OPTIMIZATION FOR GENERATION SCHEDULING WITH RENEWABLE ENERGY SYSTEM

Thesis submitted in the partial fulfillment for the award of the degree of

Master of Engineering
in
Power Systems & Electric Drives

Thapar University, Patiala

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CERTIFICATE

I hereby certify that work which is being presented in the Thesis entitled **"Optimization for Generation Scheduling with Renewable Energy System"** in partial fulfillment of the requirement for the award of degree of Master of Engineering in ***Power Systems & Electric Drives*** submitted in Electrical & Instrumentation Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under supervision of **Dr. Sanjay K. Jain**, Asst. Prof., EIED and **Mr. Yogesh K. Chauhan**, Asst. Prof., EIED.

The matter presented in this Thesis has not been submitted for the award of any other degree of this or any other university.

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It is certified that the above statement made by the student is correct to the best of our knowledge and belief.

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ABSTRACT

The use of renewable energy for electricity generation is poised to increase in the future due to environmental concerns like global warming, CO_2 emission, air pollution, deforestation, and overall global environmental degradation. Therefore, the role of renewable energy generation is becoming more significant in relation to the operation and management of electrical systems. Renewable energy, such as solar energy, has been actively researched and developed in advanced countries. Sunlight is by far the largest carbon-free energy source on the planet. The solar energy received on earth everyday can produce 2500 times more power than the current consumption. But there should have proper means and technology to harness the energy economically.

The work has been carried out with the objective to minimize the total fuel cost of thermal-units of a power system having solar system also. The model of a PV cell using an equivalent electrical circuit has been discussed. The models are simulated in MATLAB/SIMULINK environment and the characteristics of PV module are studied. An algorithm has been developed to forecast the solar radiation for major Indian cities for different time and date. The generation scheduling of a system comprises thermal and solar units has been attempted using genetic algorithm. The effect of solar system on generation scheduling for different time and date has been shown. The performance has been investigated for three and six generator systems.

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

The Kyoto agreement on global reduction of greenhouse gas emissions has prompted renewed interest in renewable energy system world-wide. Many renewable energy technologies today are well developed, reliable, and cost competitive with the conventional fuel generators. The cost of renewable energy technologies is on a falling trend as demand and production increases. There are many renewable energy sources such as solar, biomass, wind, and tidal power.

Solar energy seems to be most attractive nowadays. The quantity of energy from the sun that arrives on the earth surface in an hour is about 5100 J which is more than the total energy consumed by all people of our planet during a year. Through the photovoltaic cells the energy contained in the sun light can be converted directly into electrical energy. This method of energy conversion presents some advantages, such as simplicity, modular construction, flexibility on utilization, high reliability and low maintenance. In addition, the photovoltaic systems represent a silent, sure, no pollutant and renewable source of electric energy.

The photovoltaic (PV) power systems have made a successful transition from small stand-alone sites to large grid-connected systems. The utility interconnection brings a new dimension to the renewable power economy by pooling the temporal excess or the shortfall in the renewable power with the connecting grid that generates base-load power using conventional fuels. This improves the overall economy and load availability of the renewable plant site - the two important factors of any power system. A future mix that includes sustainable energy sources will contribute to our prosperity and health. Our future energy needs must be met by a mix of sustainable technologies that have minimal environmental impacts. Potentially, many of these technologies will use solar energy in all its forms, permitting gradual evolution into a hydrogen-based economy. A renewable energy revolution is our hope for a sustainable future.

1.2 LITERATURE REVIEW

The literature on generation scheduling problem considering renewable energy system is very much diversified, the brief review is presented on the subject of optimization of generation scheduling with renewable energy system.

Renewable energy sources are receiving significant importance in recent researches and studies due to lower electricity generation price and positive effect on environment. Among these energy sources, solar and wind power are widely investigated and their integration with thermal power systems has been studied [1-2]. Quite promising results in terms of fuel cost savings have been reached in most works.

Chowdhury [3] introduces a operational tool for integrating a photovoltaic (PV) system into the utility's generation mix. A modified dynamic dispatch algorithm is proposed which requires a Box-Jenkins time series method for forecasting short-term PV output. A short term thermal unit commitment strategy integrated with renewable energy sources (solar and wind) by facilitating a genetic algorithm (GA) has been proposed in [3]. In this model, a battery system is incorporated with solar energy to supply power in case of peak load shaving and also to facilitate the load leveling. A fuzzy-optimization approach has been proposed [4] for solving the generation scheduling problem with consideration of wind and solar energy systems. Wind and solar energy are being considered in the power system to schedule unit power output to minimize the total thermal unit fuel cost.

The problem regarding the impact of renewable energy on power system operation has been discussed in several papers. The effect of wind generation has been discussed [5] on power system operation and emission reduction. Bakirtzis and Dokopoulus [6] proposed a method for solving short-term generation scheduling in a small autonomous system with a combination of diesel, wind, solar-cells and batteries. Another study from Ummels [7] also assesses the impact of wind energy on thermal generation unit commitment and dispatch. Chalmers, et al. [8] presented results of the impact of photovoltaic (PV) generations on the operation of a utility. Although substantial amount of PV generation can be integrated into the utility system, the most severe condition is created by the sudden change in PV generator output when the entire array is completely covered or uncovered by a fast moving cloud bank. It is also concluded that PV penetration exceeding 5% causes the conventional generation some difficulty in tracking these rapid PV output changes.

The economic dispatch [9] is a significant function in the modern energy system. It consists in programming correctly the electric production in order to reduce the operational cost [10-13]. In recent years researchers have focused much attention on new solution techniques to genetic scheduling. The application of a variety of genetic algorithm (GA) approaches has been proposed [14] for solving the genetic scheduling problem. An integrated scheme for optimal power tracking of PV system has been proposed and studied by [15]. A back propagation artificial neural network (ANN) is first used to predict the insolation level and then the genetic algorithm (GA) is utilized to optimize the power generation of the PV system.

Solar resources are known to exhibit a high variability in space and time due to the influence of other climatic factors such as cloud cover. Therefore, solar resource modeling or mapping is one of the essential management tools for proper development, planning, maintenance scheduling and pricing of solar energy system. For efficient conversion and utilization of the solar resource, the solar engineer designing solar energy systems requires an accurate and detailed short-term and long-term knowledge of the solar radiation characteristics of the location in various forms such models or maps for proper sizing of the solar energy systems [16–19].

Many researchers [20–26] have developed different forms of empirical models for estimation of global solar radiation for different locations based on other available meteorological parameters. The developed empirical models are location specific and hence are limited in scope and application. Sozen *et al*. [27] reported the application of ANN model for mapping of solar potential Mellit *et al*. [28] has developed an adaptive wavelet-network model for forecasting daily total solar radiation. Comprehensive review of ANN applications in renewable energy systems has been reported by Kalogirou [29].

The fluctuations in solar irradiance may occur in a minute-to-minute time frame. Short-term generation changes in an integrated PV-utility, caused by clouds moving over PV systems, the resulting utility load following, and spinning reserve requirements has been addressed by [30]. The battery storage is one of the alternatives to the random availability of PV. The paper [31] suggested that PV systems in conjunction with battery storage play a unique role in demand-side management (peak load shaving), and will likely impact the deregulation of electric power systems. The short-term scheduling of an integrated PV-thermal system considering the effect of battery storage has been presented in [32].

1.3 OBJECTIVE OF THE WORK

The objective of the present work is to study and simulate the behavior of PV module under SIMULINK and attempt the generation scheduling of the power system comprising thermal units and solar system. The solar radiation has to be forecasted for obtain the solar generation level. How the performance is affected due to change of day, time is also to be studied and the optimization is carried out using genetic algorithm.

.*1.4 ORGANIZATION OF THESIS*

The work carried out in this thesis has been summarized in five chapters The **Chapter 1** summarized the overview of the problem, brief literature review, objectives of work and organization of the thesis. The **Chapter 2** deliberates on solar electric power, concepts of the PV cell and grid connected PV system. The **Chapter 3** discussed the modeling and simulation of a PV cell, PV module in MATLAB/SIMULINK. The **Chapter 4** details the generation scheduling of the power system containing thermal units and solar system using Genetic Algorithm. The conclusions and the scope of further work are detailed in **Chapter 5**.

CHAPTER 2

SOLAR ELECTRIC POWER

2.1 INTRODUCTION

The power generation by conventional methods by exploiting coal and petroleum which are fast depleting, may lead to energy starvation in many places. Thus, there is an urgent need for the entire humanity to tap other resources which will at the same time be ecologically friendly. Some of such resources (non-conventional) are the solar, the wind, the sea waves and geothermal sources. Among these non-conventional resources, the energy from the sun is a primary one, unbounded by territorial or monopoly limitations. And this energy is readily available during the day for anyone to tap and that too free and without any constraint.

Solar energy is simply the energy from the sun. The sun generates an enormous amount of energy each second, by converting hydrogen to helium. This energy, called solar radiation is radiated into space and reaches the earth as sunlight (47%), ultraviolet rays (7%) and infrared radiation or heat (46%). Sunlight and infrared radiation are the components of solar radiation that provides solar energy we can use. This solar radiation can be "captured" and converted to useful energy. Photovoltaic are the most recent type of technology used to produce electricity directly from sunlight .By using the free energy of the sun to free us from dependence on unreliable foreign sources of oil, photovoltaic play an important and active role in the energy production these days. They provide highly reliable, low-cost electric power, by distributing energy throughout our systems in a more diversified way. The solar systems require minimal maintenance and are environmental friendly. The photovoltaic can also be very advantageous when made to work with the utility in peak hours. The system will be used to offset peak demand and serve as an emergency power system.

2.2 SOLAR RESOURCES

The solar energy is the most abundant renewable resource. Knowledge of the sun is very important in the optimization of photovoltaic systems. The electromagnetic waves emitted by the sun are referred to as solar radiation. The amount of sunlight received by any surface on earth will depend on several factors including; geographical location, time of the day, season, local landscape and local weather. The sun is estimated to produce approximately 100,000 billion Megawatts of power, but only a small fraction (200 billion Mega Watts) reaches the earth. The range of wavelengths of light that reach the earth varies for 300nm to 400nm approximately. The sun's radiation is the most basic energy source supplying the planet by heating it, allowing plants to grow, and providing other vital services. The sun's radiation can also be harnessed and converted to electricity for human use by photovoltaic solar cells.

2.2.1 Solar Radiation at the Earth's Surface

The radiation of the sun reaching the earth, distributed over a range of wavelengths from 300 nm to 4 micron approximately, is partly reflected by the atmosphere and partly transmitted to the earth's surface. Photovoltaic applications used for space, such as satellites or spacecrafts, have sun radiation availability different from that of PV applications at the earth's surface. The radiation outside the atmosphere is distributed along the different wavelengths in a similar fashion to the radiation of a 'black body' following Planck's law, whereas at the surface of the earth the atmosphere selectively absorbs the radiation at certain wavelengths. The important terms such as spectral irradiance, irradiance and radiation can be defined

(a) ***Spectral irradiance*** I_λ**:** the power received by a unit surface area in a wavelength differential dλ, the units are W/m^2 μm.

(b) ***Irradiance:*** The integral of the spectral irradiance extended to all wavelengths of interest. The units are W/m^2.

(c) ***Radiation:*** The time integral of the irradiance extended over a given period of time, therefore radiation units are units of energy. It is common to find radiation data in J/m^2 day, if a day integration period of time is used, or most often the energy is given in kWh/m^2 day, kWh/m^2 month or kWh/m^2 year depending on the time slot used for the integration of the irradiance.

The radiant energy flux received per second by a surface of unit area held normal to the direction of the Sun's rays at the mean Earth–Sun distance, outside the atmosphere (extra-terrestrial region), is practically constant throughout the year. This value is termed the solar constant I_{SC}, and its value is now adopted to be 1367W/m^2. However, this extraterrestrial radiation suffers variation due to the fact that the Earth revolves around the Sun not in a circular orbit but follows an elliptic path, with the Sun at one of the foci. The intensity of extraterrestrial radiation measured on a plane normal to the radiation on the n^{th} day of the year is given in terms of the solar constant I_{SC}.

$$I_O = I_{SC}\left(1 + 0.033\cos\frac{360n}{365}\right) \tag{2.1}$$

2.2.2 Measurement of Solar Radiation on Earth's Surface

The solar radiation reaching the Earth's surface through the atmosphere can be classified into two components: beam and diffuse radiation. As shown in figure (2.1) beam radiation (I_B) is the solar radiation propagating along the line joining the receiving surface and the Sun. It is also referred to as direct radiation. The diffuse radiation (I_D) is the solar radiation scattered by aerosols, dust and molecules. It does not have any unique direction. The total radiation (I_G) is the sum of the beam and diffuse radiation, sometimes known as global radiation. The instruments commonly used for the measurement of solar radiation on Earth's surface are pyrheliometer, pyranometer and sunshine recorder.

Pyrheliometer: The pyrheliometer is a broadband instrument that measures the direct (or beam) component of solar radiation at normal incidence. This means the instrument is always aimed directly at the Sun, via a tracking mechanism that continuously follows the

Sun. It is sensitive to wavelengths in the band from 280 to 3000 nm (0.284 μm to 0.3 μm).

Pyranometer: A pyranometer is a type of actinometer used to measure broadband solar irradiance on a planar surface and is a sensor that is designed to measure the solar radiation flux density (in watts per metre square).

Sunshine Recorder: Average number of hours of bright sunshine each day in a calendar month or year, calculated over the period of record. Hours of bright sunshine is measured from midnight to midnight. Within the Bureau of Meteorology network bright sunshine has generally been recorded with a Campbell-Stokes recorder. This device only measures the duration of ***"bright"*** sunshine, which is less than the amount of ***"visible"*** sunshine. For example, sunshine immediately after sunrise and just before sunset is visible, but would not be bright enough to register on the Campbell-Stokes recorder.

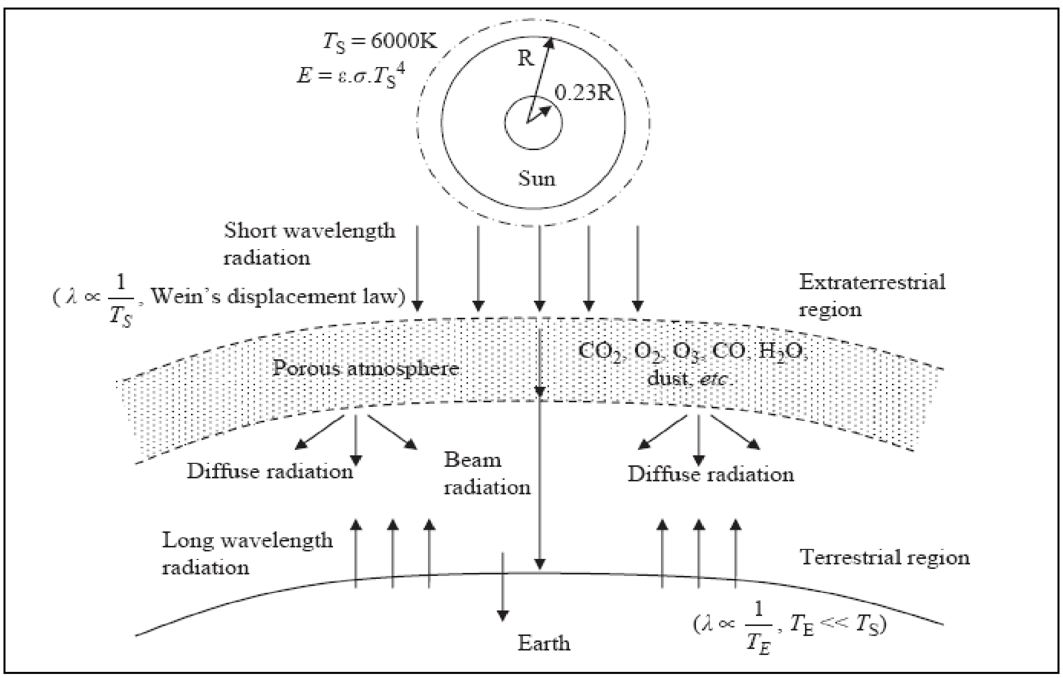


Fig.2.1 Positions of the Sun, the Earth and the Atmosphere

2.2.3 Solar Radiation Geometry

In order to find the beam energy falling on a surface having any orientation, it is necessary to convert the value of the beam flux coming from the direction of the sun to an equivalent value corresponding to the normal direction to the surface. If θ is the angle between an incident beam of flux I_{bn} and the normal to the plane surface, then equivalent flux falling normal to the surface is given by I_{bn} cosθ. The angle θ can be related by a general equation to the latitude, declination, the surface azimuth angle, and the hour angle. Each of these defined below:

Latitude $\boldsymbol{\phi}$**:** The latitude of a location is the angle made by the radial line joining the given location to the centre of the Earth with its projection on the equatorial plane. Latitude $\emptyset$gives the location of a place on Earth, i.e. north or south of the equator. Latitude is an angular measurement ranging from 0^0 at the equator to 90^0 at the poles (90^0N or 90^0S) for the north and south poles, respectively.

