022.

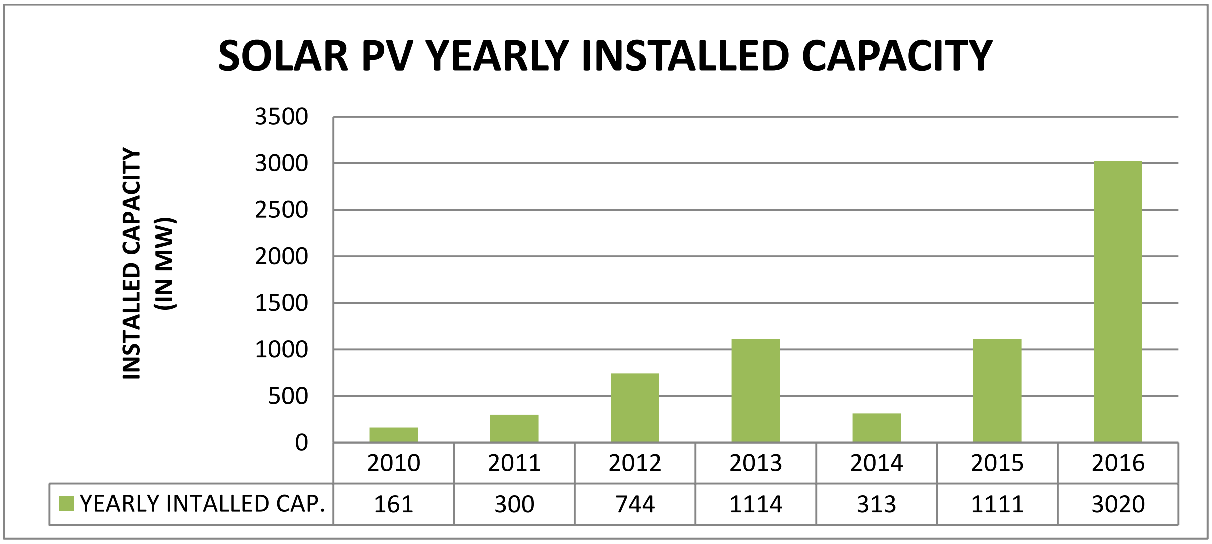


Fig 3.8: Increase in solar PV installed capacity year wise[4]

CHAPTER 4: SOLAR PHOTOVOLTAIC TECHNOLOGY

4.1 Brief History

Today photovoltaic is one of most important technology we have, to generate electricity in a clean, quiet and very simple way. Photovoltaic system consists of modules which consist of number of photovoltaic cells connected in series arrangement, inverter which convert solar dc power into usable ac power. Actually when sunlight strikes a solar cell, solar energy is converted directly into electrical energy without any motion and without creating any pollution to environment.

4.2 Solar Cell

Solar cells works on photovoltaic effect by converting sunlight directly into electric electricity by using semiconducting materials. Basic principle of photovoltaic effect was first coined by Becquerel in 1839, who observed a light dependent voltage change between electrodes immersed in an electrolyte. This followed by development of photocells based on selenium and cuprous oxide. The first silicon cell was reported in 1941 but developed in later stage with quite good efficiency. These cells were initially used as power sources in spacecraft as early as 1958.the early 1970 saw an innovative period for silicon cell development which laid down its foundation for prosperous future. With further added technology its prices declined very fast [26].

The solar cell produces voltage and current at its terminals when sunlight incident on it. The amount of electricity generated is proportional to intensity of sunlight incidence on it, area of cell, and angle at which sunlight incident on cell.

In common all solar cells irrespective of material and technology have cover at top, emitter-base junction or p-n junction in middle and back contact at bottom. At emitter –base junction, separation of positive and negative charge take place. The sunlight incident on earth consists of bundle of energy called photons. Sunlight consists of different energy photons which depend on their wavelength. The absorption of energy by solar cell depends on band gap energy of semiconducting materials. The energy of photon and band gap energy is expressed in unit electron-volt (eV).

4.2.1 Working of Solar Cell

1. The energy of incident photons falling on solar cell's front face is absorbed by semiconducting material.
2. By taking energy, electron comes out of orbit and make free electron-hole pair. Holes are considered as positive charge carrier and electrons as negative charge. When solar cell is connected to a load holes are connected at positive terminal and electrons towards negative. So due to accumulation of opposite charge carriers, we get voltage across the terminals.
3. Voltage developed across the terminals of solar cell, drives the current in the circuit. This dc current is converted at appropriate ac voltage to harness the developed power [26].

4.2.2 Parameters of Solar Cells

To study the conversion of sunlight energy into electricity by solar cell, various parameters of solar cell are studied which determines the effectiveness of sunlight energy to electric energy conversion. Solar cell parameters include [26]

- Short circuit current(I_{sc})
- Open circuit voltage (v_{oc})
- Maximum power point
- Current at maximum power point (I_m)
- Voltage at maximum power point(v_m)
- Fill factor(FF)
- Efficiency

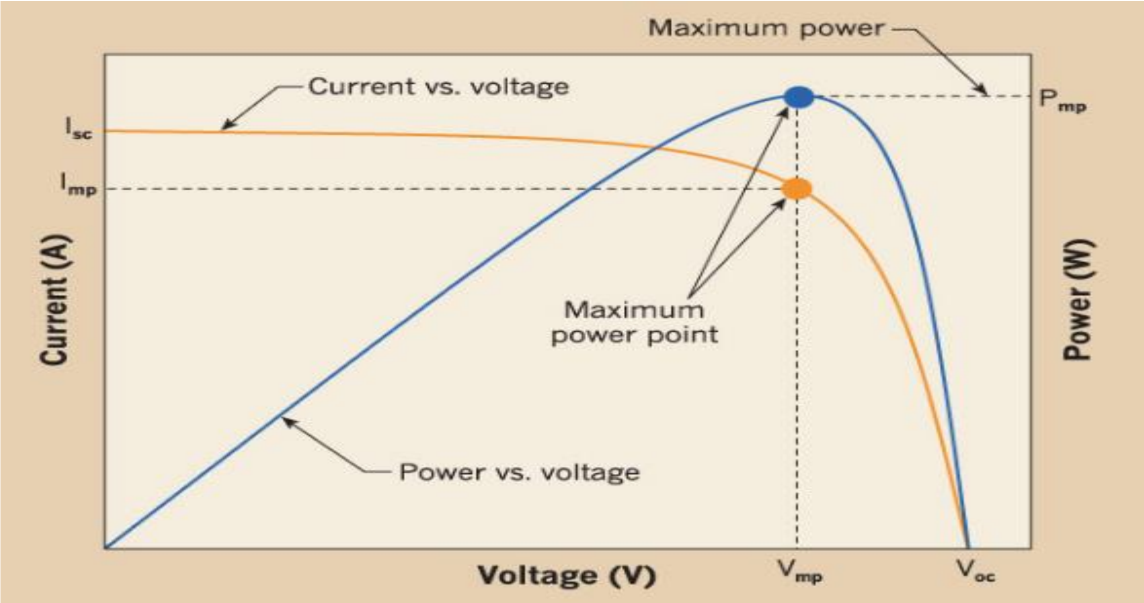


Fig 4.1: Various parameters of solar cell [25]

Short circuit current (I_{sc}): The maximum current a solar cell can produce is known as short circuit current. Higher the I_{sc} , better the solar cell is. The maximum current in solar cell depends on cell material, cell area, and intensity of solar radiation falling, angle of mounted cell to incident sunlight. In more specific way current density 'j' is used in place of it. Current density is obtained by dividing I_{sc} by area of cell. So short circuit density j_{sc} is given by I_{sc}/A.

Open circuit voltage (v_{oc}): The maximum voltage that a solar cell produces is called open circuit voltage.v_{oc} is measured in volts (V) and sometimes milli-volts(mV).it basically depends on cell technology and operating temperature, since with increasing temperature conductivity of semiconducting material decreases.

Maximum power point ($p_m or\ p_{max}$): The maximum power produced by solar cell under STC is called its maximum power point. As it is measure of maximum power, it is sometimes referred as W_p.since with varying sunlight intensity it operates at many current and voltage combinations but it produces maximum power at a particular current and voltage. In the I-V curve maximum power point is denoted at 'bend' or 'knee' of curve.

Current at maximum power point (I_m): it is the current that solar cell produce while operating at maximum power point. It is measured in ampere (A) or milli-ampere (mA).

Voltage at maximum power point ($\mathbf{v}_m$): it is the voltage that solar cell produce while operating at maximum power point. It is measured in volt (V) or milli-volt (mV).it is always being lower than$\mathbf{v}_{oc}$.

Fill factor (FF): it is the ratio of areas covered by I_m-V_m rectangle with areascovered by I_{sc}-V_{oc} rectangle. More the FF better is the cell. It indicates squareness of I-V curve.

$$FF = \frac{I_m \times V_m}{I_{sc} \times V_{oc}} = \frac{p_m}{I_{sc} \times V_{oc}}$$

Efficiency: efficiency of solar cell is defined as ratio of maximum output power (P_m) to input power P_{in}.it shows the percentage of radiation input power is converted to useful electrical energy.

$$\eta = \frac{P_m}{P_{in}} = \frac{I_{sc} \times V_{oc} \times FF}{P_{in} \times A}$$

Table 4.1: Commercial solar cells technology, materials, efficiency [26]

Solar photovoltaic technology	**Solar cell type**	**Materials used**	**Efficiency (%)**
Crystalline Silicon(c-Si)solar cell	Mono-crystalline Silicon	Mono-crystalline Silicon	14-16
	Poly or multicrystallinesi	Multi-crystalline Silicon	14-16
Thin film solar cell	Amorphous si(a-si)	Amorphous Silicon	6-9
	Cadmium telluride(cdTe)	Cadmium and Tellurium	8-11
	Copper-indium-Gallium-Selenide(CIGS)	Copper,Indium,Gallium,Selenium	8-11
Multi –junction solar cell	GaInP/GaAs/Ge Gallium Indium Phosphide/Gallium Arsenide/Germanium	Gallium(Ga), Arsenic (Ar),Indium (In), Phosphorus (P),Germanium (Ge)	30-35

Table 4.2: Typical solar cell parameters (η, J_{sc}, V_{oc},FF) of commercial solar cells with available cell areas. [26]

Solar cell type	**Efficiency (η)**	**Cell area (in cm²)**	**Output voltage(V_{oc}) (in V)**	**Output current(J_{sc}) (in mA/cm²)**	**Fill factor (FF) (in %)**
Mono-crystalline silicon	14-17	5-156	0.55-0.68 V	30-38	70-78
Poly or multi-crystalline si (mc-Si)	14-16	5-156	0.55-0.65	30-35	70-76
Amorphous Si(a-si)	6-9	5-200	0.7-1.1 V	8-15	60-70
Cadmium telluride (CdTe)	8-11	5-200	0.8-1 V	15-25	60-70
Copper –Indium-Gallium-Selenium(CIGS)	8-11	5-200	0.5-0.7 V	20-30	60-70
GaInP/GaAs/Ge Gallium Indium Phosphide/Gallium arsenide/Germanium	30-35	1- 4	1-2.5 V	15-35	70-85

4.3 Solar PV Modules

A solar PV module consists of large no. of solar cells connected in series to give higher power. Actually PV modules are the building blocks of photovoltaic system. To generate more amount of electrical energy, further connection of PV modules is done and one can generate in range of MW also. Now PV modules are available in range of 3W to 300W.

When we connect solar cells in series, it is called string of solar cells .while connecting solar cells in series, we adds voltage of solar cells. For example if terminal voltage of solar cell is 0.5 V and we added 36 cells in string then terminal voltage across string = 0.5×36 =18 V.

4.3.1 Ratings of PV Module & Module Parameters

The parameters of solar PV modules (V_{oc},I_{sc},W_p) ,mentioned on module by manufacturer are measured at standard test conditions(STC).the standard test conditions are solar input radiation of 1000 W/m^2,temperature of 25 °C,and wind speed of 1 m/s. The solar PV modules are rated in terms of their peak power (W_p) output at STC [26].