Declination δ: The angle that the Sun's rays make with the equatorial plane is known as the declination angle. In other words, the solar rays hit our planet at a certain angle with respect to the equator; this angle is the solar declination. On any day, δ is taken as a constant which changes on the next day. Cooper's empirical relation for calculating the solar declination angle (in degrees) for n^{th} day of the year is

$$\delta = 23.45 \sin\left[(284 + n) \times \frac{360}{365}\right] \qquad (2.2)$$

Solar declination can also be defined as the angle between the line joining the centers of the Sun and the Earth and its projection on the equatorial plane. The solar declination changes mainly due to the rotation of Earth about an axis. Its maximum value is 23.45^0 on 21 December and the minimum is – 23.45^0 on 21 June.

Zenith Angle **(θ_z):** The zenith angle is the angle of the Sun's ray away from the zenith direction, which varies from 0^0 to 90^0. When the Sun is either rising or setting the zenith angle is near 90^0 whereas at noon it is equal to or very near to zero. The zenith angle varies throughout the day with the movement of the Sun.

Solar Azimuth Angle (γ)***:*** This angle is measured with respect to the south direction (the directions pointed to by a compass are magnetic south and north). We must consider geographic south, which is different from magnetic south. A person standing vertically at noon (noon is the moment at which shadows are shortest) makes their shortest shadow on the Earth pointing towards geographic south and north. If the person is facing the Sun then that direction is geographic south, whereas the direction of the back of the person will be geographical north. The angle between the south direction and the projection of the rays of the Sun on a horizontal plane is known as the solar azimuth angle.

Hour Angle (ω)**:** The hour angle is the angle through which the Earth has to rotate to bring the meridian plane of any place or location under the Sun. This angle continuously decreases from sunrise to noon, becomes zero at noon and then starts increasing when its value becomes positive. At sunset the hour angle is maximum positive and at sunrise it is maximum negative for any place. In other words, the hour angle is the measure of the angular displacement of the Sun through which the Earth has to rotate to bring the meridian of the place directly under the Sun. This angle is conventionally expressed in units of time (1 hour $=15^0$).

2.3 PHYSICS OF SOLAR PHOTOVOLTAIC

The physics of the PV cell is very similar to that of the classical diode with a pn junction. When the junction absorbs light, the energy of absorbed photons is transferred to the electron–proton system of the material, creating charge carriers that are separated at the junction. The charge carriers in the junction region create a potential gradient, get accelerated under the electric field, and circulate as current through an external circuit.

2.3.1 Semiconductors and 'Doping'

PV cells consist, in essence, of a junction between two thin layers of dissimilar semiconducting materials, known respectively as 'p' (positive) type semiconductor, and 'n' (negative) type semiconductor. N-type semiconductors are made from crystalline silicon that has been 'doped' with tiny quantities of an impurity (usually phosphorus) in such a way that the doped material possesses a surplus of free electrons. Electrons are sub-atomic particles with a negative electrical charge, so silicon doped in this way is known as an n (negative) type semiconductor. P-type semiconductors are also made from crystalline silicon, but are doped with very small amounts of a different impurity (usually boron) which causes the material to have a deficit of free electrons. These 'missing' electrons are called holes. Since the absence of a negatively charged electron can be considered equivalent to a positively charged particle, silicon doped in this way is known as a p (positive)-type semiconductor.

2.3.2 The pn Junction

When the n-types and p-type meet they form a p-n junction, seen in Figure 2.2, where holes drift from the p-side to the n-side and free electrons drift in the other direction. This movement produces an electrical field across the junction. There are negative ions left behind when a hole leaves the p-side and positive ions left behind when a free electron leaves the n-side. These create a dipole layer at the junction that produces an electric field that opposes more majority carriers traveling to the opposite side of the p-n junction. This electric field will aid in the generation of electricity.

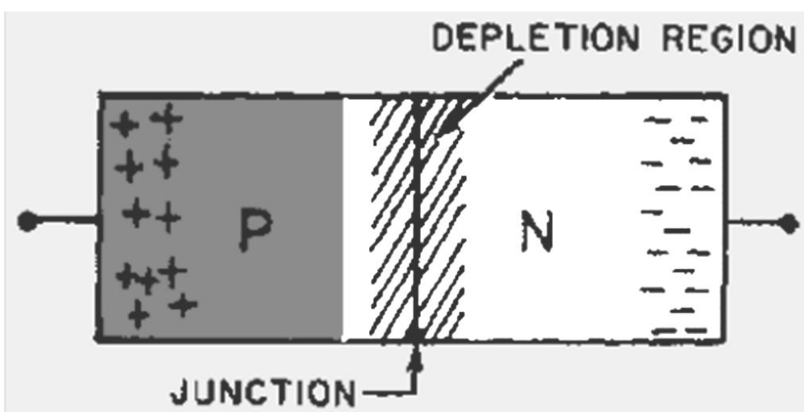


Fig 2.2 PN junction

2.3.3 The Photovoltaic Effect

Light can be considered to consist of a stream of tiny particles of energy, called photons. When photons from light of a suitable wavelength fall within the p–n junction, they can transfer their energy to some of the electrons in the material, so 'promoting' them to a higher energy level. Normally, these electrons help to hold the material together by forming so called 'valence' bonds with adjoining atoms, and cannot move. In their 'excited' state, however, the electrons become free to conduct electric current by moving through the material. In addition, when electrons move they leave behind holes in the material, which can also move.

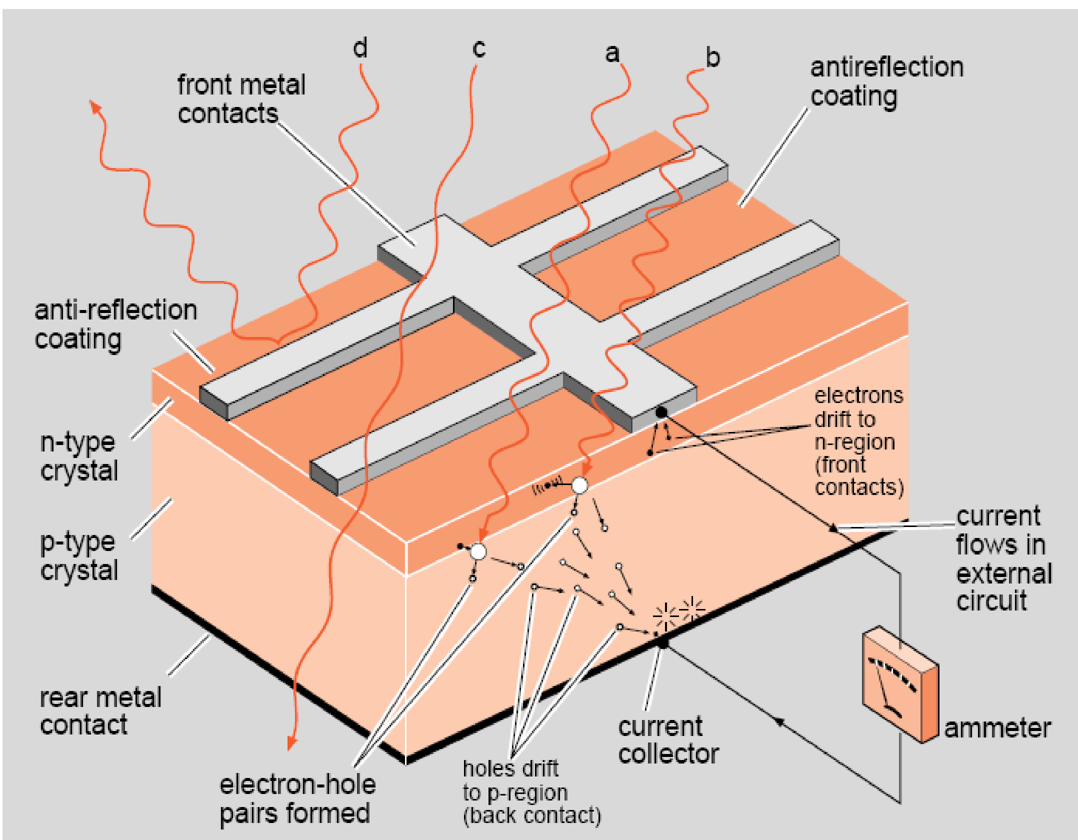


Fig 2.3 Silicon solar cell

As shown in Figure (2.3) the silicon solar cell is a wafer of p-type silicon with a thin layer of n-type silicon on one side. When a photon of light with the appropriate amount of energy penetrates the cell near the junction of the two types of crystal and encounters a silicon atom (a), it dislodges one of the electrons, which leaves behind a hole. The energy required to promote the electron into the conduction band is known as the band gap. The electron thus promoted tends to migrate into the layer of n-type silicon, and the hole tends to migrate into the layer of p type silicon. The electron then travels to a current collector on the front surface of the cell, generates an electric current in the external circuit and then reappears in the layer of p type silicon, where it can recombine with waiting holes. If a photon with an amount of energy greater than the band gap strikes a silicon atom (b), it again gives rise to an electron–hole pair, and the excess energy is converted into heat. A photon with an amount of energy smaller than the band gap will pass right through the cell (c), so that it gives up virtually no energy along the way. Moreover, some photons are reflected from the front surface of the cell even when it has an antireflection coating (d). Still other photons are lost because they are blocked from reaching the crystal by the current collectors that cover part of the front surface.

2.4 PV MATERIALS

PV cells are made of semiconductor materials with crystalline and thin films being the dominant materials. The majority of PV-cells are silicon-based but in the near future other thin films materials are likely going to surpass silicon PV cells in terms of cost and performance. PV materials may be classified into various classes namely crystalline, thin film, multi-junction, organic or photochemical. However the crystalline and thin film materials are most popular and described here.

2.4.1 Crystalline Materials

The crystalline materials the most widely available cell material. Its energy conversion efficiency ranges from 14 to 18%. The crystalline materials include single crystalline, poly crystalline and gallium arsenide.

Single-crystal silicon: Mono-crystalline silicon cells have in the past dominated the PV market but have now been overtaken by poly-crystalline silicon. The popularity of mono-crystalline silicon was due to the good stability and desirable electronic, physical and chemical properties of silicon. Moreover, silicon was already successful in microelectronics and the enormous industry thus created would benefit the smaller PV industry with regards to economy of scale

Poly-crystalline silicon: This is the currently most dominant material and has surpassed the mono-crystalline because it is cheaper. The cost of silicon is a significant portion of the cost of the solar cell. The manufacturing processes of poly-crystalline silicon reduces the cost of silicon by avoiding pulling in the manufacturing process and it results in a block with a large crystal grain structure. This results in cheaper cells with a somewhat lower efficiency. The assembly of multi-crystal wafers is easier and therefore offsets the low efficiency disadvantage.

Gallium Arsenide: This material is a compound semiconductor made of gallium and arsenic. It has a crystalline structure and has a high level of light absorbtivity. GaAs has higher efficiency than silicon but its main drawback is its cost. It is used in space applications and in concentrator systems.

2.4.2 Thin Film Materials

Since the 1990s development of thin film, processes for manufacturing solar cells have increased. These PV devices are made using very thin semiconductor films deposited on some type of low-cost structural substrate such as glass, metal or plastic. Epitaxial processes (such as vapor deposition, sputter processes and electrolytic baths) are used to achieve this. Because thin film materials have high absorptivity, the deposited layer of PV material is extremely thin. This results in the reduction of the dominating material cost although thin film PV cells suffer from poor cell conversion efficiency. There are several types of thin film materials. Some important thin film materials are amorphous silicon, cadmium telluride and copper indium diselenide.

Amorphous silicon: This material has a significant advantage of higher light absorptivity, about 40 times that of crystalline silicon. It can be deposited on a low cost substrate and the manufacturing process requires low temperature and therefore less energy. It has lower material and manufacturing costs. Amorphous hydrogenated silicon (a-Si:H) has been widely used by the Japanese to power small consumer goods such as watches and calculators. This material is a non-crystalline for silicon and does not form a regular crystal structure, but an irregular network. The material is highly defective even with hydrogenation so the minority carrier lifetimes are very low resulting in low conversion efficiency. A major drawback of this material is that it degrades under sun exposure, a mechanism called the Staebler-Wroski effect.

Cadmium Telluride (CdTe): This is one of the most promising thin film solar cells. The material is a poly- crystalline semiconductor compound made of cadmium and tellurium. CdTe has the lowest production cost among the current thin film technologies. Low-cost soda-lime glass is used as the substrate. The manufacturing processes have greatly improved over the past few years. The CdS film is grown either by chemical bath deposition (CBD), close space sublimation (CSS), chemical vapor deposition (CVD), sputtering, or vapor transport deposition (VTD). This material has a very high absorption coefficient.

Copper Indium Diselenide (CIGS): CIGS is a polycrystalline semiconductor compound of copper, indium and sele-nium, and has been a major research area in the thin film industry.It is another promising material for thin film solar cells. It can achieve high energy conversion efficiency and does not suffer from outdoor degradation problem and has demonstrated that thin film PV cells are a viable and competitive choice for the solar industry in the future. This material also has a high absorption coefficient with only 0.5 micrometers needed to absorb 90% of the solar spectrum. However it is a very complex material making it difficult to manufacture. Moreover its manufacturing process involves hydrogen selenide, an extremely toxic gas raising safety concerns.

2.5 PV HIERARCHY

The PV cell is the elementary unit, the interconnection of the number of PV cell forms the module and similarly PV array is form by combining the number modules.

2.5.1 PV Cell

PVs generate electric power when illuminated by sunlight or artificial light. To illustrate the operation of a PV cell the p-n homo junction cell is used. PV cells contain a junction between two different materials across which there is a built in electric field. The absorption of photons of energy greater than the band gap energy of the semiconductor promotes electrons from the valence band to the conduction band, creating hole-electron pairs throughout the illuminated part of the semiconductor These electron and hole pairs will flow in opposite directions across the junction thereby creating DC power. The most common material used in PV cell manufacture is mono-crystalline or poly-crystalline silicon. Each cell is typically made of square or rectangular wafers.

2.5.2 PV Module

For the majority of applications multiple solar cells need to be connected in series or in parallel to produce enough voltage and power. Individual cells are usually connected into a series string of cells (typically 36 or 72) to achieve the desired output voltage. The complete assembly is usually referred to as a module shown in figure (2.4) and manufacturers basically sell modules to customers. The modules serves another function of protecting individual cells from water, dust etc. as the solar cells are placed into an encapsulation of single or double at glasses. Within a module the different cells are connected electrically in series or in parallel although most modules have a series connection. In a series connection the same current flows through all the cells and the voltage at the module terminals is the sum of the individual voltages of each cell. It is therefore, very critical for the cells to be well matched in the series string so that all cells operate at the maximum power points. When modules are connected in parallel the current will be the sum of the individual cell currents and the output voltage will equal that of a single cell.

2.5.3 PV Array

An array is a structure that consists of a number of PV modules shown in Figure 2.4, mounted on the same plane with electrical connections to provide enough electrical power for a given application. Arrays range in power capacity from a few hundred watts to hundreds of kilowatts. The connection of modules in an array is similar to the connection of cells in a single module. To increase the voltage, modules are connected in series and to increase the current they are connected in parallel. Matching is again very important for the overall performance of the array.

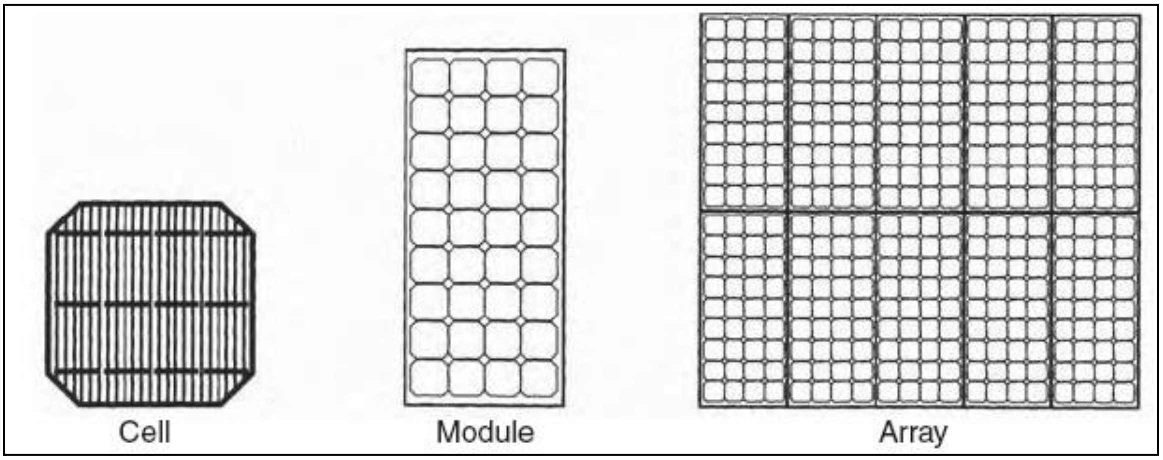


Fig.2.4 Several PV cells make a module, and several modules make an array

2.6 ELECTRICAL CHARACTERISTICS OF PV CELLS AND MODULES

In order to use PV cells efficiently it is necessary to know a little more about how they behave when connected to various electrical loads. The Figure 2.5 shows a single 100 cm^2 silicon PV cell connected to a variable electrical resistance *R*, together with an ammeter to measure the current (*I*) in the circuit and a voltmeter to measure the voltage (*V*) developed across the cell terminals. When the resistance is infinite the current in the circuit is at its minimum (zero) and the voltage across the cell is at its maximum, known as the **'open circuit voltage'** (Voc). At the other extreme, when the resistance is zero, the cell is in effect 'short circuited' and the current in the circuit then reaches its maximum, known as the **'short circuit current'** (Isc). For a silicon solar cell under a standard test condition, *V*oc is typically 0.6-0.7 V, and *I*sc is typically 20-40 mA for every square centimeter of the cell area.

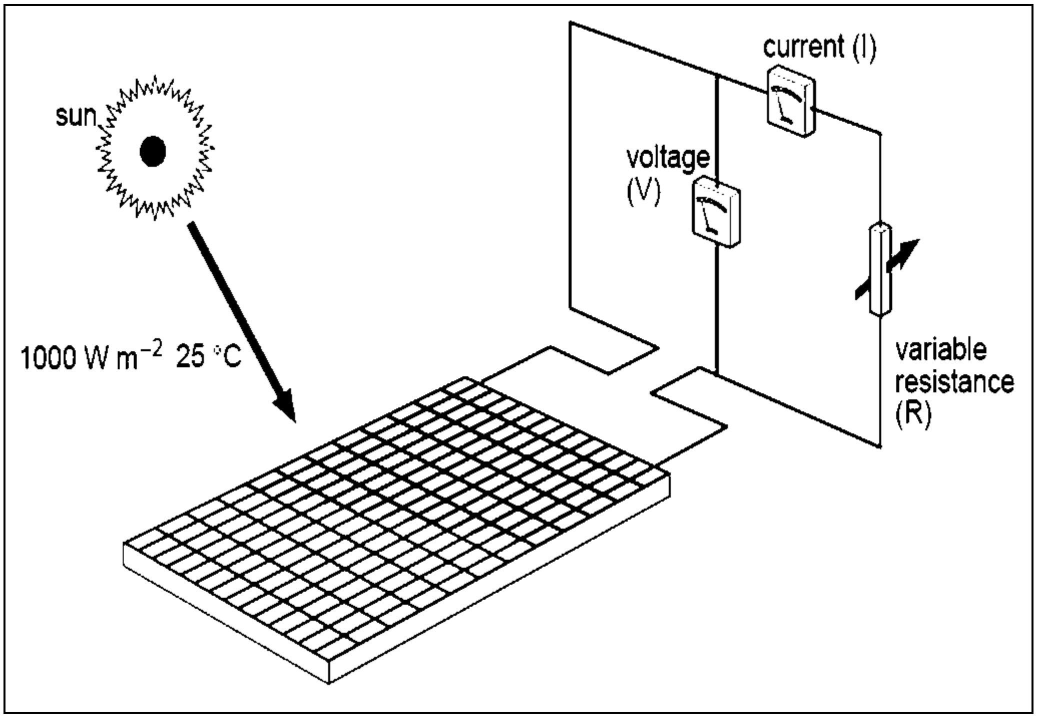


Fig.2.5 PV cell connected to variable resistance, with ammeter and voltmeter

To a good approximation, *I*sc is proportional to the illumination level, whereas *V*oc is proportional to the logarithm of the illumination level. A plot of power (*P*) against voltage (*V*) for this device shows that there is a unique point on the *I-V* curve in which the solar cell generates the maximum power at any illumination level. This is known as the maximum power point (*V*mp, *I*mp). Note that the maximum power condition always occurs at the knee of the characteristic curve.

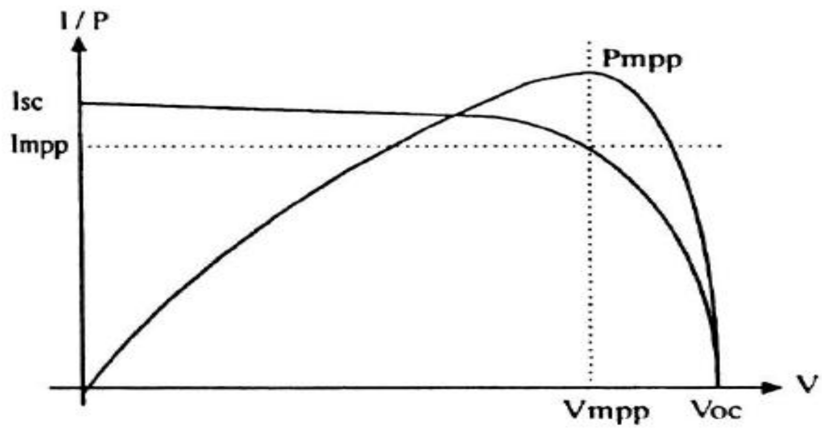


Fig.2.6 I-V curve and I-P curve

The effect of temperature on the performance of a solar cell is described in the Figure 2.7. Note that, *I*sc slightly increases in temperature, but *V*oc and maximum power majority decrease in temperature.

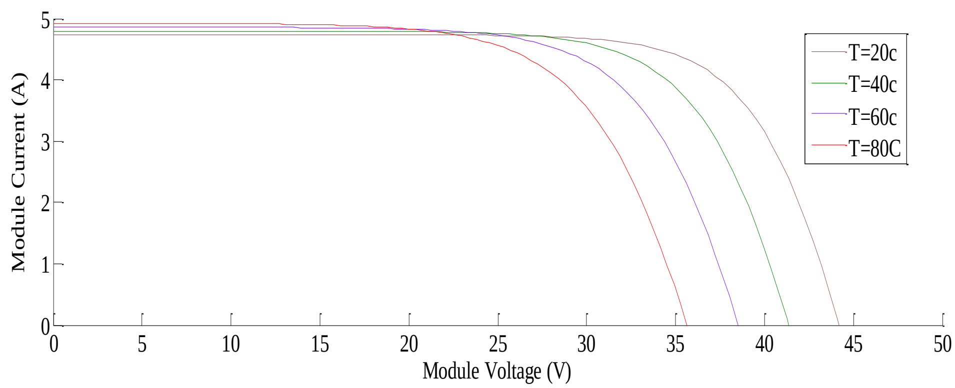


Fig 2.7 Effect of temperature on a solar cell

Figure 2.8 shows the variation of PV current and voltage at different solar radiation levels. According to Figure 2.7 and Figure 2.8, it can be concluded that the characteristic of a solar cell at a given radiation level and temperature consists of a constant-voltage segment and a constant-current segment. Its current is limited at the short circuit current and its voltage is limited at the open circuit voltage. The maximum power condition always occurs at the knee of the *I-V* characteristic curve.

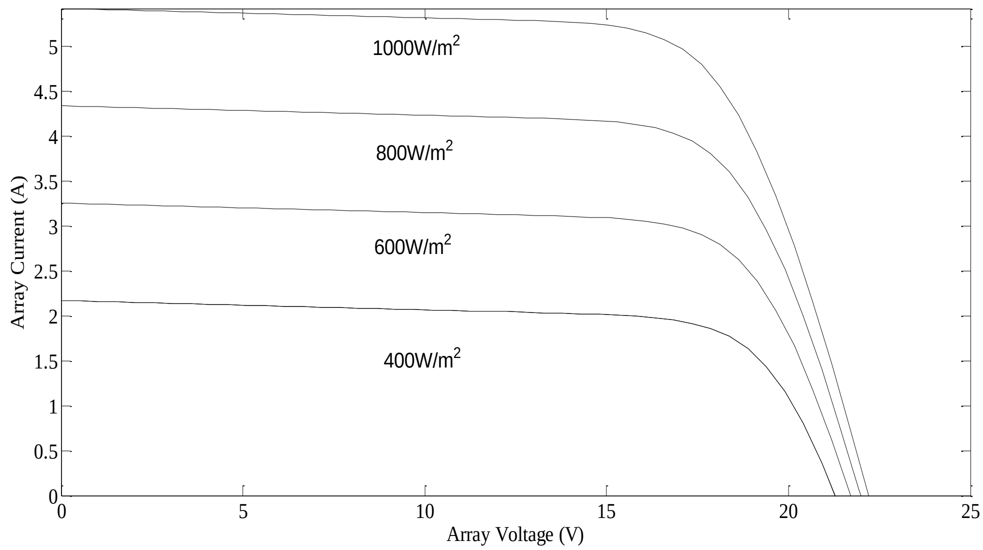


Fig 2.8 Typical I-V characteristic curves for different radiation level

2.7 GRID CONNECTED PHOTOVOLTAIC SYSTEM

Within the application of the photovoltaic solar energy, the grid connected PV systems have known a considerable development in the last few years, and everything seems to indicate that they will continue expanding with vigour in the future, under protection of the increasing taking of conscience on the environment problems that entails the present structure of the electricity production. These systems are characterized because all the energy that produce is sent to the grid. It can be considered as domestic installation those whose power tip is below 5 kW. These small domestic installations are designed to satisfy part of the power demand of the user. Thus, it himself consumes energy of the photovoltaic installation or the grid, depending on this level of power demand and hour of the day. These systems can be considered as mixed, since the power demand is covered partly by the grid and elsewhere by the photovoltaic system. These mixed system of power saving, would allow, if its use were massive, to have decentralized electrical energy and renewable origin, thus contributing to diminish the use of other power sources. The energy produced by a grid connected photovoltaic system depends on three factors:

- Climatic factor, mainly the incident radiation on the modules and the temperature of work of such, which is function mainly of the radiation and the ambient temperature.
- Technical characteristics of inverters, mainly its yield, that is function of its point of work, as well as its threshold of operation, defined as necessary power so that the inverter connects itself to the grid.
- Characteristics of the connection system-grid, that although it depends on the characteristics of the energy, when coming out of the inverter, waveform, harmonic distortion and frequency among others, also depend on the own grid, its stability and its availability.

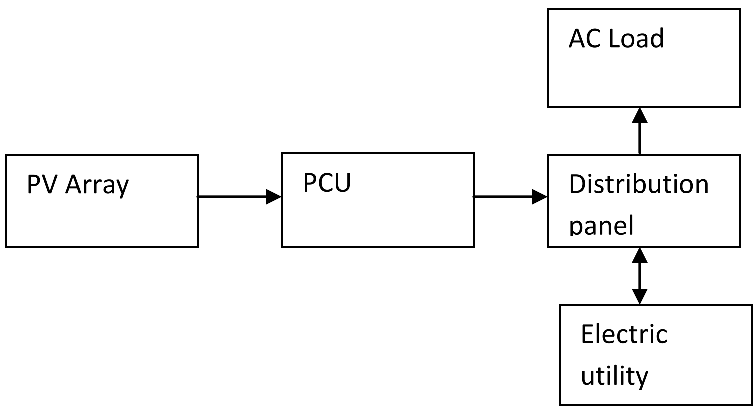


Fig.2.9 Block diagram of grid connected PV system

Grid-connected or utility-interactive PV systems are designed to operate in parallel with and interconnected to the electric utility grid. The primary component in grid-connected PV systems shown in Figure 2.9 is the inverter, or power-conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized. A bi-directional interface is made between the PV system AC output circuits and the electric utility network, typically at the on-site distribution panel or service entrance. This allows the AC power produced by the PV system to either supply on-site electrical loads, or to back feed the grid when the PV system output is greater than the on-site load demand. At night and during other periods when the electrical loads are greater than the PV system output, the balance of power required by the loads is received from the electric utility. When the utility grid is down, these systems automatically shut down and disconnect from the grid. This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back onto utility grid when the grid is down for service or repair.

2.8 TRENDS IN PV GENERATION

Due to the growing demand for renewable energy sources, the manufacture of solar cells and photovoltaic arrays has advanced dramatically in recent years. Photovoltaic production has been increasing by an average of more than 20 percent each year since 2002, making it the world’s fastest-growing energy technology. The statistics demonstrating the trends of PV generation in global and India are presented.

2.8.1 Global Trends

From the first space applications to the GW planned systems, more than 40 years have passed. The last decade has seen PV technology emerging as a potentially major technology for power generation in the World. The robust and continuous growth experienced in the last ten years is expected to continue in the coming years. By the end of 2008, the World cumulative PV power installed was approaching 16 GW and today, almost 23 GW are installed globally which produce about 25 TWh of electricity on a yearly basis. Europe is leading the way with almost 16 GW of installed capacity in 2009, representing about 70% of the World cumulative PV power installed at the end of 2009 while Japan (2.6 GW) and the US (1.6 GW) are following behind. China makes its entry into the TOP 10 of the World PV markets and is expected to become a major player in the coming years.