PV module parameters are same as of solar cell mentioned earlier. The parameters include

- Open circuit voltage (v_{oc})
- Short circuit current(I_{sc})
- Maximum power point
- Current at maximum power point (I_m)
- Voltage at maximum power point(v_m)
- Fill factor(FF)
- Efficiency

4.3.2 Factors Affecting Electricity Generated by A Solar PV Module:

4.3.2.1 Conversion Efficiency (η): since all light incident of PV module couldn't convert into electricity. Conversion efficiency is defined as ratio of electrical energy generated to the input light energy. If instantaneous solar radiation or solar insolation is represented by P_{in} and P_m is maximum power output then efficiency of module is given as:

$$\eta = \frac{P_m}{P_{in} \times A}$$

4.3.2.2 Change in Amount of Input Light (P_{in}):

As sunlight intensity keep changes from morning to evening, which changes power output throughout day. The electric current generated is directly proportional to amount of light falling on it but Output voltage is not strongly .so amount of power generated (power =current ×voltage) is changes with change in light.

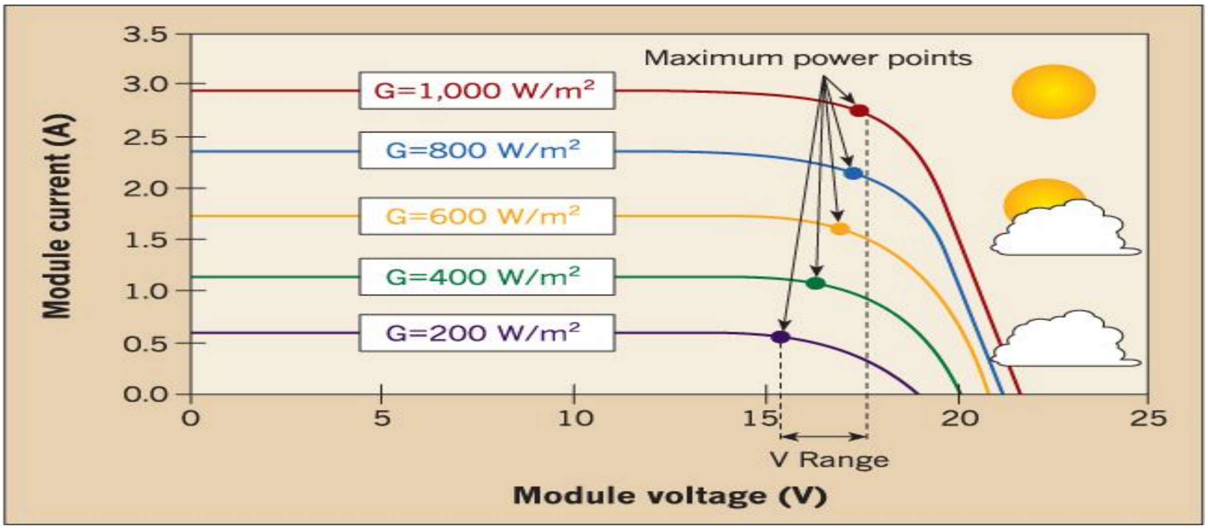


Fig 4.2: Variation of maximum power point with change in solar intensity. [25]

4.3.2.3 Effect of Change in PV Module Temperature:

As solar PV modules output voltage, power, efficiency ratings are given at standard test condition (STC =1000 w/m², 25℃).in practice actual operating temperature is different than 25℃ due to varying ambient temperature with time. Due to glass cover plate it adds to green house effect in module and raises its temperature even more than the ambient temperature. With the increasing cell temperature in PV modules, voltage output of PV module decreases, which lowers PV module efficiency and output power up to 12%. The change in parameters with temperature for different cells is given below [26].

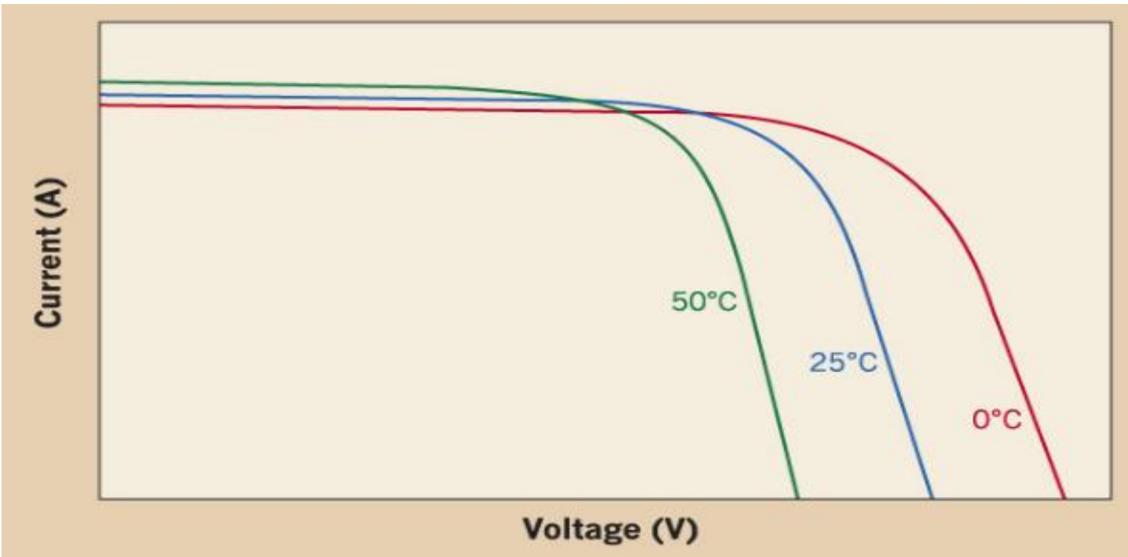


Fig 4.3: Variation of maximum power point with change in temperature.[25]

Table 4.3: Typical change in parameter value per °C rise in cell temp from STC of commercial available technologies [26]

PV Technology Name	**Temp Coefficient of Current(I_{sc})**	**Temp Coefficient of Voltage(V_{oc})**	**Temp Coefficient of Fill Factor (FF)**	**Temp Coeff of Power (P_m)**
Crystalline silicon	+0.08%/°C	-0.35%/°C	-0.15%/°C	-0.45%/°C
Cadmium telluride	+0.04%/°C	-0.25%/°C	-0.035%/°C	-0.25%/°C
Double junction amorphous silicon	+0.07%/°C	-0.3%/°C	-0.095%/°C	-0.25%/°C

To find parameter value as compared to STC due to increase in temperature is given by

PV module parameter Value at operating temp., P_{temp}= Parameter value at STC – ((temp coeff of parameter=TC) × (parameter value at STC=P_{STC}) × difference in temp with respect to STC=ΔT))

$$P_{temp}=P_{STC}-TC\times P_{STC}\times \Delta T$$

4.3.2.4 Change in PV Module Area

The module of large area gives more power than a small area due to increase in number of cells. When more number of cells are joined together by increasing area of cell then voltage output of module increases and it gives rise to more power irrespective of same value of current in module in series combination [26].

4.3.2.5 Change in Angle of Light Falling on PV Module

The angle of incident sunlight greatly affects the output power. When sunlight falls perpendicularly to module surface than it gives more power as compared to non perpendicular sunlight. Because when light falls at some angle than some part of it gets reflected. So now PV systems with tracking mechanism are commercially using for more power output [26].

4.4 Batteries in Solar PV System

Today batteries are most important medium for electrical energy storage. In standalone system since PV system generates electricity only during day time, so for night time usage we have to store electrical energy in the batteries. But in case of grid connected PV system, we do not require any storage medium. Battery has same analogy to that of water tank as battery is electrical energy storage device and water tank as water storage medium.

A battery is a two terminal device. One terminal is called negative (-) terminal and other terminal is positive (+).when battery is charged, there is a voltage difference between the terminals. This voltage difference dives the current when connected to appliance [26].

4.5 Charge Controller, MPPT, Inverters

When a PV system is installed, it needs several other components .these components jointly referred as balance of system (BoS) which includes inverters (DC to AC converters), batteries, battery charge controllers, DC to DC converters, maximum power point tracking(MPPT),supporting structures for mounting the PV panels, protection relays and so on. The BoS components are mainly the electronic components which are required to regulate the power flow from source to load [26].

4.5.1 Power Converters

In PV systems it is required to bring the current and voltage to the desired level. The conversion of current level, voltage level or type of power can be obtained by using power converters. The power converters can be of following types-

- AC to DC converters (Rectifiers)
- DC to AC converters (inverters)
- DC to DC converters

4.5.2 AC to DC Converters

Rectifiers convert AC power to DC .many of our daily using gadgets including computers; mobile phones require DC power to operate. But in our homes we get AC power from grid. So to operate above mentioned things we need to convert AC power to DC.

4.5.3 DC to AC Converter

As PV modules produce DC power but most of our appliances work on AC power so there is a need to convert DC power to AC .for this conversion we use devices called inverters. Inverter converts DC input power into AC output power as below and its efficiency is defined as ratio of output AC power to input DC power.

DC input power =$V_{dc}\times I_{dc}$

AC output power = $V_{rms}\times I_{rms}$

$$\text{Efficiency of inverter} = \frac{\text{outputpower}}{\text{inputpower}}\times 100$$
$$= \frac{V_{rms}\times I_{rms}\times PF}{V_{dc}\times I_{dc}}$$

4.5.4 Inverter Specification

Battery Input

Battery Voltage: The range of voltages that can be applied to the input of inverter, called DC input window
DC Current: this is maximum DC current that inverter can take.

Solar Panel Input

Voltage Range: The range of voltages that can be supplied to solar panel input of inverter, called DC input voltage.
Maximum Short Circuit Current: It is maximum current that the inverter can sustain from solar panel.

Output

Continuous Output Power (W): The output power which the inverter can maintain for a long time at a particular temperature. With the increase of inverter temperature, its rated power output decreases.
Output Voltage: it is the AC output voltage of inverter whose value is either 230 V or 400V since our loads also run at same voltage levels.

Frequency: In India frequency is 50 Hz. inverters are designed for the same specific frequency.

Efficiency: This is defined as ratio of output AC power to input DC power of a inverter.

Table 4.4: Typical inverter specification of SMA 20 kW inverter [27]

Input (DC)	
Max. DC power (@cosØ=1)	20440 W
Max. input voltage	1000 V
MPP voltage range/rated input voltage	320 V to 800 V /600V
Max input current input A/input B	33 A /33 A
Output (AC)	
Rated power (@230 V,50 Hz)	20000 W
Nominal AC voltage range	160 V to 280 V
Max efficiency	98.4 %

4.5.5 DC to DC Converters:

DC to DC converters are used to convert one level of DC voltage (usually unregulated and uncontrolled) to another level of DC voltage (controlled and regulated voltage level).for example, if a PV system is designed to give 24 volt but our appliances work at 230 V AC power, so a DC to DC converter is used which integrated with inverter itself. The DC to DC circuits are also used in noise isolation, current boosting and power bus regulation [26].

4.5.6 Charge Controllers

It controls the flow of charge to the battery and from the battery .They protect the battery from overcharging or deep discharge and preserve their life and performance. When battery become full charged then charge controller cut it off from the circuit. Similarly if battery goes into deep discharging or over discharging due to excessive use by load than charge controller detects it and disconnects the battery from the circuit. So a charge controller protects the battery.

4.5.7 Working

The status of overcharging and deep discharging is detected by measuring voltage level of the battery .in overcharging condition, voltage level of battery goes up beyond a certain level similarly in deep discharging, voltage level of battery goes down below a certain level. So in overcharging and deep discharging charge controller disconnects battery from the circuit [26].

4.5.8 Types of Charge Controllers

Nowadays following types of charge controllers are widely used:

1. Pulse width modulation (PWM) charge controller or standard charge controller.
2. Maximum power point tracking (MPPT) charge controller.