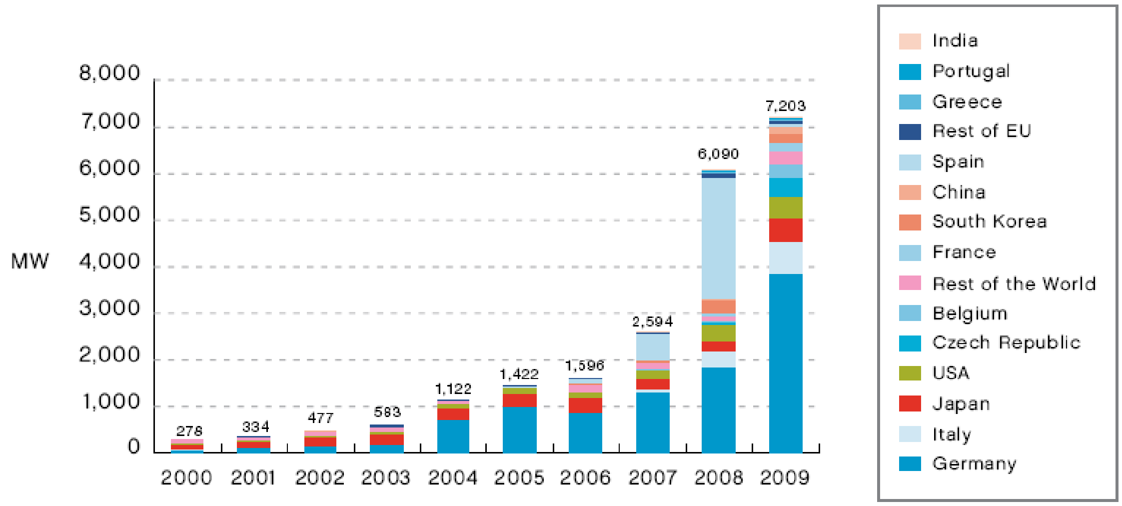
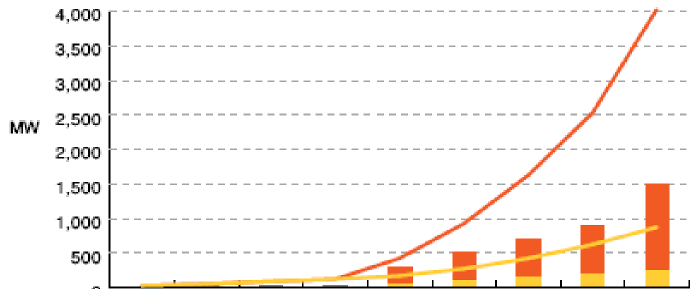


Fig.2.10 World cumulative PV power installed in main geographies

The annual market has developed from less than 1 GW in 2003 to more than 7.2 GW in 2009 in spite of the difficult financial and economic circumstances. After a 160% CAGR (Compound Annual Growth Rate) growth from 2007 to 2008, the PV market in 2009 continued to grow another 15% in 2009. While Germany reclaimed its leadership, many other markets have started to show significant development. South Korea and, in particular Spain, saw to the contrary their installation figures dropping.

2.8.2 Indian Trends

The total installed power capacity in the country as on 31 March 2008 is 1,43,061 MW. Out of this, the respective shares of thermal power and hydropower are 64.2% and 25.1%. The share of power from renewable energy technologies is about 7.8%, which is incidentally more than double the share of power obtained from nuclear energy. A capacity addition of nearly 78,520 MW has been planned by the Ministry of Power during the Eleventh Five year Plan period (2007–12). As of now, about 52.5% of the total power production takes place in the state sector, while the central and private sectors produce 34% and 13.5%, respectively. Presently, a total of 4,87,338 villages (82.1%) stand electrified. There is a target of increasing the per capita power consumption to about 1000 units from the existing 681 units. There is a need large scale power generation from both the non-renewable and renewable energy sources to sustain a targeted GDP annual growth of about 8%–10%. Considering all this, there is a need to exploit solar energy for power generation through financial and fiscal measures as far as possible



		2006	2007	2008	2009	2010e	2011e	2012e	2013e	2014e
Annual market (MW)	EPIA Moderate scenario	12	20	40	30	50	100	150	200	250
	EPIA Policy-Driven scenario					300	500	700	900	1,500
Projected cumulative PV power installed (MW)	EPIA Moderate scenario CUM	31	51	90	120	170	270	420	620	870
	EPIA Policy-Driven scenario CUM					420	920	1,620	2,520	4,020

Fig.2.11 Indian Market History and Forecast until 2014

Among the Sunbelt countries (located between 30 degrees North and 30 degrees South of the equatorial line), India has a specific role to play. With an increasing electricity demand and high irradiation levels, the country has definitively a huge potential for PV. The recent targets defined by the government (20 GW of PV in 2022) tend to favour the idea that this market could boom in the coming years. Starting from a low 30 MW installed in 2009, it could grow to 1.5 GW in 2014 in the Policy-Driven scenario and probably well beyond afterwards. The market size in 2010 will clearly depend on the political choices to possibly reach between 50 MW and 300 MW. Besides the National Solar Mission of 2009, the market expects much of the possible decision this year to define a long term power purchase agreement that could definitively trigger PV deployment in India.

2.9 CONCLUDING REMARK

With the pace of development the demand of energy is growing rapidly. It has become impossible to meet this growing need of energy with conventional resources. Solar energy is an alternative to sustain the pace and development. The review on solar energy, the global and Indian position is presented. The physics and electrical characteristics of solar cell are also presented in this chapter.

CHAPTER 3

SIMULATION OF PV SYSTEM

3.1 INTRODUCTION

The history of PV dates back to 1839 when a French physicist, Edmund Becquerel, discovered the first photovoltaic effect when he illuminated a metal electrode in an electrolytic solution. Thirty-seven years later in 1876 British physicist, William Adams, and Richard Day, discovered a photovoltaic material, selenium, and made solid cells with 1~2% efficiency. In 1954 the first generation of semiconductor silicon-based PV cells was born, with efficiency of 6%, and adopted in space applications. Today, the production of PV cells is following an exponential growth due to technological advancement continuously taking place to improve efficiency and reduce cost.

This chapter discusses the modeling of PV cells using an equivalent electrical circuit. The models are implemented using MATLAB/SIMULINK to study PV characteristics and simulate a PV module and PV array.

3.2 MODELING OF PV CELL

The use of equivalent electric circuits makes it possible to model characteristics of a PV cell. The method used here is implemented in MATLAB programs for simulations. The same modeling technique is also applicable for modeling a PV module.

3.2.1 Equivalent Electrical Circuit

The complex physics of the PV cell can be represented by the equivalent electrical circuit shown in Figure 3.1. The circuit parameters are as follows. The current I at the output terminals is equal to the light-generated current I_L, less the diode current I_d and the shunt-leakage current I_{SH}. The series resistance R_S represents the internal resistance to the current flow, and depends on the pn junction depth, impurities, and contact resistance. The shunt resistance R_{SH} is inversely related to the leakage current to ground. In an ideal PV cell, $R_S = 0$ (no series loss), and $R_{SH} = \infty$ (no leakage to ground).

In a typical high-quality silicon cell, R_S varies from 0.05 to 0.10 Ω and R_{SH} from 200 to 300 Ω. The PV conversion efficiency is sensitive to small variations in R_S, but is insensitive to variations in R_{SH}. A small increase in R_S can decrease the PV output significantly.

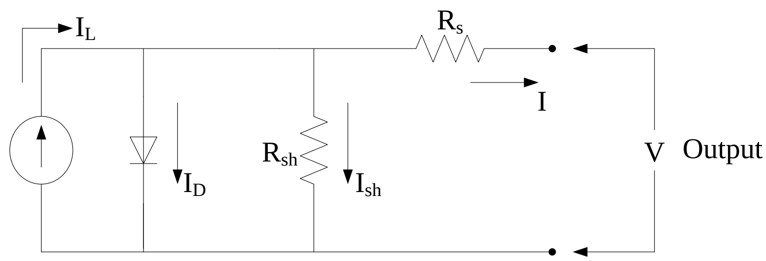


Fig.3.1 Equivalent circuit of PV cell showing the diode and ground leakage currents.

The open-circuit voltage V_{OC} of the cell is obtained when the load current is zero, i.e., when I = 0, and is given by the following:

$$V_{OC} = V + IR_{SH} \tag{3.1}$$

The diode current is given by the classical diode current expression:

$$I_d = I_D \left[exp\left(\frac{QV_{OC}}{KT}\right) - 1\right] \tag{3.2}$$

Where

I_D = the saturation current of the diode

Q = electron charge = 1.6×10^{-19} C

k = Boltzmann constant = 1.38×10^{-23} J/°K

T = temperature on absolute scale °K

The load current is therefore given by the expression:

$$I = I_L - I_D \left[exp\left(\frac{QV_{OC}}{KT}\right) - 1\right] - \left(\frac{V}{R_{SH}}\right) \tag{3.3}$$

The last term is the leakage current to the ground. In practical cells, it is negligible compared to I_L and I_D and is generally ignored. The diode-saturation current can therefore be determined experimentally by applying a voltage V_{OC} to the cell in the dark and measuring the current going into the cell. This current is often called the dark current or the reverse diode-saturation current.

3.3 SIMULATION OF SOLAR CELL

The Figure 3.2 shows the simulink model of a PV cell. The cell operate at room temperature, V_T=26mV. The reverse saturation current is $I_s=1x10^{-9}$A. The temperature is constant during simulation. The output of the simulation display in a X-Y graph block.

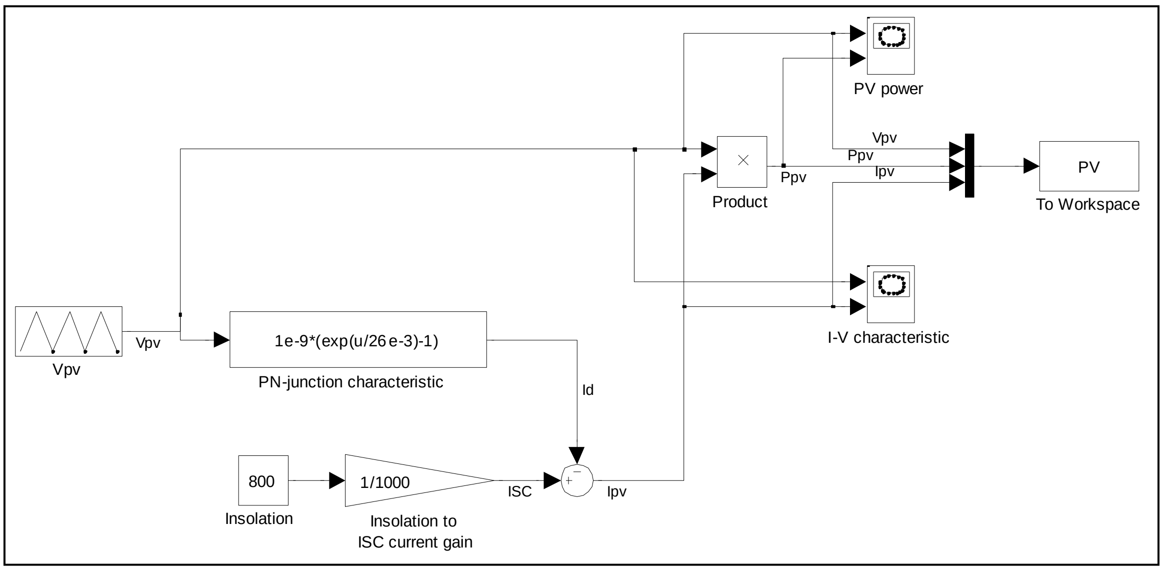


Fig.3.2 Simulink Model of PV Cell

3.3.1 Result of Solar Cell Simulation

The output power P_{PV} as a function of V_{PV} is shown in Figure 3.3. The output current I_{PV} as a function of V_{PV} is shown in Figure 3.4. Output power Ppv, current I_{PV}, voltage V_{PV}, and simulation time are stored in a "structure" variable PV, which is made available (using the "To Workspace" block) for further processing in the MATLAB Command Window.

The maximum peak power of the PV cell is 0.3458 W

The voltage of PV cell at maximum peak power is 0.46 V

The current of PV cell at maximum peak power is 0.75A

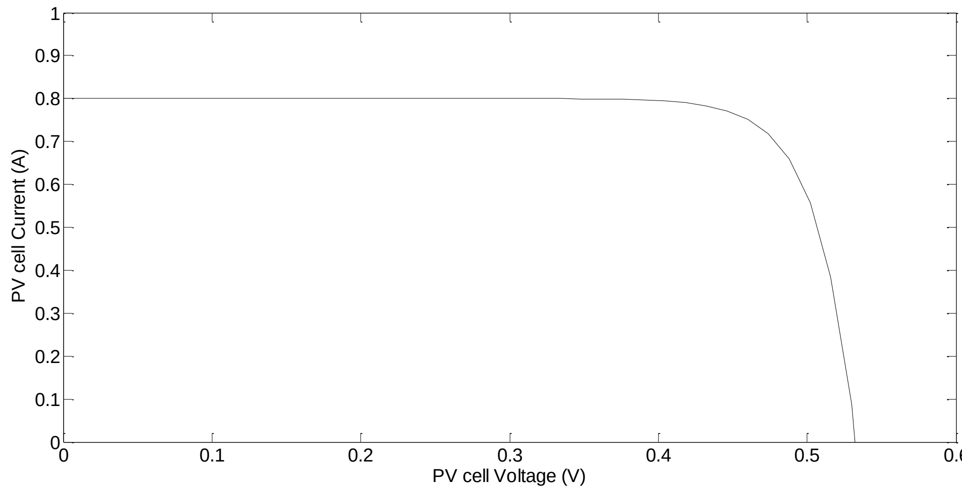


Fig 3.3 Current Voltage curve of a PV cell

As shown in Figure 3.3,the PV cell current remains largely constant at 0.8 A upto the cell voltage of 0.4V. thereafter it decreases exponentially ay nearly 0.53 volt. The solar power in Figure 3.4 increases linearly with the PV cell voltage upto 0.4 volt then it attains nonlinear pattern. After attaining the maximum power of 0.3458 watts it decreases exponentially as the current dcresses and attain zero level at 0.53.

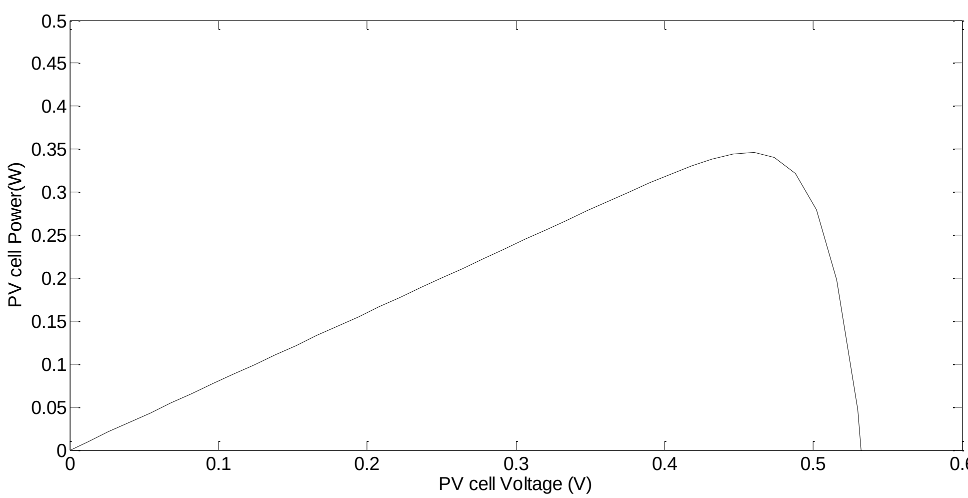


Fig 3.4 Power Voltage curve of PV cell

3.4 SIMULATION OF PV MODULE

For the majority of applications multiple solar cells need to be connected in series or in parallel to produce enough voltage and power. Individual cells are usually connected into a series string of cells (typically 36 or 72) to achieve the desired output voltage. The simulink model of PV module is given in Figure 3.5 and its subsystem is presented in Figure 3.6.

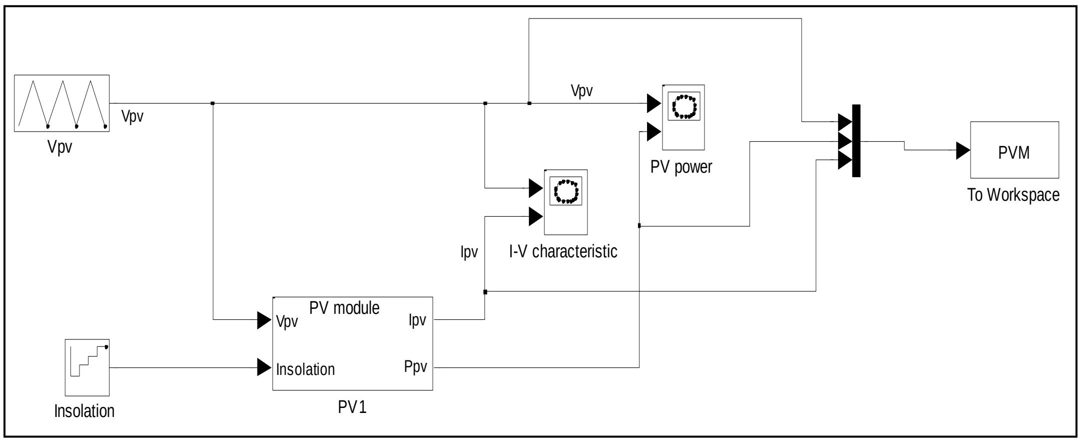


Fig.3.5 Simulink model of a PV Module

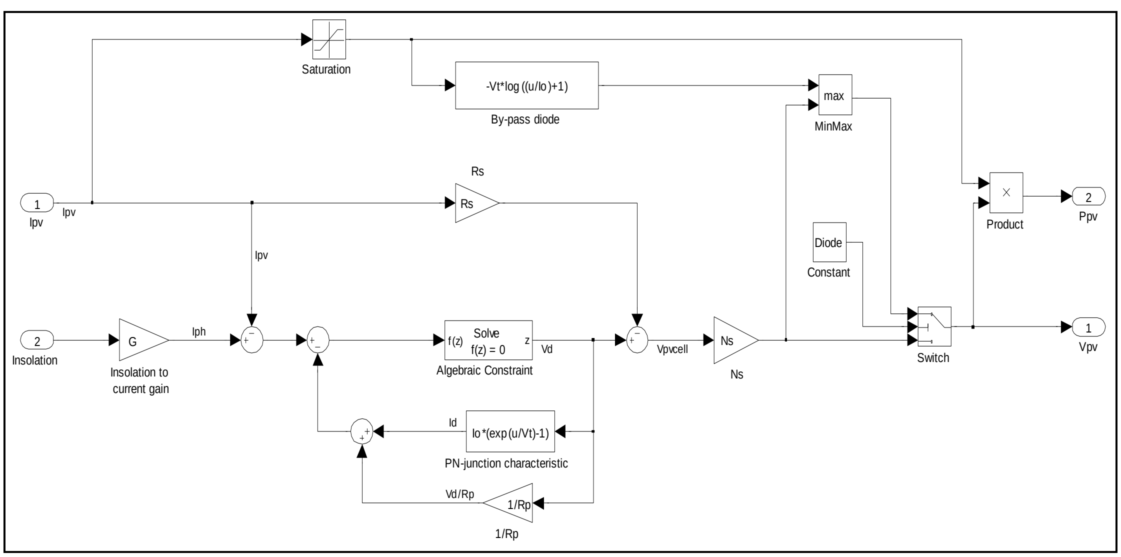


Fig.3.6 Subsystem of a PV Module

3.4.1 Result of PV Module Simulation

In this PV module the inputs are voltage V_{PV} and different insolation level i.e 400, 600, 800,1000 W/M^2 respectively. The rated voltage magnitude is 25V. The output of the module is current I_{PV} and power P_{PV}. The output of the I-V characteristic of PV module and its P-V characteristic is shown in Figure 3.7 and 3.8 respectively.

As shown in Figure 3.7 as the solar insolation level is increases from 400 W/m^2 to 1000W/m^2, the module output current is increases from 2.2A to 5.5A.While there is a very small change in output voltage.The maximum output power of the module is obtained when the solar insolation is 1000W/m^2 which is about 85 watts.

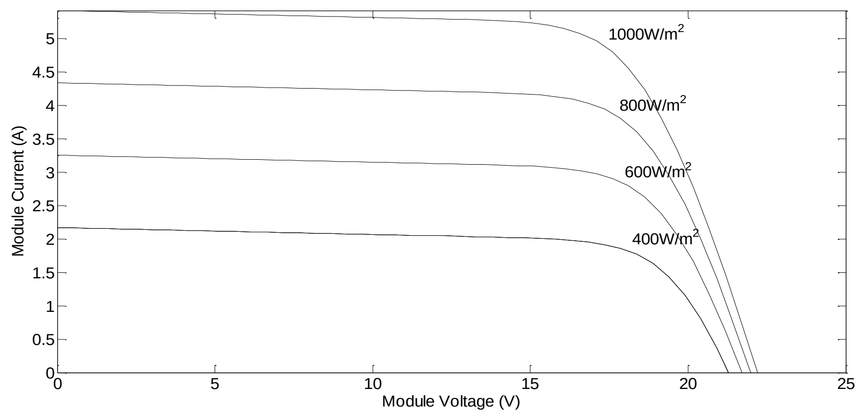


Fig 3.7 Current-voltage characteristics of PV module at different insolation level

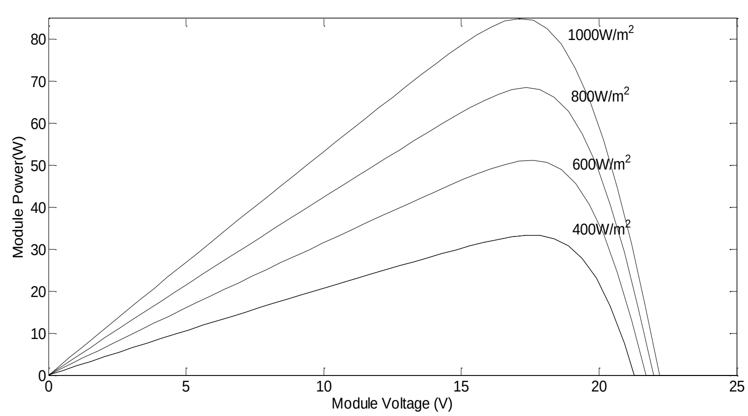


Fig.3.8 Power-Voltage characteristics of PV module

3.5 SIMULATION OF PV ARRAY

The six PV module are connected in series in order to obtained more voltage and power. If the requirement is more current then connect the PV module in parallel. The Figure 3.9 shows the PV array model in which six modules are connected in series in order to obtained the maximum voltage and the insolation level on each modules are same i.e 1000W/m^2.

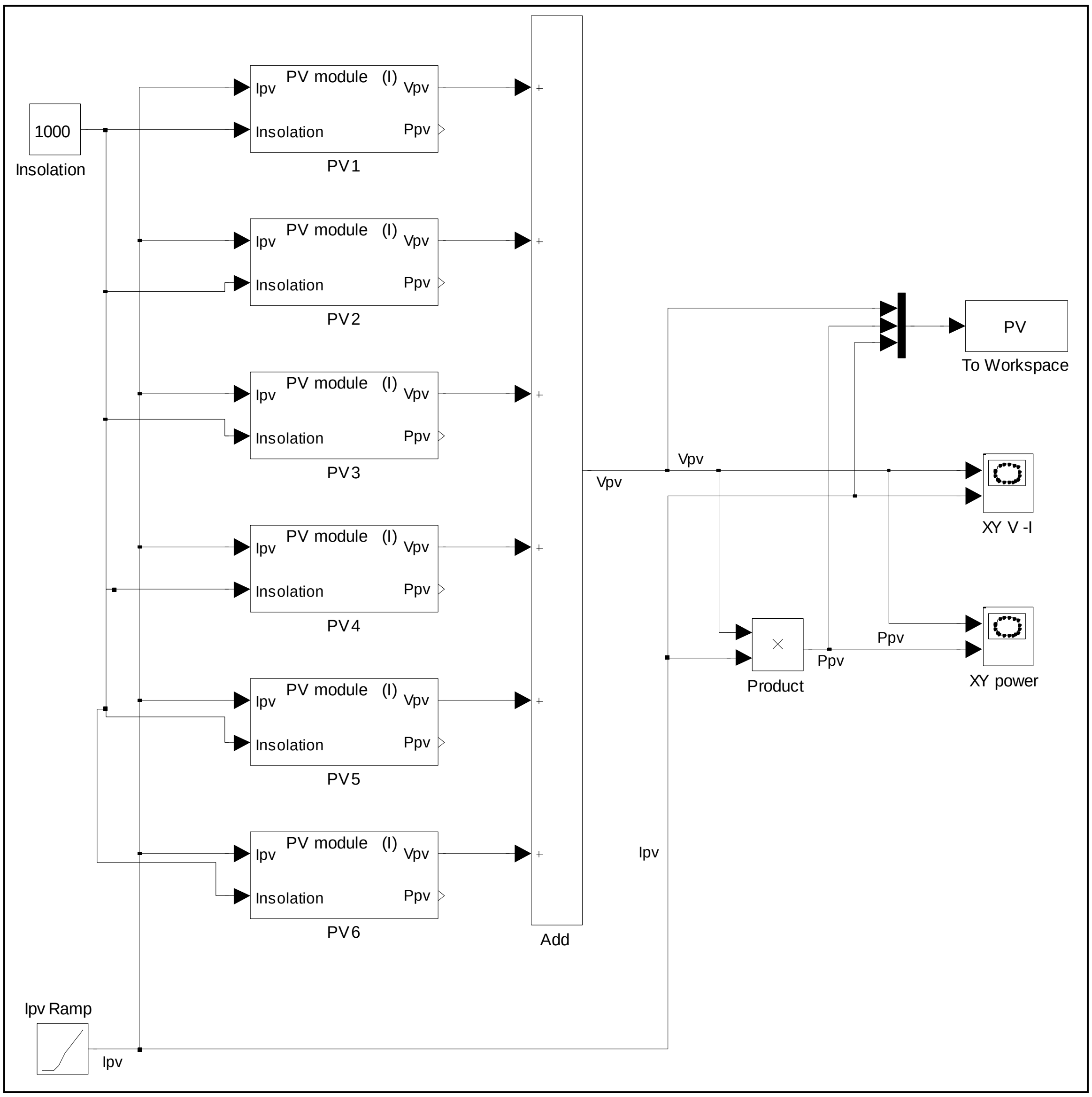


Fig.3.9 Simulink Model of PV Array

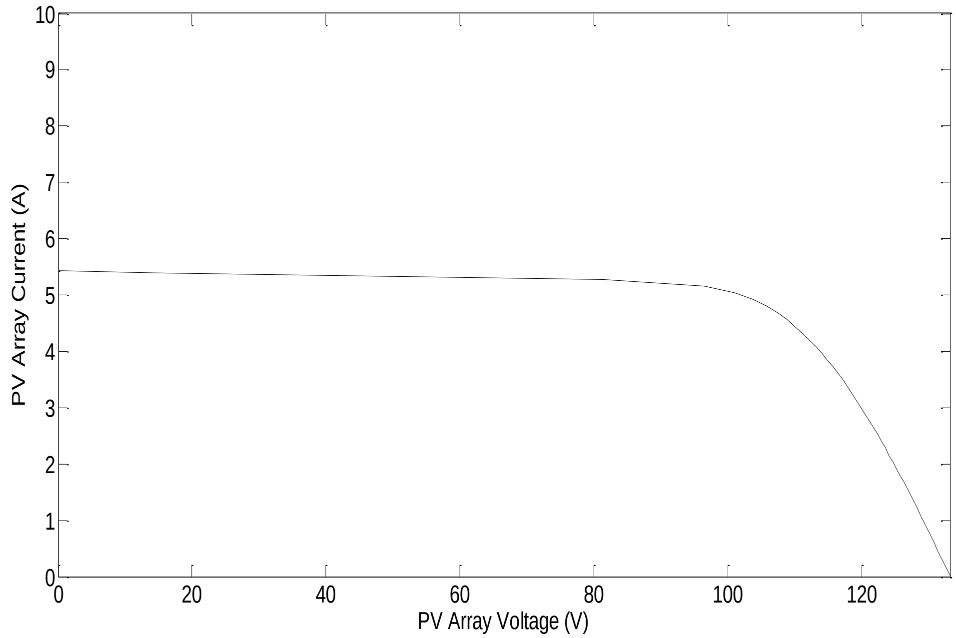


Fig 3.10 Current-voltage characteristics of PV Array

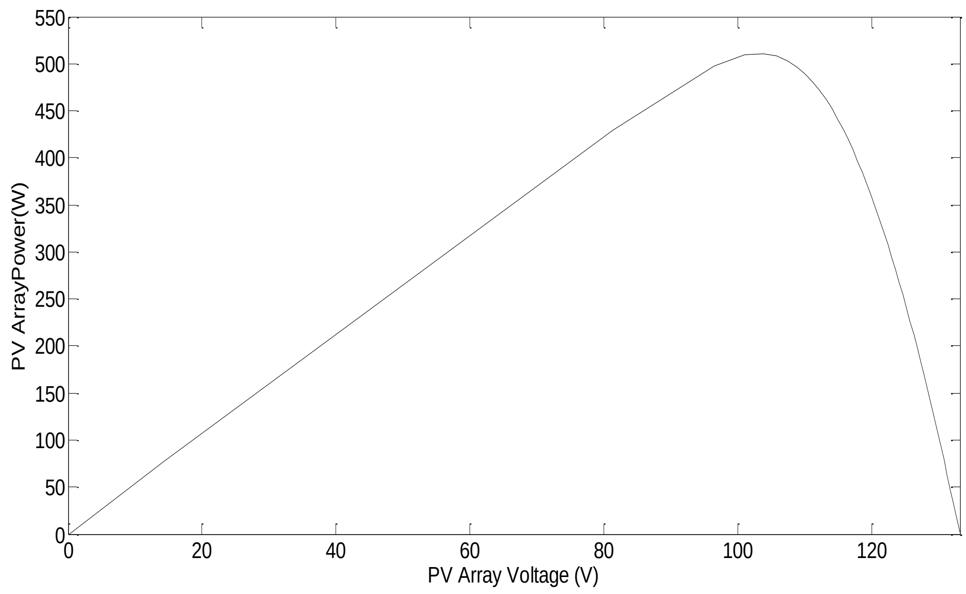


Fig 3.11 Power-voltage characteristics of PV Array

3.5.1 Simulation Result of PV Array

In the Figure 3.9 all the six module receive equal amount of solar insolation level which is 1000W/m^2. In this case maximum power at the knee of the curve in Figure 3.11 is 510.7 W and the voltage is 103.8 V. If there is a shade on any of the module then it will provide a high impedance, to avoid this there is a bypass diode.