PWM charge controller has same nominal voltage across battery bank and PV array but MPPT charge controller can have different voltages across PV array and battery bank and operate at maximum power point tracking of PV panel. MPPT charge controller allows having a solar panel array with a much higher voltage than battery bank voltage.

Table 4.5: Example Datasheet of 4.5 A, 12 V rated charge controller from morning star corporation [28]

Electrical specifications	
Rated solar input	4.5 A
Maximum input (5 min)	5.5 A
System voltage	12 V
Maximum solar voltage	30 V
Regulation voltage	14.1 V
accuracy	60 mV
Self consumption	6 mA
Temperature compensation	-28mV/℃
Reverse current leakage	<10µA
Operating temperature	-40℃ to 85℃

4.5.8.1 Maximum Power Point Tracking

In order to extract maximum power from PV modules, load connected to modules should work at maximum power point or the operating point of PV module-load combination should be at maximum power point.The output power of PV modules depends not only on input solar radiation but also on operating point (combination of current and voltage).for example even under bright light condition, if PV module is operating in open circuit or in short circuit mode power output will be zero. There is one operating point at which power output is maximum (maximum power point) and this operating point changes with change in solar radiation intensity. So there are electronic devices which ensure that under all light conditions, solar PV modules operate at maximum power point [26].

4.5.8.2 MPPT device

It's a device whose function is to bring the operating point of a load near to maximum power point under different operating conditions. This device is known as maximum power point tracking or MPPT. So in this way MPPT extracts maximum available power from PV modules at any radiation conditions(less radiation, more radiation, high temperature).The mechanism of maximum power tracking makes use of an algorithm and an electronic circuitry. This mechanism is based on principle of impedance matching between load and PV module which is necessary for maximum power extraction. So whenever the impedance matches with impedance of source, maximum power transfer takes place between source and load. In this way MPPT ensures to avail maximum power from PV modules.Now a day's many manufacturer combine function of MPPT and charge controller in one device called MPPT charge control [26].

CHAPTER 5: GRID CONNECTED SOLAR PHOTOVOLTAIC SYSTEMS

5.1 Introduction to Grid Connected SPV System

The system consists of two main components, solar PV array and grid tied inverter. The controller to extract maximum DC power from PV array is in built in an inverter. This type of system is easy to install, efficient and cost effective, however it has no means of supplying AC power when grid in not available.

In small power applications, as long as solar array produces more power than local demands, the surplus power is fed into the utility distribution grid. The surplus power is supplied to remote loads via the distribution grid. During morning and evening, when the local load demands more than power than what the solar array can produce, the deficit power is taken from grid. The grid supplies power during night as well [26].

5.2 Components of Grid Connected SPV System

A grid connected solar PV system typically consists of following components [26]

5.2.1 Solar PV array

5.2.2 Array combiner box

5.2.3 Dc cabling

5.2.4 Dc distribution

5.2.5 Inverter

5.2.6 Ac cabling

5.2.7 Ac distribution box

5.2.1 Solar PV Array

A solar PV array is used to convert solar energy into DC electrical energy. The array consists of a number of solar PV modules connected in series and /or parallel combinations. The series connection is used to increase voltage output while a parallel connection is used to increase current output. A number of modules are connected in series string and a number of series strings are connected in parallel connection is used to increase current output. A number of modules are connected in series string and a number of series strings are connected in parallel to make a series-parallel connected solar PV array. A number of modules can also be connected in a parallel string [26].

5.2.2 Array Combiner Box

It is used to electrically interconnect solar PV strings to make an array. The combiner box also houses DC voltage and current protections used in a solar PV array.

5.2.3 DC Cabling

The PV modules used in a string are connected in series using DC cables. The DC cables are also used to interconnect strings to make an array and connect PV array output to inverter DC input. The string cables are rated to make an array for a minimum of 1.25 times the string short circuit current at each location.

5.2.4 DC Distribution Box

This box is used to distribute DC cables to inverter. Two-pole DC disconnect switch is used to isolate PV array from inverter .The DC surge protection devices can be incorporated with DC distribution box. The output of this box is connected to inverter DC input.

5.2.5 Inverter

The grid connected inverter is used to convert PV array DC output to AC voltage and current. The output of grid connected inverter is tied to mains AC grid. The AC voltage, frequency, and phase of inverter output are matched with mains AC grid voltage, frequency, and phase. The grid connected inverter has maximum power point tracker (MPPT) controller input stage used to extract maximum Dc power from solar PV array at all times.

5.2.6 AC Cabling

The outputs of inverter used with solar array are connected to AC distribution box using AC cables. The cables are rated for a minimum of 1.25 times the AC circuit breaker current rating.

5.2.7 AC Distribution Box

It is used to distribute AC cables to transformer or load. A two pole AC circuit breaker is used to isolate inverter from transformer or load. The AC circuit breaker current rating is typically 1.2 times the maximum load current. The AC line fuses and surge protection devices can be incorporated with AC distribution box.

5.3 Working Principle of Grid Connected SPV System

In grid connected rooftop or small SPV system, the DC power generated from SPV panel is converted to AC power using power conditioning unit and is fed to the grid either of 33 kV/11 kV three phase lines or of 440/220 Volt three/single phase line depending on the capacity of the system installed at institution/commercial establishment or residential complex and the regulatory framework specified for respective States. They generate power during the day time which is utilized fully by powering captive loads and feed excess power to the grid as long as grid is available. In case, where solar power is not sufficient due to cloud cover etc., the captive loads are served by drawing power from the grid. The grid-interactive rooftop system can work on net metering basis wherein the beneficiary pays to the utility on net meter reading basis only. Alternatively two meters can also be installed to major the export and import of power separately.

The mechanism based on gross metering at mutually agreed tariff can also be adopted. Many such power plants can be installed at the roofs of residential and commercial complex, housing societies, community centres, government organizations, private institutions etc.

Ideally, grid interactive systems do not require battery back-up as grid acts as the back-up for feeding excess solar power and vice-versa. However, to enhance the performance reliability of the overall systems, a minimum battery backup of one hour of load capacity is recommended. In grid interactive systems, it has, however to be ensured that in case the grid fails, the solar power has to be fully utilized or stopped immediately feeding to the grid (if any in excess) so as to safe-guard any grid person/technician from getting shock (electrocuted) while working on the grid for maintenance etc. This feature is termed as 'Islanding Protection'.

The grid connected rooftop solar photovoltaic power generation plants, generates electricity at the consumption centre and hence contributes to reducing the network losses of the distribution licensee. The electricity generation shall also contribute to meeting the demand and supply gap and shall also enable the obligated entities for complying with their solar purchase obligation targets as specified by appropriate Electricity Regulatory Commissions'. India has also a huge potential for deployment of grid connected rooftop solar photovoltaic power generation plants [26].

5.4 Design Steps of Grid Connected SPV System:

To meet our energy consumption requirements, we will design a system using solar photovoltaic. Since energy flow happens from PV array to load but the PV system design should proceed in reverse direction of energy flow i.e., from load to PV array as in reverse path, we will account for all the losses in PV system and will incorporate in our design. In a grid connected SPV system, since power capacity is normally large as compared to a small standalone system, and hence power losses in dc as well as in ac cables must also be considered. Since the grid is connected to the PV system, any deficit of power required by load will be drawn from grid [26].

5.4.1: Estimate Daily Energy Usage:

Here, the estimation of energy consumption by the load is done. We can take any additional load or allowances in load for near future expansion for e.g. new fans or computers in future.

Current load+ future load= …….. KWh/day

Based on daily energy requirements, average monthly and yearly energy requirements can also be estimated.

5.4.2: Average Daily Solar Radiation in Terms of Equivalent Sunshine Hours:

Average daily solar radiation for a given location say New Delhi ,where SPV plant is to be installed, is normally taken from metrological department data in terms of KWh/m^2/day. Normally in India daily solar radiation varies between 4 and 7 KWh/m^2/day. The solar PV modules are rated for standard test condition (STC) which is equal to sunlight power density of 1 KW/m^2 and temperature of 25 °C.

5.4.3: Estimate the AC Power Supplied to the Load:

Ac power output can be determined by dividing the total energy supplied to the load (given in terms of KWh) by equivalent daily hours of sunshine (given in terms of hours or h).

$$\text{Ac power to load (in KW)} = \frac{\text{daily energy to load(in KWh)}}{\text{equivalent daily sunshine hours (in h)}}$$

5.4.4: Estimate the AC Power Output of Inverter or PV Plant Power Output

The ac output power losses consist of transformer and ac cable losses. The ac output power losses are typically of order of 2% to 5%.

$$\text{Ac power output of inverter (in KW)} = \frac{\text{power fed to load (KW)}}{(1-\text{ac power losses})}$$

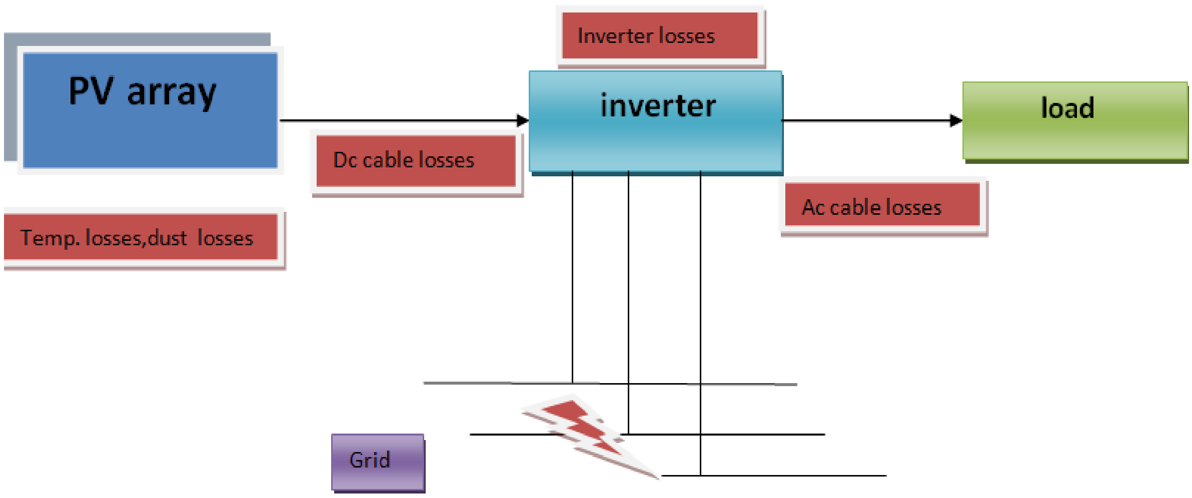


Fig 5.1: Block diagram of grid connected PV system with indications of various losses in PV System [26].

5.4.5: Estimate the DC Power Input to Inverter

The inverter power losses consist of MPPT tracking and dc to ac conversion losses. The inverters are becoming very efficient and power losses in inverter ranges from 2% to 5%.

$$\text{Inverter dc power input (in KW)} = \frac{\text{inverter ac power output(KW)}}{(1-\text{inverter power losses})}$$

5.4.6: Estimate DC Power Output of PV Array

Between the PV array and the inverter, there are dc cables. The dc cable losses depend on the length and cable thickness. Typical systems are designed for maximum dc losses of 3 %.

PV array dc power output (in KW) =$\frac{\text{inveter dc power input (KW)}}{(1-\text{dc cable losses})}$

5.4.7: Operating Losses

While PV modules are under operation in field, there are several losses that can occur. The module or PV array output gets reduced by following ways:

1. Manufacturing tolerance/ module mismatch loss.

2. Module temperature loss.

3. Module soiling loss.

Module Mismatch Losses: The typical manufacturing tolerance of PV module output power ranges between ±3%.So module mismatch losses is 3%.

Module Temperature Losses: To determine module temperature losses, module average operating temperature needs to be determined. The normal operating cell temperature (NOCT) is defined as module cell temperature under STC at 25 ℃.Typical PVNOCT is specified at 45 ℃.The average operating temperature of module cell depends on ambient temperature conditions. For an average ambient temperature of 30℃, the average module temperature is 50℃.