As shown in the Figure 3.12 If there is a shadow on some part of the PV module then the insolation level will not same on all the module and hence the output power will reduce. In the above model if the insolation level is 400W/m^{2}and 700W/m^2 respectively, then the output power obtained is 334 W and the voltage is 67V.

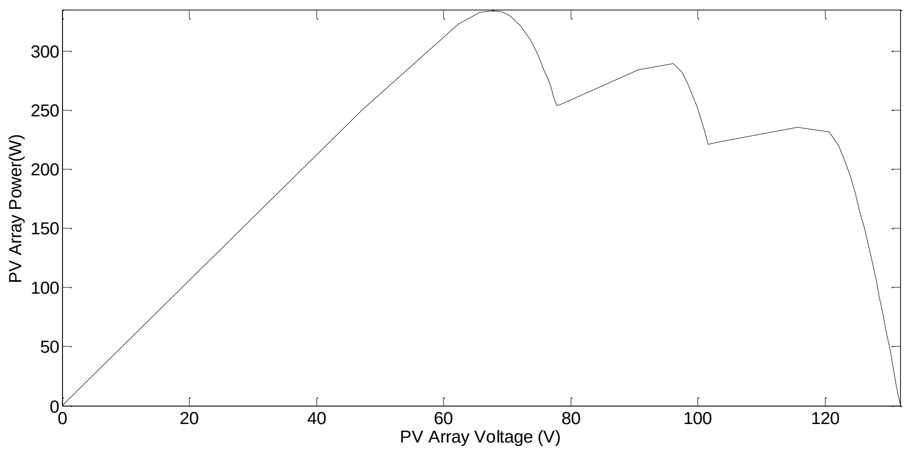


Fig.3.12 Power-Voltage Characteristics of PV Array Under Shadow

3.6 CONCLUDING REMARK

A general PV models which are representative of the all PV cell, module, and array have been developed with MATLAB/SIMULINK.. The proposed model takes sunlight irradiance as input parameters and outputs the I-V and P-V characteristics. The effect of the shadow on the array can be easily observed by reducing the insolation level on PV module. Such PV module can be used as simulink block library for case of modeling and simulation under MATLAB/SIMULINK environment.

CHAPTER 4

GENERATION SCHEDULING CONSIDERING SOLAR ENERGY

4.1 INTRODUCTION

In recent years, environmental concerns have significantly increased the pressure for cleaner and more efficient generation of electricity. In European countries, there are requirements to produce a certain amount of electricity from renewable generation. Solar power is expected to contribute significantly to the renewable energy targets owing to advancements in PV technologies, falling capital costs, abundance of the free resource and commercial viability.

In order to maintain a high degree of economy and reliability of the power system, economic dispatch is one of the options available to the utility companies. It allocates the total power demand among the online generating units in order to minimize the cost of generation while satisfying pertinent system constraints. The important factors that influence economic operation of the system are operating efficiency of generating units, fuel and operating cost, and transmission losses. GA method is an effective method for solving various cases of the generation scheduling problem in power systems. Genetic algorithms are stochastic search techniques based on the mechanism of natural selection and survival of the fittest. Also, they combine solution evaluation with randomized, structured exchanges of information among solutions to obtain optimality. As a robust and powerful adaptive tool for solving search and optimization problems, they have been applied to various power system problems such as economic dispatch, unit commitment, reactive power control etc.

This chapter discusses the brief review of economic load dispatch with losses and genetic algorithm. The two case studies are used in order to investigate the impact of renewable energy (solar power) on the load dispatching calculation.

4.2 GENERATION SCHEDULING

Generation scheduling methodologies are mainly based on minimizing power system operation costs subject to system security. It is the process of allocating generation levels to the generating units, so that the system load is supplied entirely and most economically. The objective of generation dispatch problem is to minimize the overall cost of generation, i.e.

Minimize

$$C_t = \sum_{i=1}^{NG} C_i \tag{4.1}$$

Where NG is the set of dispatchable generating units.

Subjected to,

$$\sum_{i=1}^{NG} P_i = P_D + P_L \tag{4.2}$$

$$P_i^{min} \leq P_i \leq P_i^{max} \qquad i=1,2\ldots..NG$$

The cost of generating unit C_i is expressed as

$$C_i = a_i P_i^2 + b_i P_i + C_i \tag{4.3}$$

Where

a_i, b_i, c_i are cost coefficients for unit i,

C_t= total cost of generation

P_D = load demand

P_L = total system transmission loss

Pi = generation of ith plant and

P_i^{max}, P_i^{min} = minimum and maximum generating limits respectively for plant i

Transmission losses may be neglected when transmission losses are very small but in a large interconnected network where power is transmitted over long distances, transmission losses are a major factor and affect the optimum dispatch of generation. One common practice for including the effect of transmission losses is to express the total transmission loss as a quadratic function of the generator outputs as

$$P_L = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_i B_{ij} P_i \tag{4.4}$$

4.3 REVIEW OF GENETIC ALGORITHM

Genetic algorithm is a search method that employs processes found in natural biological evolution. These algorithms search or operate on a given population of potential solutions to find those that approach some specification or criteria. To do this, the genetic algorithm applies the principle of survival of the fittest to find better and better approximations. Genetic algorithm (GAs) were invented by John Holland in the 1960s and were developed with his students and colleagues at the University of Michigan. GA is a method for deriving from one population of "chromosomes" (e.g., strings of ones and zeroes, or bits) a new population. This is achieved by employing "natural selection" together with the genetics inspired operators of recombination (crossover), mutation, and inversion. Each chromosome consists of genes(e.g. bits), and each gene is an instance of a particular allele(e.g,0 or 1).The selection operator chooses those chromosomes in the population that will be allowed to reproduce, and on average those chromosomes that have a higher fitness factor(defined bellow),produce more offspring than the less fit ones. Crossover swaps subparts of two chromosomes, roughly imitating biological recombination between two single chromosome ("haploid") organisms; mutation randomly changes the allele values of some locations (locus) in the chromosome; and inversion reverses the order of a contiguous section of chromosome.

4.3.1 Operators of Genetic Algorithm

A basic genetic algorithm comprises three genetic operators are selection, crossover, and mutation. Starting from an initial population of strings (representing possible solutions),the GA uses these operators to calculate successive generations. First, pairs of individuals of the current population are selected to mate with each other to form the offspring, which then form the next generation.

4.3.1.1Selection

This operator selects the chromosome in the population for reproduction. The more fit the chromosome, the higher its probability of being selected for reproduction.

The various methods of selecting chromosomes for parents to crossover are Roulette-wheel selection**,** Boltzmann selection**,** Tournament selection**,** Rank selection**,** Steady-state selection. The roulette-wheel and tournament selection are explain briefly.

Roulette-Wheel Selection: The commonly used reproduction operator is the proportionate reproductive operator where a string is selected from the mating pool with a probability proportional to F_i where F_i is the fitness value for that string. Since the population size is usually kept fixed in a simple GA, The sum of the probabilities of each string being selected for the mating pool must be one. The probability of the i^{th} selected string is

$$p_i = \frac{F_i}{\sum_{j=1}^{n} F_j}$$

Tournament Selection: GA uses a strategy to select the individuals from population and insert them into a mating pool. Individuals from the mating pool are used to generate new offspring, which are the basis for the next generation. As the individuals in the mating pool are the ones whose genes will be inherited by the next generation, it is desirable that the mating pool consists of good individuals .A selection strategy in GA is simply a process that the mating pool consists of good individuals .A selection strategy selection strategy in GA is simply a process that favors the selection of better individuals in the population for the mating pool.

4.3.1.2 Crossover

The cross over operator involves the swapping of genetic material (bit-values) between the two parent strings. This operator randomly chooses a locus (a bit position along the two chromosomes) and exchanges the sub-sequences before and after that locus between two chromosomes to create two offspring. For example, the strings 1110 0001 0011 and 1000 0110 0111. The crossover operator roughly imitates biological recombination between two haploid (single chromosome) organisms. The crossover may be a single bit cross over or two bit cross over. In case of two bit crossover two points are chosen where the binary digits are swapped.

4.3.1.3 Mutation

The two individuals (children) resulting from each crossover operation will now be subjected to the mutation operator in the final step to forming the new generation. This operator randomly flips or alters one or more bit values at randomly selected locations in a chromosome. For example, the string 1000 0001 0011 might be mutated in its second position to yield 1**1**00 0001 0011. Mutation can occur at each bit position in a string with some probability and in accordance with its biological equivalent; usually this is very small, for example, 0.001. If 100% mutation occurs, then all of the bits in the chromosome have been inverted. The mutation operator enhances the ability of the GA to find a near optimal solution to a given problem by maintaining a sufficient level of genetic variety in the population, which is needed to make sure that the entire solution space is used in the search for the best solution. In a sense, it serves as an insurance policy; it helps prevent the loss of genetic material.

GAs operate with coded versions of the problem parameters rather than parameters themselves i.e., GA works with the coding of solution set and not with the solution itself. Almost all conventional optimization techniques search from a single point but GAs always operate on a whole population of points(strings) i.e., GA uses population of solutions rather than a single solution for searching. This plays a major role to the robustness of genetic algorithms. It improves the chance of reaching the global optimum and also helps in avoiding local stationary point. GA uses fitness function for evaluation rather than derivatives. As a result, they can be applied to any kind of continuous or discrete optimization problem. The key point to be performed here is to identify and specify a meaningful decoding function. GAs use probabilistic transition operates while conventional methods for continuous optimization apply deterministic transition operates i.e., GAs does not use deterministic rules. The flowchart of the genetic algorithm is given in Figure 4.1.

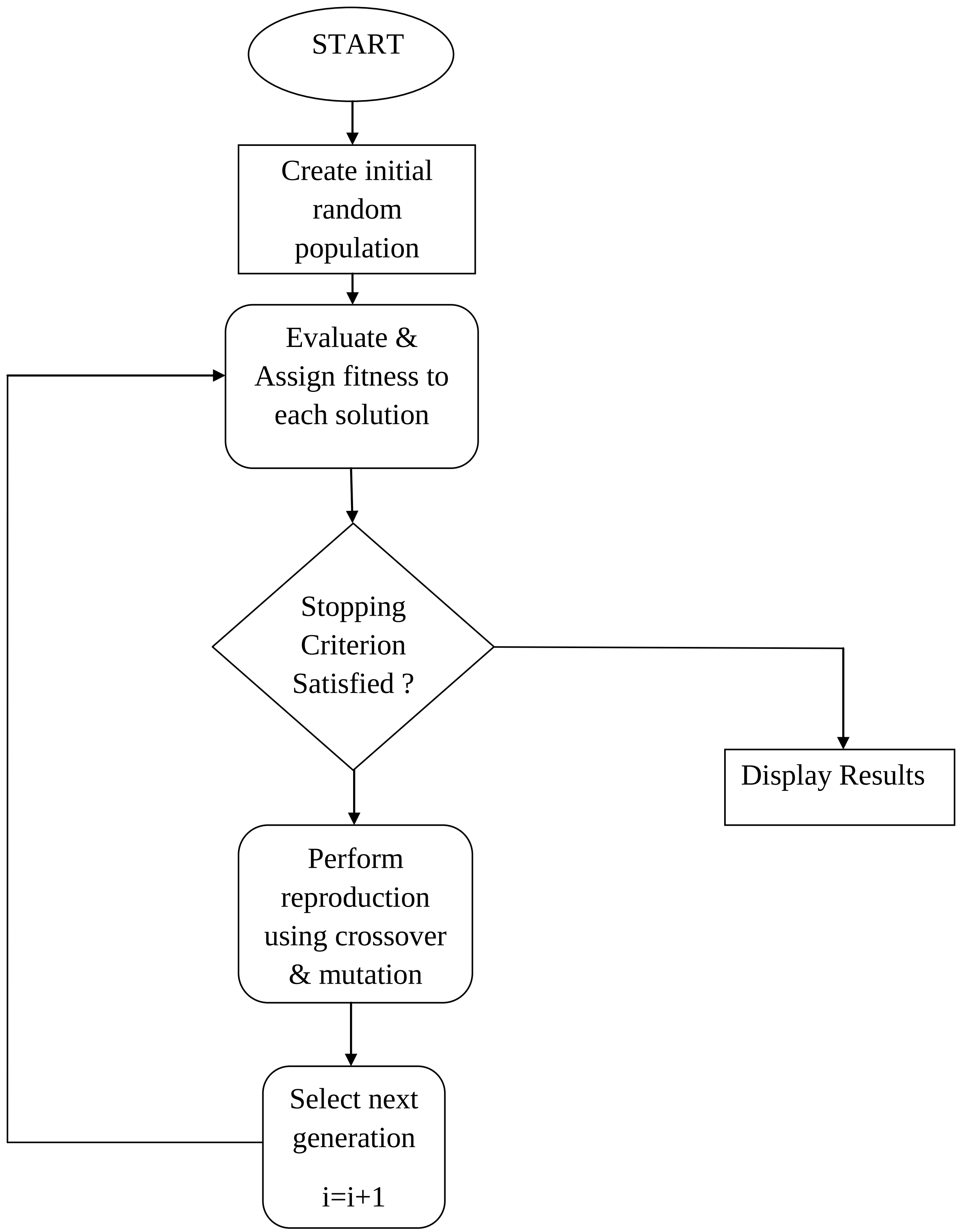


Fig.4.1 Flowchart of Genetic Algorithm

4.4 FORECASTING OF SOLAR RADIATION

Detailed information about the availability of solar radiation on horizontal surface is essential for the optimum design and study of solar energy conversion system. Total daily solar radiation is considered as the most important parameter in the performance prediction of renewable energy systems, particularly in sizing photovoltaic (PV) power and solar heating systems. The global solar radiation increases from the sunrise till noon and decreases till sundown. With the increase of the atmospheric haze the global solar radiation decreases especially for large sun heights. Because of cloudiness influence during the warm part of the year the global solar radiation after noon is lower compared to before noon at one and the same sun height. Daily amounts of solar radiation are minimal in December and maximal in July. The limits, in which the daily amounts of the global solar radiation are changing, are small in winter. This is due to the small sun height and the considerable cloudiness. In summer, when sun height is large, the variability of the solar radiation and cloudiness are larger, the annual amounts of global solar radiation are varying in larger limits.

4.4.1 Methods of Predicting the Availability of Solar Radiation

Several empirical formulas have been developed to calculate the global solar radiation using various parameters. These parameters includes, the sunshine hours, the relative humidity and sunshine hours, the declination angle and the latitude, sunshine duration, Relative humidity and max. Temperature. Among the above mentioned empirical models, the most popular is the regression equation of the Angstrom type model.

For the forecasting of monthly average daily global radiation the amount of sunshine can be related by linear relation of the form.

$$\frac{\overline{H_g}}{\overline{H}_0} = a + b\left(\frac{\bar{S}}{\bar{S}_{max}}\right) \tag{4.5}$$

Where,

$\overline{H}_g$ = monthly average of the daily global radiation on a horizontal surface at a location (kJ/m^2)

$\overline{H}_O$ = monthly average of the daily extra-terrestrial radiation which could be fall on a horizontal surface at the location under consideration.

$$S_{max} = \frac{2}{15}\cos^{-1}(-\tan^{-1}\emptyset\tan\delta) \tag{4.6}$$

Where,

$\bar{S}_{max}$ = monthly average of the maximum possible sunshine hours per day at the location

$\bar{S}$.= monthly average of sunshine hours per day at the location

a, b =constant obtained by fitting data

Value of a and b have been obtained for 17 Indian cities which is given in Appendix A.