The temperature coefficient for output power of PV module ranges between 0.25%/℃ to 0.5%/℃.This power temperature coefficient gives an indication of loss of power for every degree centigrade rise in temperature. The crystalline silicon modules have power temperature coefficient of about 0.45%/℃ while thin film modules have temperature coefficient ranging from 0.2%/℃ to 0.3%/℃. Normally the power temperature coefficient of PV modules is mentioned in datasheet of manufactures. It depends mainly on material of PV modules but to some extent also depends on manufacture as well. Note here that the temperature coefficient is given in terms of per degree centigrade. Thus if PV module is characterized at STC condition of 25℃ and if average operating temperature is 50℃,then the loss in power output of module or array by increase in temperature is:

E.g. Percentage power loss for crystalline silicon modules or PV array due to temperature rise is-

Module temperature loss = 50℃ - 25℃×$\frac{0.45\%}{\text{o℃}}$ =11.25%

Module Soiling Losses: The modules are typically soiled by dust, dirt, bird droppings etc .The periodic cleaning of modules is recommended to minimize soiling loss. Typical soiling loss is estimated at 5%.

Thus the total PV module losses while in operation include:

Total module losses =mismatch loss +temperature loss +soiling loss

= 3% +11.25% +5%
=19.25%

5.4.8: Estimate Final Required PV Array Capacity

The PV array must supply the dc power required as estimated in step 6 but the array also counter with the operating losses estimated in step 7.so considering this, totalPV array required capacity would be:

Final PV array power output (in KW) =$\frac{\text{PV array dc power output(KW)}}{1-\text{operating losses}}$

5.4.9: Estimation of Number of PV Modules Required

For this purpose, one can choose the modules that are available in market .PV modules are available in power capacity of $30\mathrm{w_p}$ to $300\mathrm{w_p}$.Normally for application of several$\mathrm{KW_p}$, we should choose modules of higher wattage rating. In higher wattage rating, crystalline si-PV modules of $230\mathrm{w_p}$, $250\mathrm{w_p}$and $300\mathrm{w_p}$ are easily available.

The connection of these PV modules would depend on inverter power rating and input dc voltage the inverter can take.

5.4.10: Estimate Inverter Power Rating

In step 6, it was estimated that the dc power input to inverter is x kW, it means that an inverter should be able to process this much power. Normally, for the safety purpose little higher power rating is chosen. This is required because reflection from clouds or other objects may temporarily increase the sunlight falling on module, resulting in higher power generation. About 10% higher inverter capacity should be chosen. Also we have considered about 3% mismatch losses, in case there is mismatch in modules. The extra power would appear at inverter input, we should take safety of this as well. Overall, our inverter capacity should be 10% to 15% higher than input power value estimated in step6.

$$\text{Inverter power rating (KW)} = \frac{\text{dc input power to inverter(KW)}}{1-\text{saftey factor}}$$

Note that this is input power rating of inverter. Due to losses within inverter the output power rating will be less.

5.4.11: PV Array Configuration:

The PV array configuration or the number of PV modules to be connected in series or in string and the number of parallel strings depend on selected available inverter voltage ratings. The PV string v_{oc} and v_{mp}must be within permissible limits of inverter ratings. Maximum i_{sc} of PV array should also be within allowable limit to inverter.

Final array configuration is selected based on inverter input dc voltage window of operation. Inverter manufacturer specifies a range of v_{mp}value for its MPPT operation. Based on module tolerance and its minimum and maximum temperature of operation, a range of module v_{mp} output is mentioned in its data sheet. For a number of modules connected in series string, range of string v_{mp}values iscalculated. The number of modules in a series or string is determined such that its range of v_{mp} output falls well within the pemited range of v_{mp} values of inverter.

Inverter manufacturer also specifies maximum input dc voltage rating in data sheet. Based on module tolerance and its minimum temperature of operation, maximum module v_{oc}output is mentioned by manufacturer. For a number of modules connected in a series string, maximum string v_{oc} output is equal to maximum module v_{oc} multiplied by the number of modules. The maximum array v_{oc} is equal to maximum string v_{oc} for a number of strings connected in parallel to make an array. It is now verified that the maximum array v_{oc} should be less than maximum input dc voltage rating of the inverter .It is also verified that the maximum array i_{sc} should be well within the maximum input dc current rating of inverter. The maximum module i_{sc} is calculated based on module tolerance, maximum available solar radiation and the maximum temperature of operation .The maximum string $i_{sc}$is equal to maximum module i_{sc} for a series connected string, and the maximum array i_{sc} is maximum string i_{sc} multiplied by number of stings in an array.

Determining the Number of Modules in String

Let us now find out the number of modules we should be connecting in a string. This is decided by considering the allowable v_{mp} and v_{max} at input of inverter and v_{mp} and v_{oc} of PV modules selected for installation.

Total Number of PV Modules Required:

As totalPV array capacity is calculated in step 8

Suppose we choose module……………….

Total no of modules required=$\frac{\text{total PV plant capacity}}{\text{rated power of one module}}$

Number of PV Modules in a String:

In order to determine the number of PV modules in array, we should look at the acceptable voltage rating of inverter and try to match it with voltage ratings of strings as per the presentation given in fig.

$$\text{Number of modules in string} = \frac{v_{mp}\ \text{voltage of selected inverter}}{v_{mp}\ \text{of selected PV module}}$$

Number of PV Strings in Parallel:

$$\text{Number of strings in parallel} = \frac{\text{total no.of PV modules in system}}{\text{no of PV modules in a string}}$$

5.4.12: Select Balance of System (BOS) Components

DC BOS COMPONENTS:

Various Balance of Systems (BOS) components are required to integrate and to install the system. The PV array support structure, dc cables, dc distribution boxes and string and array combiner boxes are used on the dc system side.

PV array support structure is of 3 types: fixed, auto tracking and manual tracking. The module mounting frames are typically fabricated by using galvanized iron or aluminium sections and are designed to withstand outdoor temperature, wind, humidity and other environmental factors. The modules are either bolted onto frames or held with clips. The frames are secured onto roof structure or on ground by using suitable support members. The support members are usually fabricated using metal sections matching module frame sections or using treated wooden sections. The support structures are typically grouted into concrete blocks secured onto terrace or firm ground. The support structures can also be rammed into soft ground.

The string/array combiner box are typically double insulated and rated for IP65.The surge protection devices are typically rated for 600 Vto 1000 V DC. The double pole DC disconnect switch is rated for minimum of 1.25 times PV array shot circuit current. The dc disconnect switch inside array combiner box is used to isolate PV array from dc cables in the building and inverter. The ground fault detector interrupter (GFDI) device is typically designed to detect 5% of PV array maximum output current as ground fault current and interrupt DC input circuit.

The dc disconnect switch and surge protection devices also housed in the DC distribution box located near inverter. Alternatively, they are integrated with the inverter Dc input circuit. The DC disconnect switch inside DC distribution box is used to isolate DC circuit inside building from the inverter.

If dc cables are rated for a minimum of 1.25 times the string short circuit current at each location, string fuses are optional. The string blocking diodes are also optional for small size power plants using less than four strings. The dc cables are either rated for outdoor environment or are housed inside conduits which, in turn are rated for outdoor use.

The total length of string DC cables is two times (positive and negative cables) the distance between modules and the string combiner box. The total length of array DC cables (positive and negative cables) is two times the distance between array combiner box and inverter. The DC cable size is selected such that the total power loss over the entire length of DC cables is within 3% of rated PV array output power.

AC BOS COMPONENTS:

The BOS components on ac system side are ac circuit breakers, ac overvoltage protection devices, ac output transformers, ac cables, ac distribution boxes and AC energy meters.

The AC circuit breakers and ac overvoltage protection devices are typically integrated with inverter output AC circuit. Alternatively, they can be housed inside AC distribution box to facilitate the isolation of inverter output near AC output transformers or loads. The AC circuit breakers are typically rated for 1.2 times the maximum AC output current of inverter.

The ac voltage protection devices are typically rated for 400 V AC for 230V single phase circuits and 600 V AC for 415 V three phases' circuits.

The AC output transformer is normally built within the inverter for LV circuits and is rated for 1.2 times the maximum AC output power of inverter. For MV circuits, an eternal three phase step up transformer is used to supply AC power to MV grid. The MV transformer is rated for 1.05 to 1.1 times the maximum AC output power of inverter. The AC input and output circuit breakers and AC voltage protection devices are used with AC output transformer. The transformer losses are typically in range of 2% to5% of its rated output power.

The ac cables are typically rated for 1.2 times the maximum AC current carried. The AC cables from inverter output to transformer housed inside control room are rated for indoor environment .the AC cables from transformer output to load housed inside building are also rated for indoor specifications. The total length of LV AC cables is twice the distance between inverter and transformer or load. The total length of MV AC cables is twice the distance between inverter and transformer and grid distribution centre. The AC cable size is selected such that the total power loss over the entire length of AC cables is within 2% of rated inverter AC output power.

5.4.13: Select Energy Meter

The energy meters are used to monitor energy generated by PV power plant, energy consumed by load and energy supplied to grid by plant.

In PV power plant for small power applications, net energy meter is used to monitor net energy drawn by load from grid or net energy supplied by inverter to grid. The net energy meter is rated for low tension (LT) grid voltage and PV power plant maximum output ac current or maximum load ac current whichever is higher. The PV generated AC energy and the AC energy consumed by load can be monitored by separate energy meters. Alternatively, DC energy meter can be used at output of PV array to monitor PV generated DC energy.IN PV power plant for large power applications, three phases AC energy meters are used to monitor energy produced by PV power plant and supplied to MV grid. These energy meters are rated for MV AC voltage. Additionally, inverter also monitors AC energy produced by PV power plant [26].

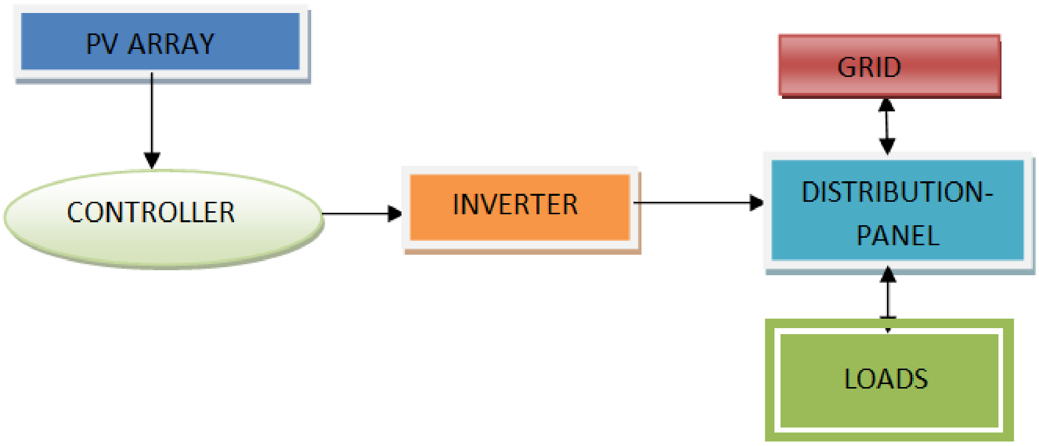


Fig 5.2: Grid connected solar PV power system without battery backup [26]

5.5 Design Calculations of 40 KW SPV System at DTU.

5.5.1: Energy Consumption Per Day

Table 5.1: Load calculation of administrative building at DTU

S.No	Type of load	Power rating(w)	Qty	No. of hours of operation(h)	total units consumed daily(kWh)
1	Air conditioning systems	1800	42	6	454
2	Fan	80	84	8	54
3	Tube light	40	103	10	42
4	Computer desktop	200	54	7	76
5	Miscellaneous load				70
				Total consumption	**696**

As we can see energy requirement for the administrative building in around 98 kW but rooftop area available is 4000 ft² which can only accommodate 40 kW SPV system. Therefore 58 kW load will be catered through grid due to use of grid connected solar PV system at admin building.

5.5.2: Average Solar Radiation

Since solar PV systems are designed on global horizontal insolation values. Since by seeing latitude of location, we can find out average GHI.