For equation (4.5), $\overline{H}_o$ is the mean of the value H_o for each day of the month, where H_o is given as

$$H_O = \frac{24}{\pi} I_{SC}\left(1 + 0.033\frac{360n}{365}\right)(\omega_S \sin\emptyset\sin\delta + \cos\emptyset\cos\delta\cos\omega_S) \tag{4.7}$$

Where I_{SC} is the solar constant, $\emptyset$ is the latitude , δ is the solar declination and ω_S is the sunset hour angle and n is the day of year.

$$\delta = 23.45\sin\left[(284+n)\times\frac{360}{365}\right] \tag{4.8}$$

And,

$$\cos\omega_S = -\tan\emptyset\tan\delta \tag{4.9}$$

For predicting the variation of the monthly average hourly global radiation at a location the daily global radiation can be related by linear relation of the form.

$$\frac{\bar{I}_g}{\overline{H}_g} = (a + b\cos\omega)\left(\frac{\bar{I}_0}{\overline{H}_O}\right) \tag{4.10}$$

Where,

$\bar{I}_g$ = monthly average of the hourly global radiation on a horizontal surface at a location (kJ/m^2-h).

$\bar{I}_o =$ monthly average of the hourly extra-terrestrial radiation which could be fall on a horizontal surface at the location under consideration(kJ/m^2-h).

For the equation (4.10) the value of *a* and *b* can be obtained by using the given equation

$$a = 0.409 + 0.5016\sin(\omega_s - 60^0) \tag{4.11}$$

$$b = 0.6609 - 0.4767\sin(\omega_s - 60^0) \tag{4.12}$$

$\bar{I}_0$ is the mean of the value I_O, where I_O is given as

$$I_O = 1.367\left(1 + 0.033\cos\frac{360n}{365}\right)(\sin\emptyset\sin\delta + \cos\emptyset\cos\omega_S) \tag{4.13}$$

With the help of the above equations the monthly average hourly global radiation and the daily global radiation can be forecasted.

4.4.2 Algorithm of Forecasting the Solar Radiation

The hourly output of a PV generating unit varies with time. This is an important factor in the reliability evaluation of these systems. Calculation of the available power from a PV conversion system (PVCS) involves modeling the solar radiation available on the earth at the site location in order to provide the necessary radiation data. The radiation data then can be converted into electric power. The algorithm for solar radiation forecasting, which is shown in Figure 4.2, can be briefly described as follows:

1. Calculate the radiation at the horizontal surface based on the day of the year and the site latitude and then establish a clearness index.
2. The clearness index is then used to calculate the direct, diffuse and random components of the radiation on a horizontal surface.
3. The total radiation is then calculated from the direct, diffuse and random values.

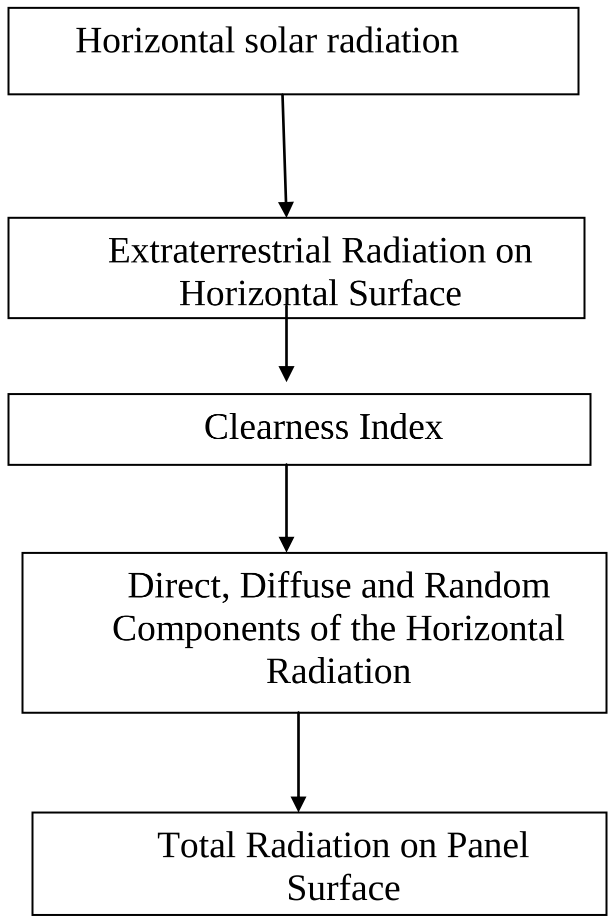


Fig.4.2 Flowchart for Calculating Solar Radiation

4.5 PROBLEM FORMULATION

The generation system under study is comprised of thermal system and solar energy systems. The objective of the short-term generation scheduling problem considering solar energy systems is to determine the optimal amounts of generation power for the thermal units and solar energy systems over the study period so that the total thermal unit fuel cost is minimized subject to power balance equations. The study period is divided into T time intervals and the short-term generation scheduling problem can be formulated as follows.

Minimize

$$C_t = \sum_{i=1}^{NG} C_i \tag{4.14}$$

where NG is the set of dispatchable generating units.

The fuel cost of the i^{th} thermal unit can be expressed as a quadratic function of real power generation,

$$C_i = a_i P_i^2 + b_i P_i + c_i \tag{4.15}$$

a_i, b_i, c_i are cost coefficients for unit i,

C_t= total cost of generation

P_i = generation of i^{th} plant

Subject to,

$$\sum_{i=1}^{NG} P_i = P'_D + P_L \tag{4.16}$$

$$P_i^{min} \le P_i \le P_i^{max}$$

Where ,

$$P'_D = P_D - P_S$$

The problem consists in extracting the maximum of power from the renewable source P_S. Then slice this power of the total demand P_D. The remaining total demand P'_D distributed between the thermal power stations.

P_D = load demand

P_L = total system transmission loss

P_S= solar power

P_i^{max} ,P_i^{min} = minimum and maximum generating limits respectively for plant i.

The system load demand and solar radiation must be known before the generation scheduling problem can be performed. These values can only be known through short-term forecasting. A genetic algorithm is then used to determine an optimal solution.

4.6 RESULT AND DISCUSSION

In this section, the results of generation scheduling considering solar energy system after the implementation of GA are discussed. The algorithms are implemented in MATLAB to solve optimization problem. The main objective is to determine the optimal amounts of generation power for the thermal units and solar energy systems over the study period so that the total thermal units fuel cost are minimized. The performance is evaluated with and without solar energy system for two set generator data, which are referred as Case I and Case II.

Case I: Six generator test system.[30]

Case II: Three generator test system.[31]

4.6.1 Case I : Six- Generator Test System

The specifications of six generator test system are detailed in given Tables 4.1. The coefficients of fuel cost and the maximum and minimum power limits are given in below Table 4.1(a) and loss coefficient matrix B_{ij} is given in Table 4.1(b).The power demand [32] and monthly average hourly global solar radiation data of 13 hours (6 am-6pm) of the three months are given in Table 4.2.

The result of the generation scheduling corresponding to the month of February, June and November are detailed in section (4.6.1.1), (4.6.1.2), and (4.6.1.3) respectively.

UNIT	P_i^{min} (MW)	P_i^{max} (MW)	a_i ($)	b_i ($/MW)	c_i ($/MW^2)
1	100	500	240	7.0	0.0070
2	50	200	200	10.0	0.0095
3	80	300	220	8.5	0.0090
4	50	150	200	11.0	0.0090
5	50	200	220	10.5	0.0080
6	50	120	190	12.0	0.0075

(a)

0.0017	0.0012	0.0007	-0.0001	-0.0005	-0.0002
0.0012	0.0014	0.0009	0.0001	-0.0006	-0.0001
0.0007	0.0009	0.0031	0.00	-0.0010	-0.0006
-0.0001	0.0001	0.000	0.0024	-0.0006	-0.0008
-0.0005	-0.0006	-0.0010	-0.0006	0.0129	-0.0002
-0.0002	-0.0001	-0.0006	-0.0008	-0.0002	0.0150

(b)

TABLE-4.1. Specifications of 6-generator test system

(a) Cost coefficients and power limits

(b) Loss coefficients

Table 4.2 Load Demand and Solar Radiation Data

TIME	FEBRUARY		JUNE		NOVEMBER	
	Load Demand (MW)	Solar Radiation (W/m^2)	Load demand (MW)	Solar radiation (W/m^2)	Load Demand (MW)	Solar Radiation (W/m^2)
6	1342	0	925	40	863	0
7	1342	41	912	102	880	27
8	1377	222	982	277	882	158
9	1382	425	964	455	890	316
10	1384	594	1007	619	885	450
11	1381	744	1014	730	794	533
12	1385	836	1020	783	878	577
13	1387	833	1021	772	894	569
14	1393	772	1011	683	900	513
15	1379	647	1014	555	882	422
16	1392	455	1015	400	881	294
17	1395	230	1020	233	884	144
18	1366	38	995	86	884	22

The Figure 4.3 presented the daily load demand graph of the three months i.e February, June and November. It has been observed that the power demand during the month of February is more than the month of June and November.

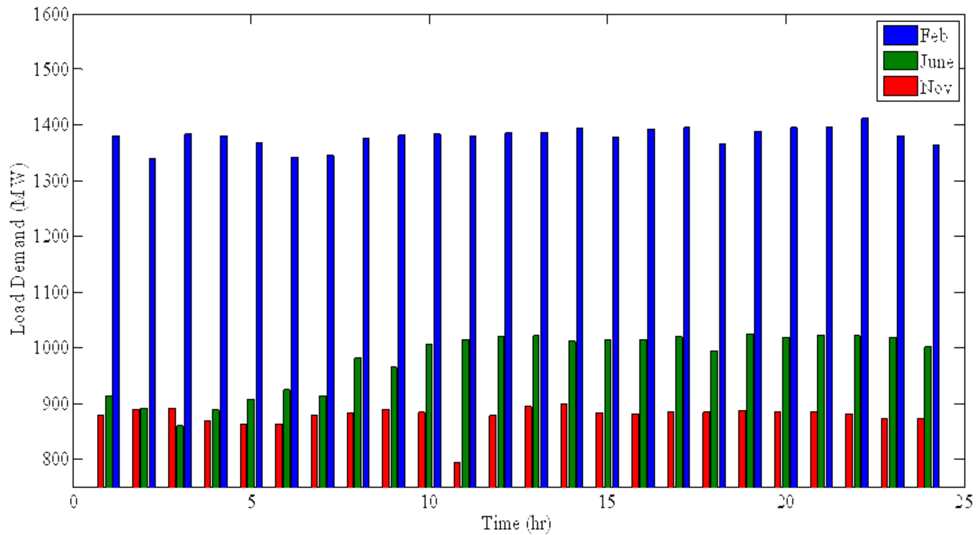


Fig.4.3 Daily Load Demand Graph of Three Months

The Figure 4.4 represent the monthly average hourly global solar radiation of the three month. In all the three month the solar radiation is increses from the sunrise till noon and decreses till sunset. In the month of Februrary the solar radiation level is more in comparision with the other two month.

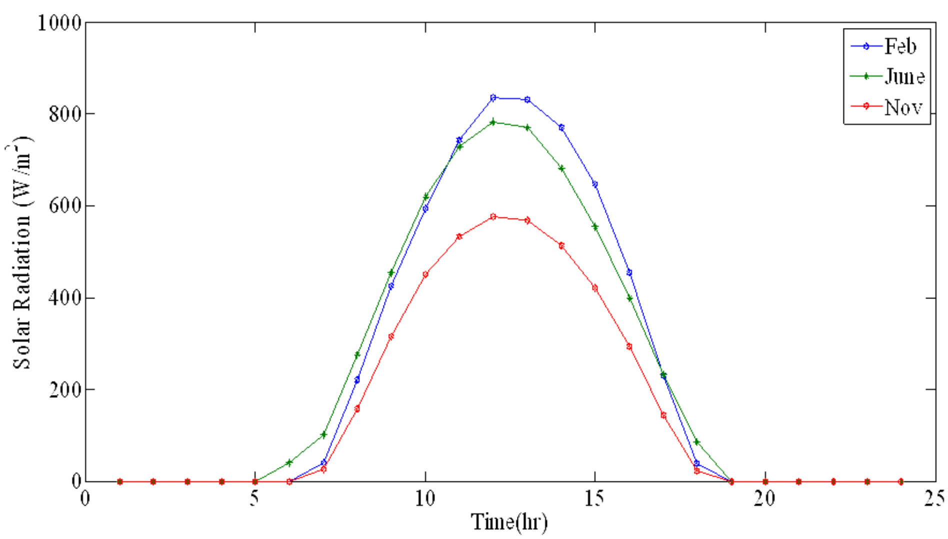


Fig4.4 Solar Radiation Graph of Three Months

4.6.1.1Optimum Solution for the Month of February

Developed program returns the systems generated power P, fuel cost and the losses. The simulated results of the generation scheduling are shown below. Here we considered two cases thermal units with solar unit and without solar unit. The rating of the PV module is 300W and the number of PV modules are 1000000. The load demand and solar radiation data of 12 hours for the February month is given in Table 4.2.

Table.4.3 Generation Scheduling With Solar Power

TIME (hr)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	Psolar (MW)	P loss (MW)	Fuel Cost($/hr)
7	459.86	179.99	279.75	150.00	177.32	99.56	12.30	13.79	16470
8	458.85	173.35	267.11	150.00	173.46	101.69	66.66	13.28	16080
9	441.04	172.42	260.88	150.00	163.81	78.39	127.50	12.06	15330
10	435.00	160.61	265.54	123.76	153.80	78.53	178.20	11.06	14679
11	425.84	160.15	240.85	121.05	149.12	71.30	223.20	10.53	14036
12	420.30	152.88	245.55	112.64	148.41	64.66	250.80	10.27	13725
13	421.90	150.83	249.58	114.98	139.53	70.47	249.90	10.21	13760
14	422.49	161.04	251.93	119.74	147.45	69.36	231.60	10.64	14083
15	429.12	161.97	253.39	124.39	152.28	74.75	194.10	11.02	14395
16	448.81	173.10	267.14	130.78	163.13	84.92	136.50	12.39	15340
17	460.32	177.07	274.83	149.20	179.13	99.11	69.00	13.68	16302
18	468.33	187.68	272.57	150.00	184.28	106.06	11.40	14.33	16690

From Table 4.3, it can be summarized as :

Total fuel cost is 180890 $/hr and average fuel cost is 15074.16 $/hr.

Total power loss is 143.26 MW and average power loss is 11.93 MW.

Total solar power generated is 1751MW and average solar power generated is 145.9 MW

Table.4.4 Generation Scheduling Without Solar Power

TIME (hr)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P loss (MW)	Fuel Cost($/hr)
7	461.41	184.51	274.91	150.00	185.53	102.75	14.14	16560
8	471.51	193.27	282.52	150.00	187.41	107.13	14.86	17007
9	472.79	191.45	280.04	150.00	200.00	102.84	15.14	17079
10	464.95	200.00	279.82	150.00	200.00	104.38	15.16	17108
11	475.55	191.42	287.79	150.00	182.82	108.25	14.91	17060
12	470.88	185.11	281.39	150.00	200.00	112.85	15.24	17120
13	477.79	200.00	284.80	150.00	182.44	106.97	15.02	17140
14	473.20	192.06	300.00	150.00	185.90	107.05	15.22	17230
15	471.48	200.00	285.20	150.00	186.72	100.47	14.88	17036
16	480.67	194.34	285.41	150.00	187.80	108.96	15.20	17217
17	476.39	200.00	287.44	150.00	184.92	111.47	15.23	17250
18	468.02	185.46	288.43	150.00	186.45	102.25	14.62	16855

The results of the six generation system without solar power have summarized as:

Total fuel cost is 204662$/hr and the average fuel cost is 17055.16 $/hr

Total power loss is 179.8 MW and average power loss is 14.98 MW.