New Delhi last 14 years (2000-2014) average GHI value=5-5.5 kWh/m²/day

Let we take average GHI of our location=5.16 kWh/m²/day

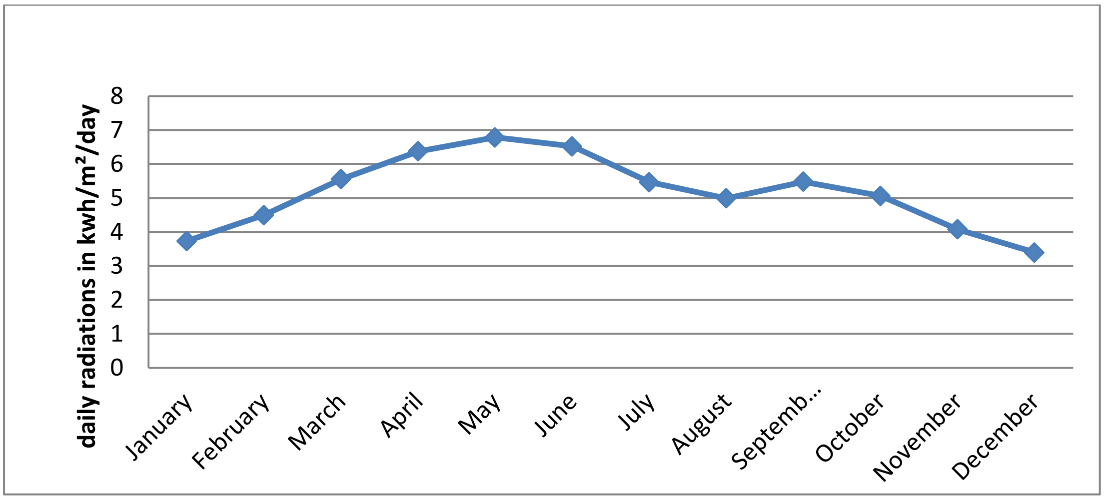


Fig 5.3: Average value of solar irradiance in various months obtained from NREL [24]

5.5.3: Estimate Required Number of PV Modules

Let we choose module as under-

Peak power=250 w_p

Table 5.2: Specification of 250Wp photon energy module [29]

PV MODULE Photon Energy PM 0250	
Maximum power (P_{max})	250 W_p
Voltage at maximum power (V_{mp})	30.72 V
Current at maximum power(I_{mp})	8.15 A
Open circuit voltage (V_{oc})	37.05 V
Open circuit current (I_{sc})	8.58 A
Tolerance	±2%
Maximum system voltage	1000V

Fig 5.4: Actual picture of installed PM250 photon energy modules at 40 kW SPV system at DTU.

So, No. of PV modules required $= \frac{40 \times 1000}{250}$ = 160 modules

5.5.4: Inverter Power Rating

Since PV array size is for 40 KW so we used 2 * 20 KW SSE international grid connected inverters

Table 5.3: Specifications of SSE inverter of 20kW [30]

SSE- International Model :SPS20KTL-B			
DC INPUT		**AC OUTPUT**	
V_{max} PV	1000 V	Max continuous current	32 A
MPP voltage rating	300 V-800 V	Max continuous power	20000 W
Max current	25 A×2	Frequency	50 Hz
I_{sc}PV	29 A×2	Nominal voltage	3 N-400 V
		Power factor range(full load)	>0.99

Fig5.5: Actual picture of installed two 20 kW SSE inverters at 40 kW SPV system at DTU [30].

5.6 Single Line Diagram of 40 KW SPV System at DTU

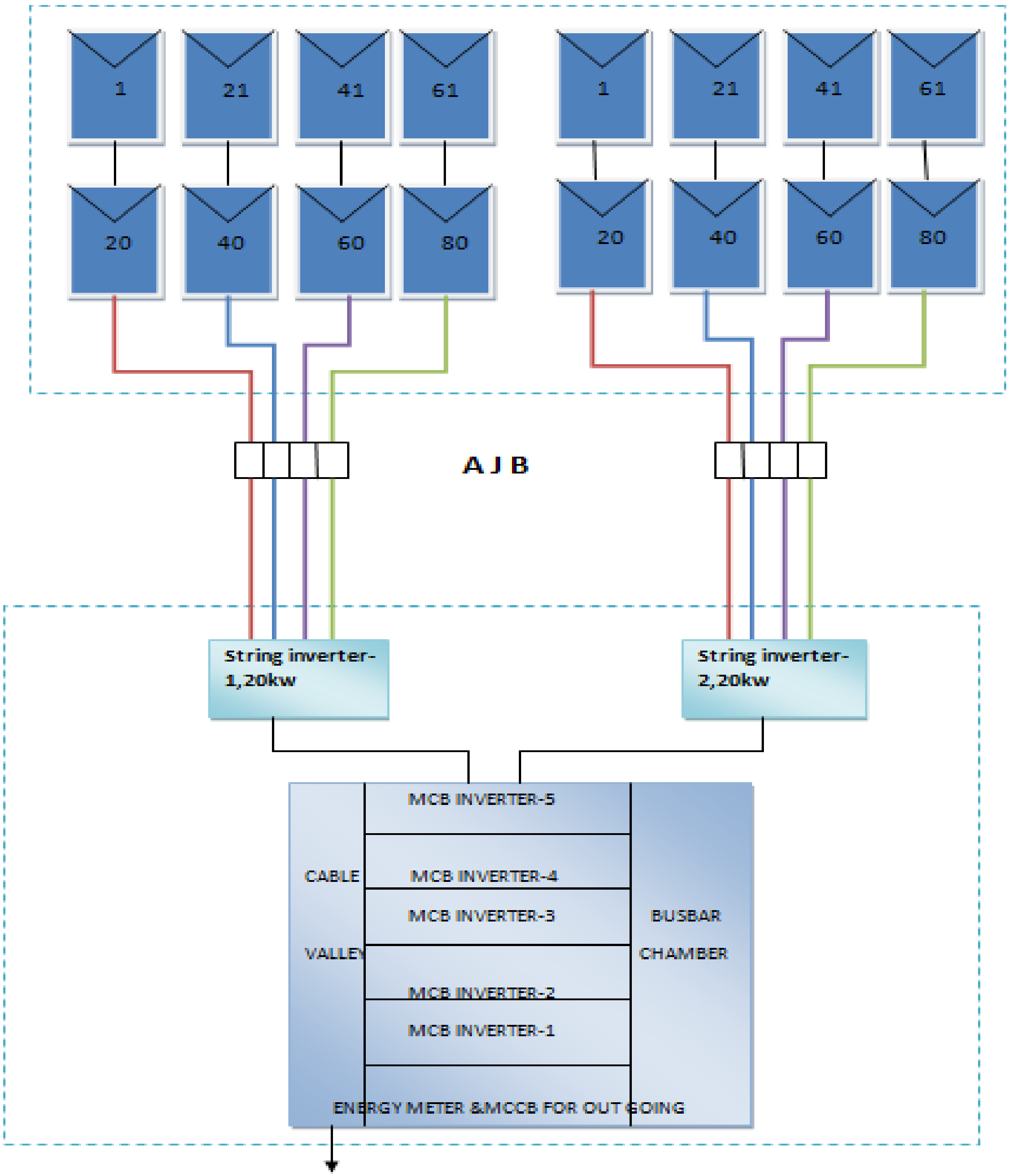


Fig 5.6: Single line diagram of installed 40 kW solar PV system at DTU.

CHAPTER 6: PERFORMANCE AND ECONOMIC ANALYSIS OF 40 KW SPV SYSTEM AT DTU

6.1 Daily Energy Output of 40 KW SPV System at DTU.

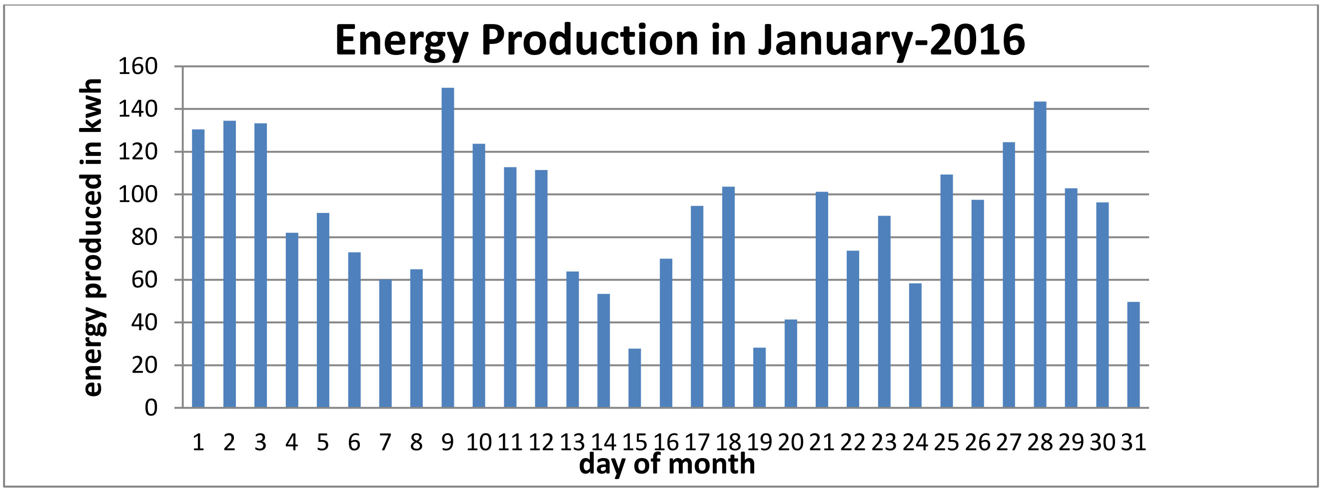


Fig 6.1: Energy generation per day in January 2016 from 40 kW SPV Plant at DTU.

The monthly average solar insolation of january is 4.15 kWh/m²/day .In the month of January as radiations intensity is good as compared to other years due to less cold, The 40 kW SPV system at DTU produced energy with month average of 90.23 kWh per day. Maximum energy produced was 149.94 kWh which was observed on 9th jan 2016. Due to clouds on 15 jan, minimum energy produced was 63.87 kWh. Total energy produced in january was 2797.35 kWh.

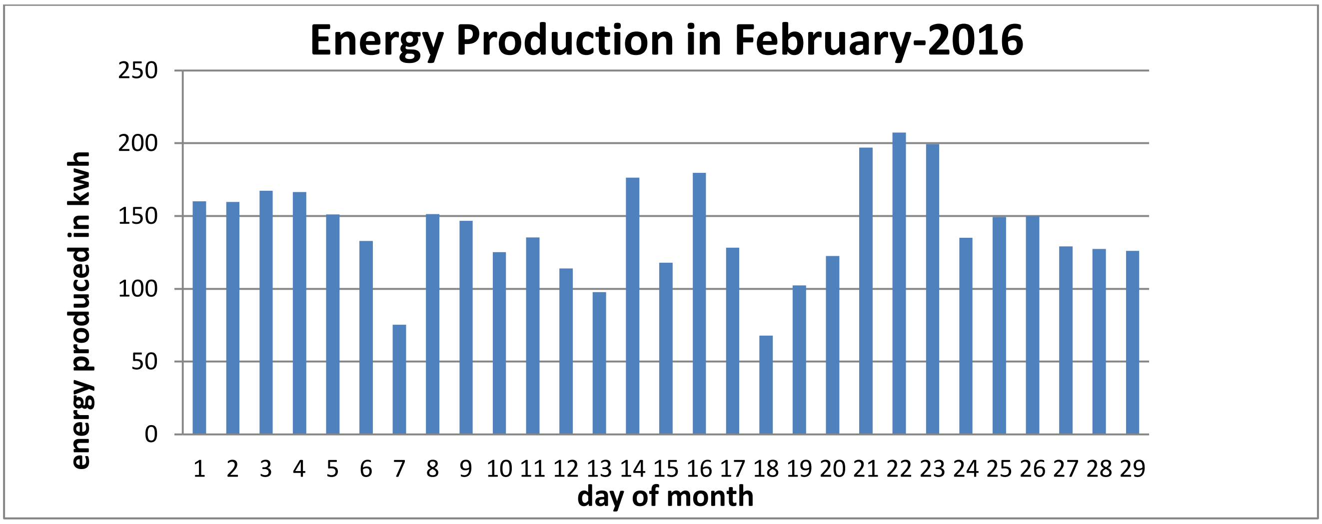


Fig 6.2: Energy generation per day in February 2016 from 40 kW SPV Plant at DTU.

The monthly average solar insolation of February is 5.4 kWh/m²/day. The 40 kW SPV system at DTU produced energy with monthly average of 141.32 kWh per day. Maximum energy produced was 207.41 kWh which was observed on 22nd feb 2016 and minimum energy produced was 67.89 kWh on 18th feb 2016. Total energy produced in february was 4098.45 kWh.

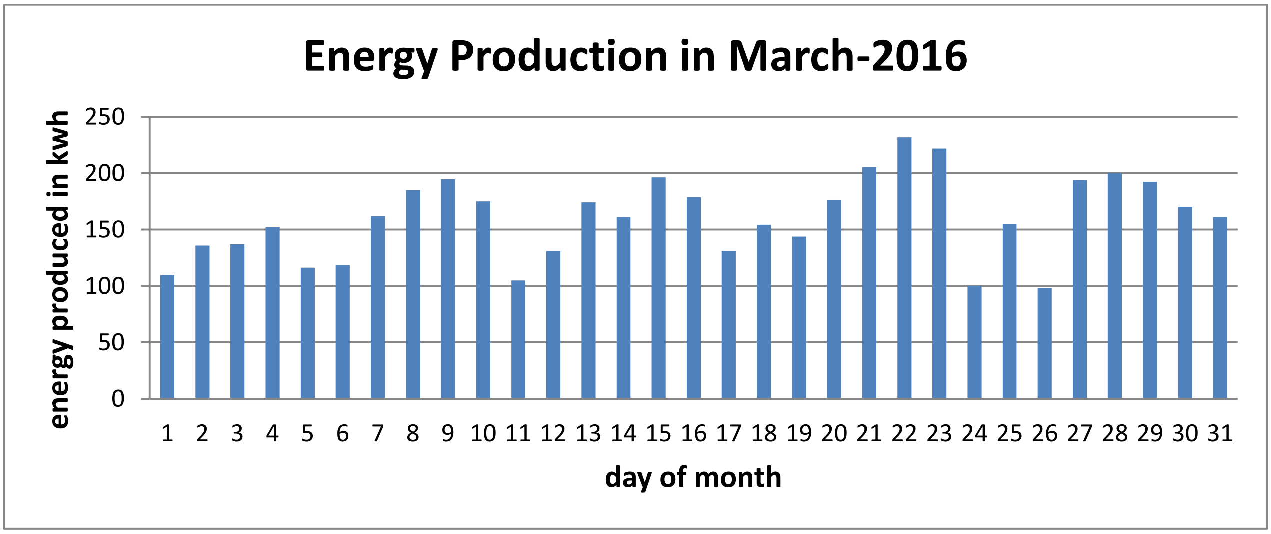


Fig 6.3: Energy generation per day in March 2016 from 40 kW SPV System at DTU.

The monthly average solar insolation of March is 6.45 kWh/m²/day. The 40 kW SPV system at DTU produced energy with monthly average of 160.27 kWh per day. Maximum energy produced was 231.87 kWh which was observed on 22nd feb 2016 and minimum energy produced was 67.89 kWh on 18th feb 2016.Total energy produced in march was 4967.18 kWh

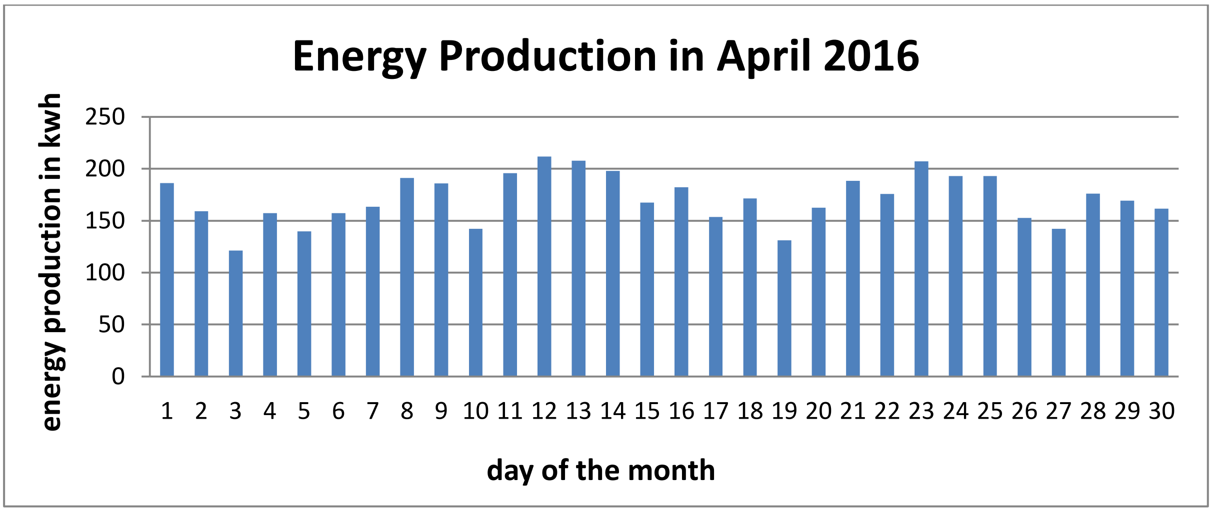


Fig 6.4: Solar energy generated each day in month of April from 40 kW SPV at DTU

The monthly average solar insolation of april is 6.84 kWh/m²/day. The 40 kW SPV system at DTU produced energy with monthly average of 171.42 kWh per day. Maximum energy produced was 211.75 kWh which was observed on 12th april 2016 and minimum energy produced was 121.36 kWh on 3rd april 2016. Total energy produced in april was 5142.68 kWh. This month showed very less variations in solar radiations subsequently widely constant energy production.

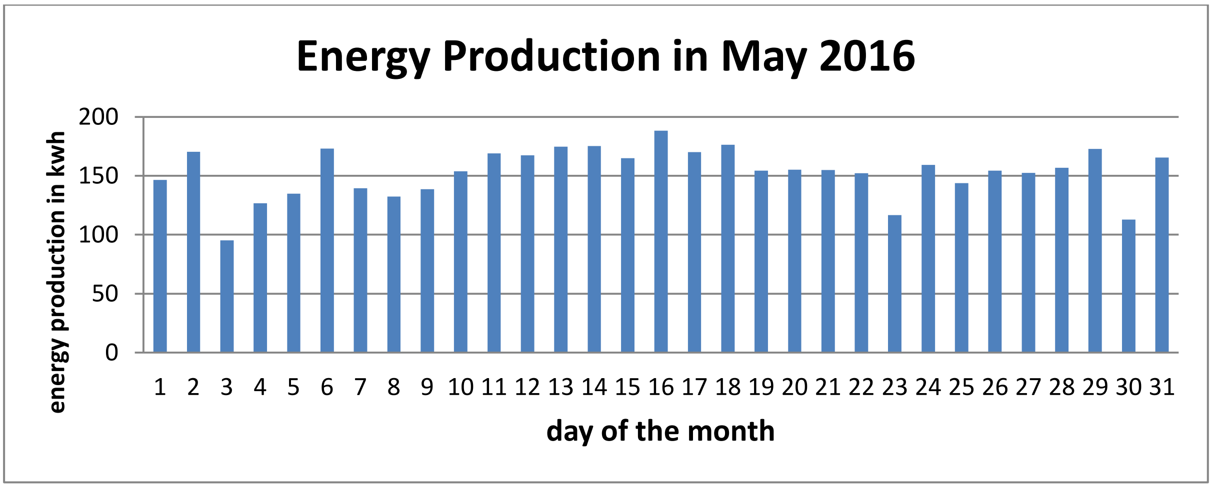


Fig 6.5: Solar energy generated each day in month of May from 40 kW SPV at DTU

The monthly average solar insolation of May is 6.08 kWh/m²/day. The 40 kW SPV system at DTU produced energy with monthly average of 153.10 kWh per day. Maximum energy produced was 188.15 kWh which was observed on 16th May 2016 and minimum energy produced was 95.07 kWh on 3rd may 2016.Total energy produced in may was 4746.23 kWh.

6.2 Comparative Analysis of Energy Generation in Various Months

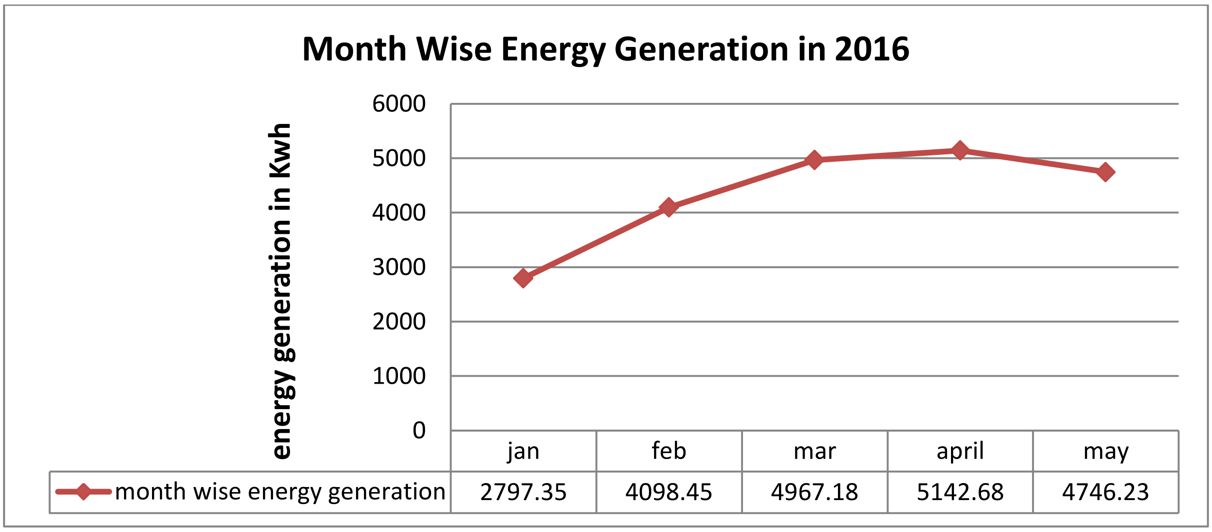


Fig 6.6: Energy generation per month from 40 KW solar photo voltaic plant at DTU.

As solar insolation increases from January to April i.e, 4.15 kWh/m²/day (jan) to 6.84 kWh/m²/day (april) , similarly energy output from SPV system increases according to solar radiation intensity and in month of april it produced maximum energy of 5142.68 kWh. From May onwards due to decrease in solar radiation , energy production decreases.

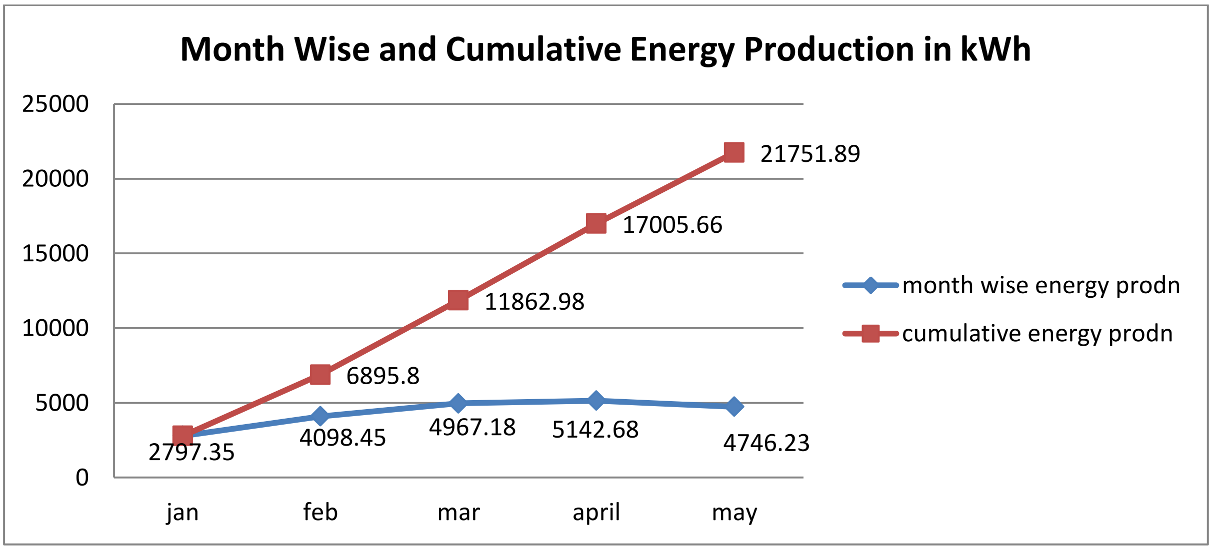


Fig 6.7: Energy generation per month and their cumulative addition from 40 kW solar photo Voltaic Plant at DTU.

6.3 Power and Cumulative Energy Variation on Particular Days

6.3.1 Power and Energy Variation on 23 March 2016

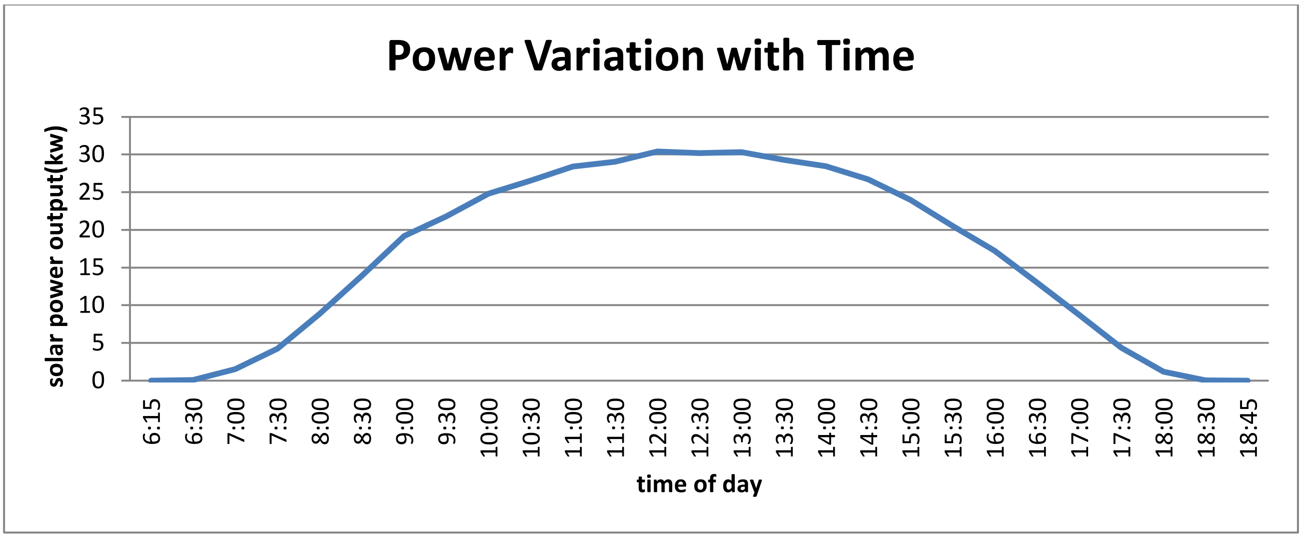


Fig 6.8: Power generation with time on 23 March 2016 from 40 kW SPV plant at DTU.

As solar radiation intensity increases from morning to around 12.30 PM and again decreases to minimum in evening. According to solar radiation intensity, power generation capacity also increases to maximum 30.18 kW at 12.30 PM. The average power generation throughout the day is 16.4 kW while operating for around 5-6 hours.

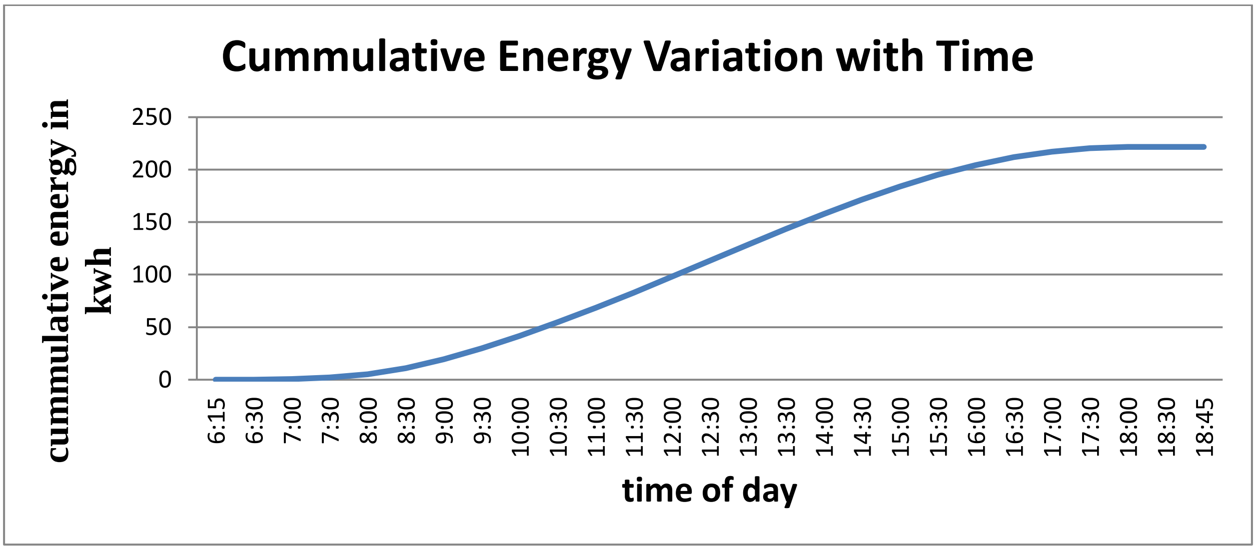


Fig 6.9: Energy accumulation on 23 march 2016 from 40 kW solar photo voltaic plant at DTU.

On 23 march 2016 the cumulative energy produced by 40 kW SPV plant with time is shown as above. The total energy produced by Plant on this day is 221.68 kWh. Significant adding of energy was observed between time interval of 9.00 AM to 16.00 PM.

6.3.2 Power and Energy Variation on 2nd May 2016 and Inverter Efficiency Calculation

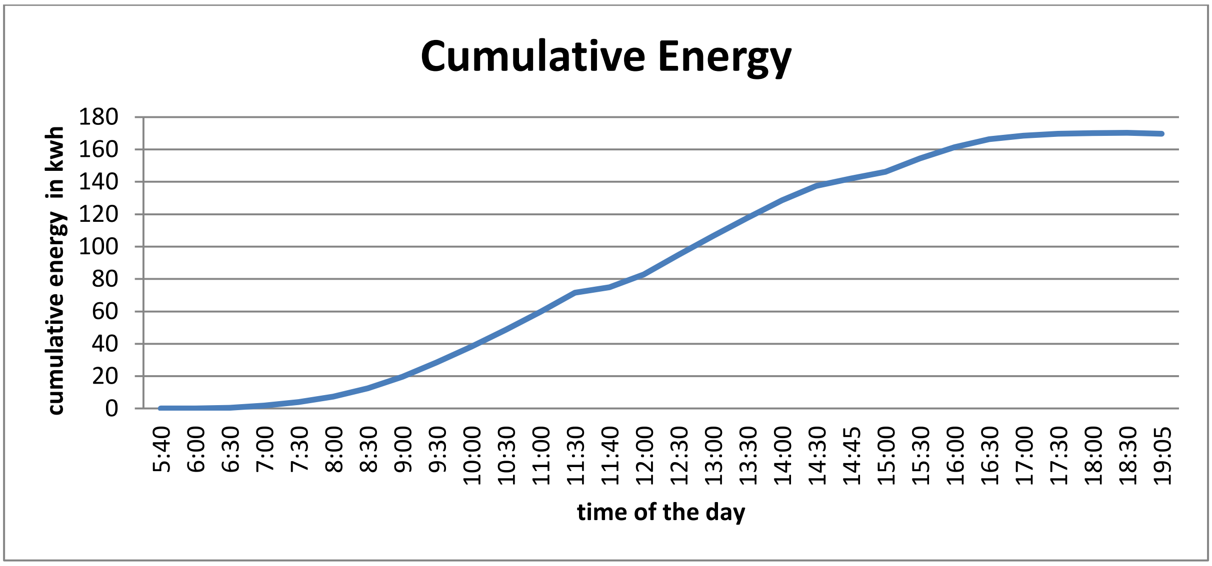


Fig 6.10: Energy accumulation on 2nd May 2016 from 40 KW solar photo voltaic plant at DTU.

On 2nd may 2016 the cumulative energy produced by 40 kW SPV plant with time is shown as above. The total energy produced by Plant on this day is 170.32 kWh. Significant adding of energy was observed between time interval of 9.00 AM to 16.00 PM.

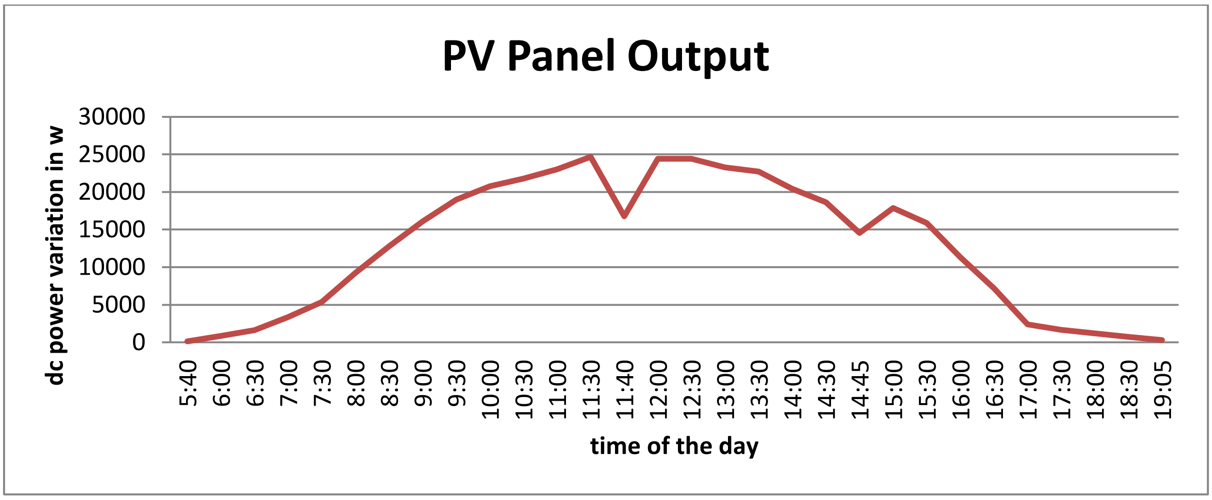


Fig 6.11: DC Power variation with time on 2nd may 2016 from 40 kW SPV plant at DTU

As solar radiation intensity increases from morning to around 12.30 PM and again decreases to minimum in evening. According to solar radiation intensity, power generation capacity also increases to maximum 25.0 kW at 11.30 PM & around 12.30 PM. The average power generation throughout the day is 16.4 kW while operating for around 5-6 hours.

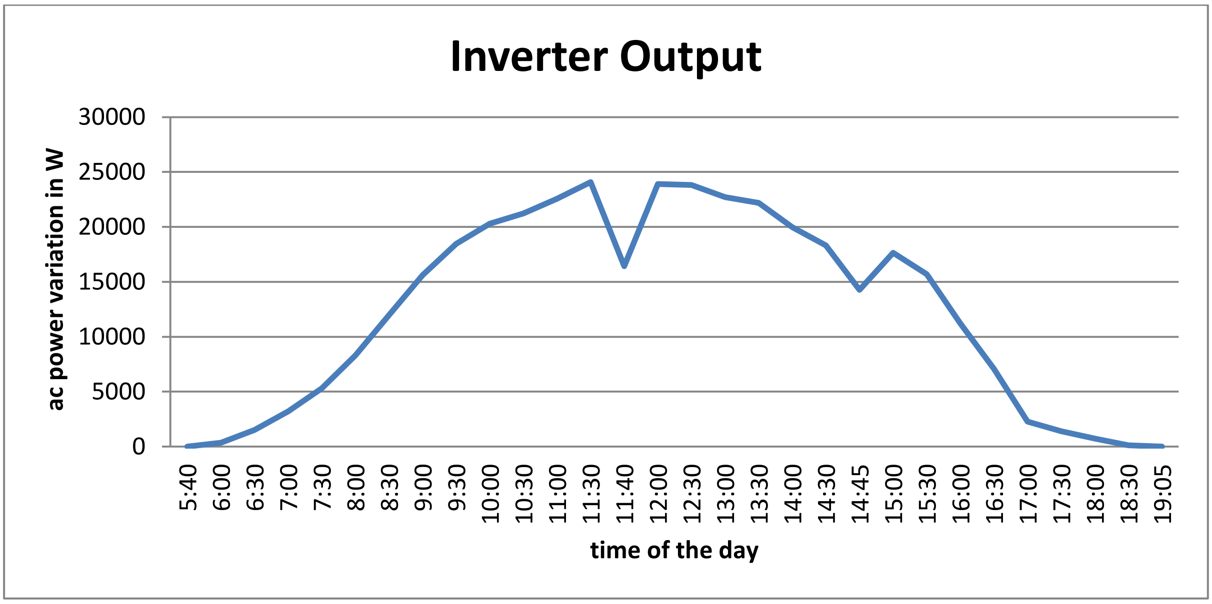


Fig 6.12: AC Power variation with time on 2nd may 2016 from 40 kW SPV plant at DTU

Each 20 kW SSE INVERTER converts DC energy produced by solar PV modules into AC power. SSE inverter works at maximum efficiency of 97 % so DC power conversion into AC reaches to maximum 24.8 kW at 11.30 PM and around 12.30 PM. The average power generation throughout the day is 16.4 kW while operating for around 6-7 hours

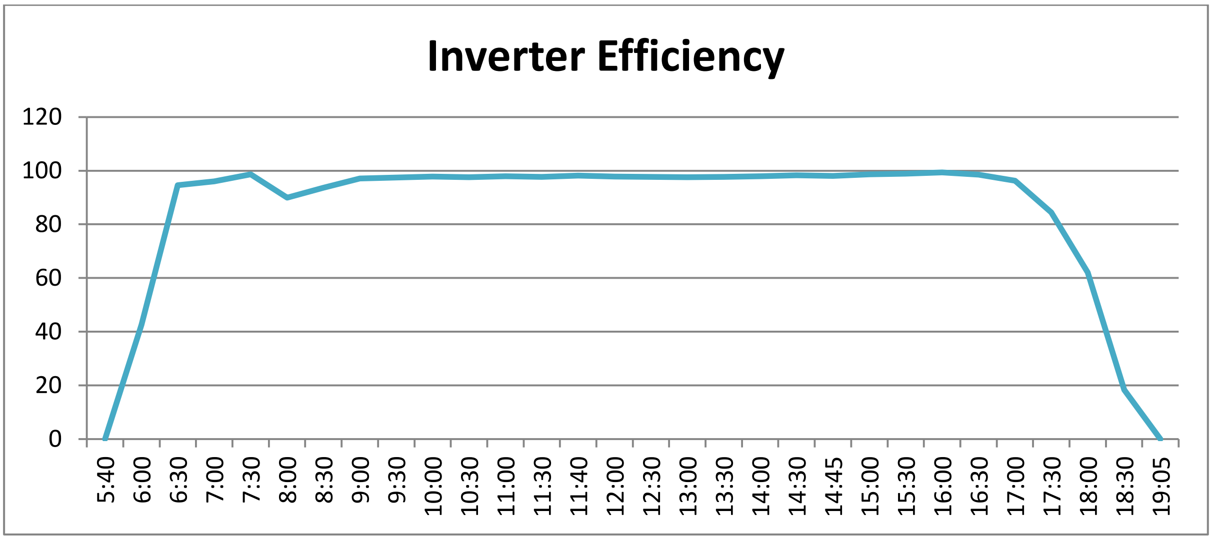


Fig 6.13: Inverter Efficiency of 40 kW solar photovoltaic system at DTU.

Each 20 kW SSE INVERTER converts DC energy produced by solar PV modules into AC power. Inverter gains its efficiency to maximum in a very short time interval. SSE inverter works at maximum efficiency of 97 % .so DC power conversion into AC reaches to maximum 24.8 kW at 11.30 PM and around 12.30 PM. The average power generation throughout the day is 16.4 kW while operating for around 6-7 hours.

6.4 Economic Analysis of 40 kW SPV System

Payback period is calculated on the basis of benefits incurred by DTU @ Rs 8.80/- per unit of electricity and amount incurred by DTU for installing the SPV system. Following table gives the steps for calculating payback period.

Table 6.1: Economic analysis and payback period of 40 kW solar photovoltaic system at DTU

Component	**Quantity required**	**Total cost**
Module cost @ Rs 47/watt p	160 modules of 250 Wp each	Rs 1880000/-
Inverter cost @ Rs 16/watt	2 inverters of 20 KVA rating each	Rs 640000/-
Structure and civil work @ Rs 12/ watt	1 complete set for 40 kW PV array mounting	Rs 480000/-
Electrical interconnection with grid @ Rs 13/watt	Array interconnection, connection to inverter and to LT panel/grid	Rs 520000/-
Miscellaneous	Transportation, taxes etc	Rs 440000/-
Total cost for 40 KW system		**Rs 3960000/-**
MNRE subsidy availed @ 30 % of project cost under institution scheme		Rs 1188000/-
Net cost incurred by DTU		**Rs 2772000/-**
Annual Units generated @ 5.16 KWh/m2/day	**54,515 units**	
Annual benefits @ Rs 8.80/ unit		**Rs 4,79,732/-**
Payback period	**Rs 2772000/ Rs 479732**	**5.77 years**

Simple payback period of around 5 years is achieved which make this SPV technology highly beneficial for institute which are getting electricity under commercial consumer category with high prices per unit consumed.

Chapter 7: Results, Conclusions and Scope for Future Work

7.1: Results of present work

1. First we calculated expected performance of 40 kW with "PV WATT CALCULATOR" software and then actual data of 40 kW SPV system was taken down till date to compare its actual performance with result given by software.

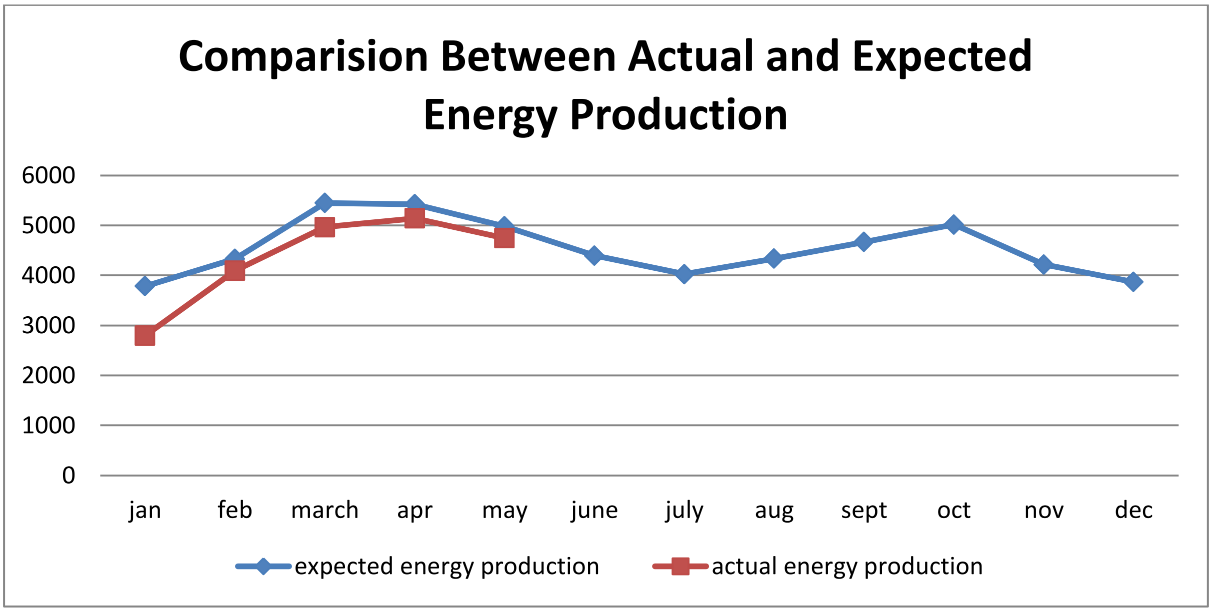


Fig 7.1: Comparison Between Actual and Expected Energy Production of 40 kW SPV System at DTU

2. The economic analysis of 40 KW grid connected SPV system at DTU shows that technology is fully viable and financially attractive also. 54,515 units will be generated annually and the payback period comes out to be 5.77 years. As plant life is around 25 years, next 20 years energy output will be free of cost for DTU.

8.2: Conclusions

In the thesis first we have analyzed world and Indian energy demand. India's electricity production is 298.06 GW as on 31 March 2016.In this renewable amounts to 13 % share of total electricity production and particularly power installed capacity is 6763 MW which amounts to 15.8% of total renewable energy.

A detailed performance analysis is done by calculating each day energy unit's production. Month wise total energy production comparison is also done to check variation month wise. Power variation and energy accumulation is also calculated by 30 minutes basis for particular days.

The economic analysis of 40 KW grid connected SPV system at DTU shows that technology is fully viable and financially attractive also. 54,515 units will be generated annually and the payback period comes out to be 5.77 years. As plant life is around 25 years, next 20 years energy output will be free of cost for DTU.

After successfully implementing of this technology, this model needs to be replicated on all Institutions buildings of Delhi which will have MWs of potential and help Delhi to become Smart city and Green capital of India. This also makes hand in fulfilling 100 GW solar PV target by 2022 Under MNRE national solar mission.

8.3 Recommendations & Scope for Future Work

1. As performance output decreases due to rise of module temperature due to its semiconducting property, future work can be done to decrease module temperature and improve efficiency of plant output even upto 10%.
2. Soiling losses can also be decreased by having good research in the field.

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Appendix1

NREL

RESULTS **54,514 kWh per Year ***

Month	Solar Radiation (kWh / m² / day)	AC Energy (kWh)	Energy Value (₹)
January	4.15	3,786	34,078
February	5.40	4,333	38,993
March	6.45	5,450	49,047
April	6.84	5,424	48,814
May	6.08	4,984	44,858
June	5.46	4,399	39,590
July	4.64	4,026	36,231
August	4.93	4,337	39,036
September	5.59	4,670	42,030
October	5.86	5,017	45,149
November	4.92	4,220	37,982
December	4.28	3,869	34,817
Annual	**5.38**	**54,515**	**₹ 490,625**

Location and Station Identification

Requested Location	new delhi
Weather Data Source	(IN) Gridded 10km Satellite Data 5.7 km
Latitude	28.65° N
Longitude	77.25° E

PV System Specifications *(Residential)*

DC System Size	40 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	28°
Array Azimuth	180°
System Losses	17%
Inverter Efficiency	96%
DC to AC Size Ratio	1.1

Initial Economic Comparison

Average Cost of Electricity Purchased from Utility	9.00 ₹/kWh