It has observed from the above Table 4.3 and Table 4.4 that when solar power system operating with six generator systems then there is a reduction in total and average fuel cost and power loss.

The Figure 4.3 presented the power generated curve of six thermal unit (PG1 to PG6) with and without solar unit (PS). The solar unit power output increases from morning till noon and then it decreases after noon, during this period the requirement of the power generation from thermal unit is reduced.

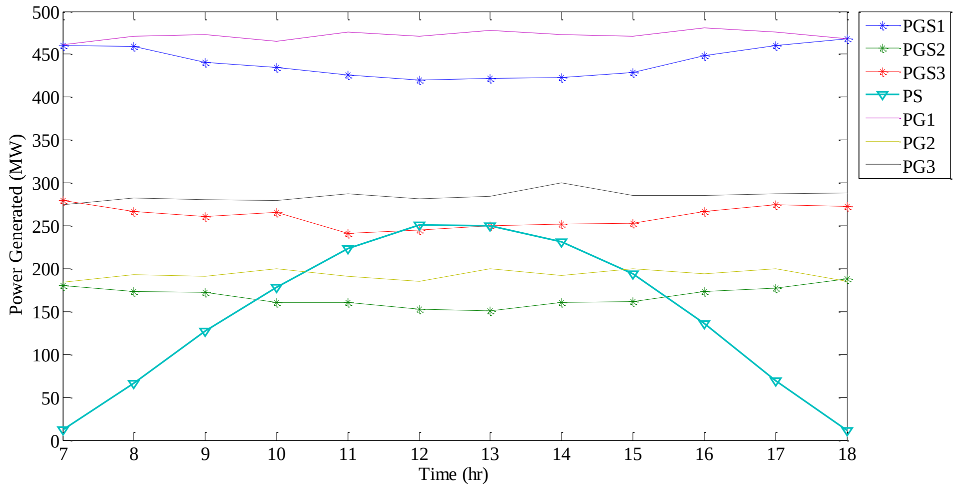


Fig.4.5(a) Power Generated With And Without Solar Power

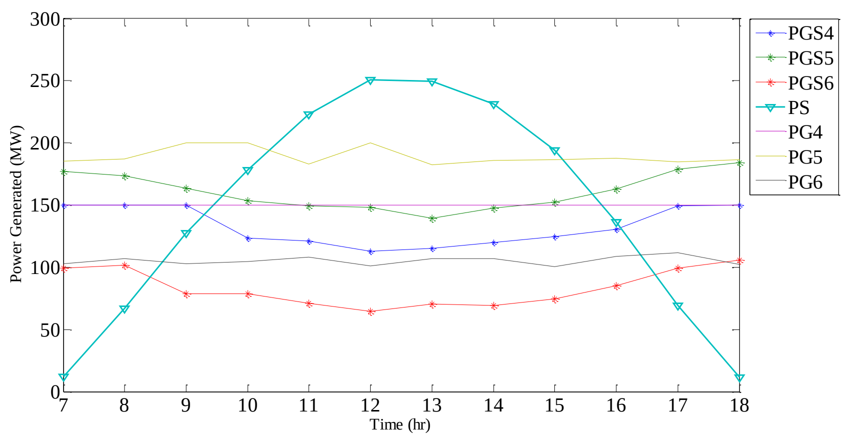


Fig.4.5(b) Power Generated With And Without Solar Power

PGS: Power generated with solar unit

PG: Power generated without solar unit

The Figure 4.4 shown that there is reduction in power losses when solar unit is also generated power. At noon power loss with solar unit is minimum in comparison with morning and evening.

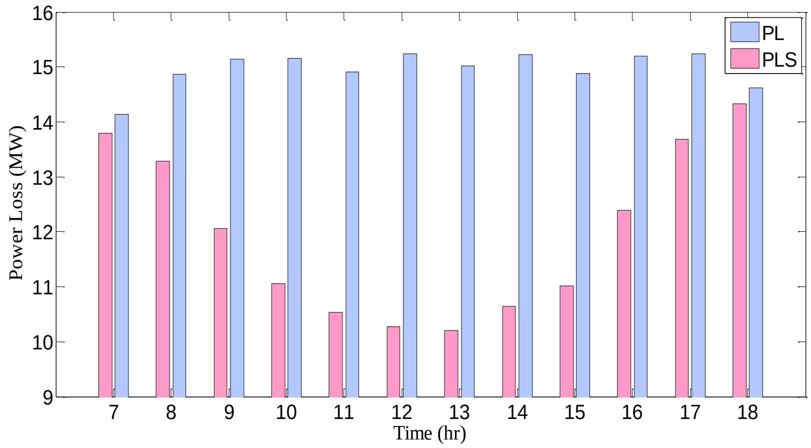


Fig.4.6 Power Loss With And Without Solar Power

PLS: Power loss with solar unit

PL: Power loss without solar unit

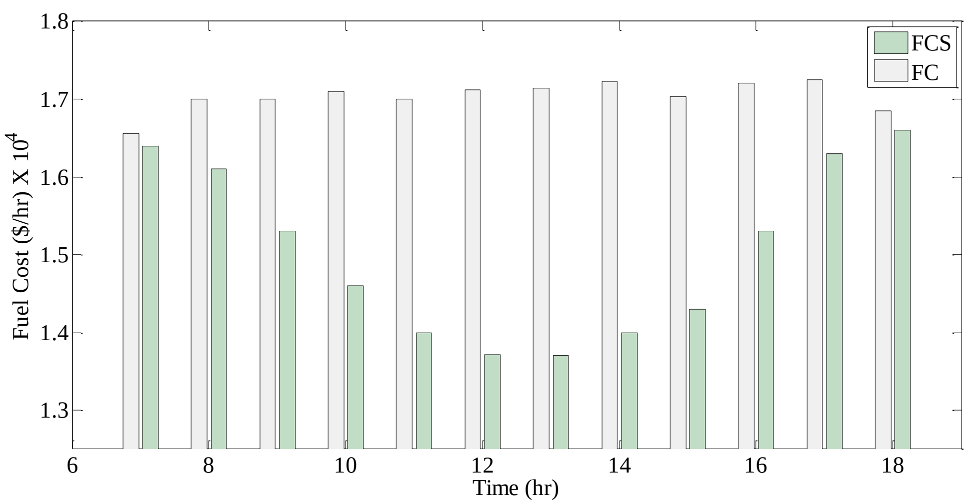


Fig.4.7 Fuel Cost With And Without Solar Power

FCS: Fuel cost with solar unit

FC: Fuel cost without solar unit

4.6.1.2 Optimum Solution for the Month of June

The simulated results of the generation scheduling are shown in Table 4.5. Here we considered two cases thermal units with solar unit and without solar unit. The rating of the PV module is 300W and the number of PV modules are 1000000. The load demand and solar radiation data of 12 hours for the June month is given in Table 4.2.

Table 4.5 Generation Scheduling With Solar Power

TIME (hr)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	Psolar (MW)	P loss (MW)	Fuel Cost($/hr)
7	373.02	109.25	190.84	72.02	91.48	51.16	30.60	6.39	10511
8	365.03	107.66	199.00	70.47	112.25	51.18	83.10	6.71	10726
9	354.79	102.66	186.00	53.71	85.81	50.32	136.50	5.83	9853
10	343.44	105.08	181.56	57.02	88.72	51.13	185.70	5.66	9779
11	338.05	100.74	179.86	50.91	80.54	50.26	219.00	5.38	9463
12	337.49	91.12	176.42	52.36	81.92	50.98	234.90	5.22	9345
13	344.57	90.92	181.48	50.85	76.62	50.27	231.60	5.33	9396
14	346.72	98.49	177.36	54.35	84.46	50.19	204.90	5.49	9596
15	352.36	103.02	190.58	69.23	87.89	50.31	166.50	5.91	10096
16	366.03	114.80	200.68	68.12	101.99	50.02	120.00	6.60	10670
17	374.64	123.54	211.01	80.08	118.06	50.16	69.90	7.42	11361
18	381.83	131.99	208.24	84.68	116.56	53.50	25.80	7.63	11602

For six generation test system with solar power the results are obtained as :

Total fuel cost is 122398 $/hr and average fuel cost is 10199.8 $/hr

Total power loss is 73.57 MW and average power loss is 6.13 MW

Total solar power generated is 1706MW and average solar power generated is 142 MW

Table 4 .6 Generation Scheduling Without Solar Power System

TIME (hr)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P loss (MW)	Fuel Cost($/hr)
7	372.45	113.75	199.98	77.52	104.92	50.16	6.809	10886
8	383.30	122.74	220.25	93.92	116.16	53.33	7.74	11736
9	386.34	127.13	207.99	85.11	109.57	55.36	7.52	11537
10	395.15	131.31	222.85	92.84	123.01	50.04	8.23	12078
11	391.83	138.86	222.66	96.21	120.80	51.88	8.26	12168
12	396.88	132.55	223.89	98.86	126.12	50.06	8.38	12244
13	401.88	132.82	225.96	89.61	127.87	51.39	8.54	12258
14	391.68	129.12	230.02	91.74	125.92	50.84	8.33	12130
15	388.86	135.25	226.56	93.31	127.02	51.32	8.34	12168
16	397.73	139.11	218.36	96.04	121.79	50.26	8.30	12181
17	394.05	138.73	224.31	95.51	123.60	52.17	8.39	12244
18	384.73	149.94	216.07	87.18	114.73	50.37	8.05	11930

For six generation test system without solar power the results are given below
Total fuel cost is 143560$/hr and the average fuel cost is 11963.3 $/hr.
Total power loss is 96.5 MW and average power loss is 8.04 MW.

It has observed from the above Table 4.5 and Table 4.6 that when solar power system operating with six generator systems then there is a reduction in total and average fuel cost and power loss. The average fuel cost when solar power is in system is 10199.8 $/hr whereas the without solar unit the average fuel cost is 11963.3$/hr.

The Figure 4.8 reflects the power generation output during the month of June. The thermal power output is lower when system is operated with solar unit as some part of load demand is shared by solar unit.

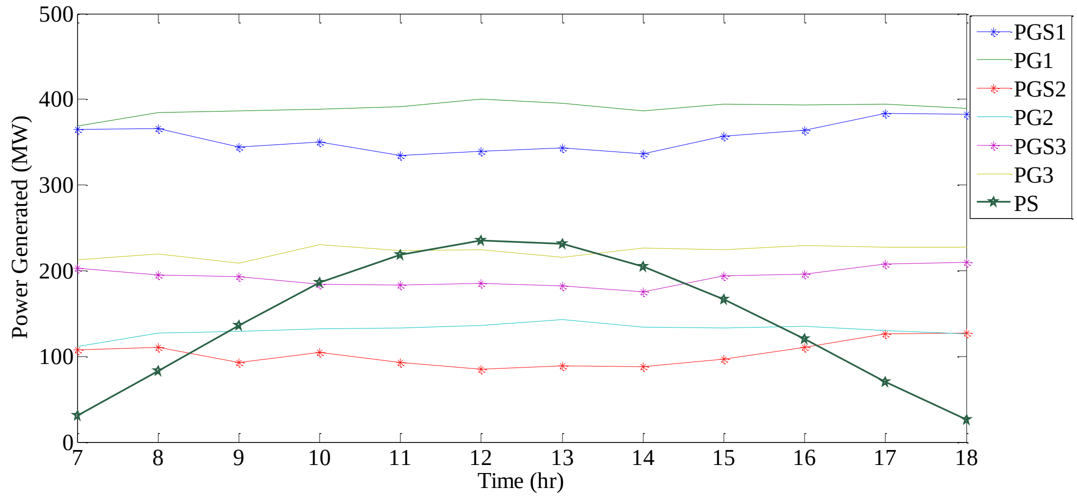


Fig.4.8 (a) Power Generated With and Without Solar Power

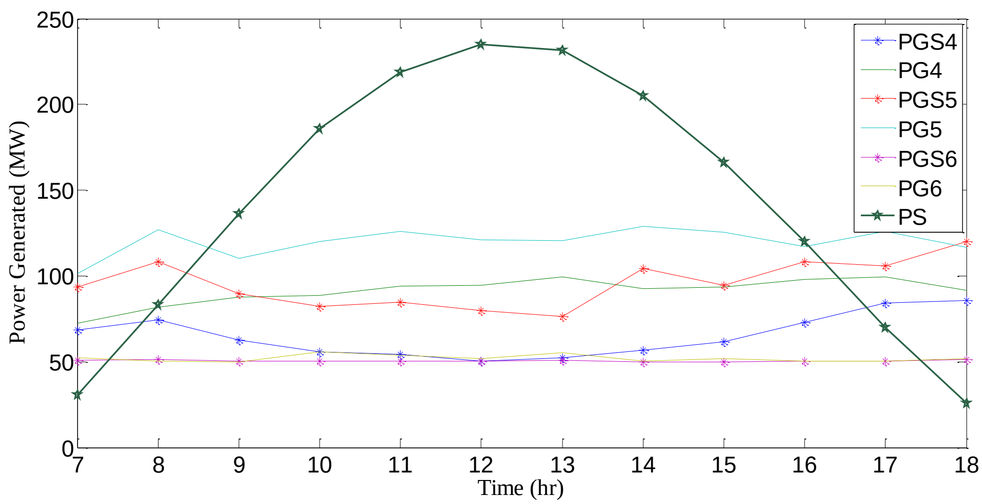


Fig.4.8 (b) Power Generated With And Without Solar Power

PGS: Power generated with solar unit

PG: Power generated without solar unit

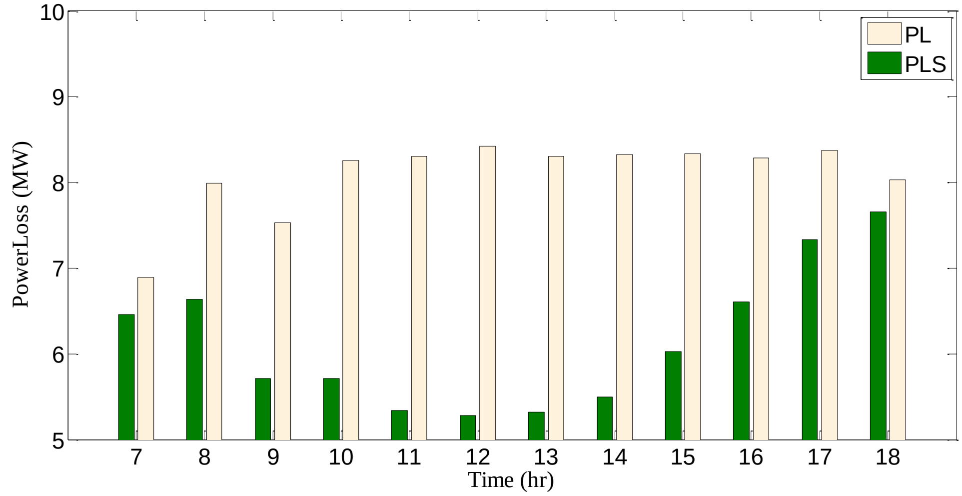


Fig.4.9 Power Loss With and Without Solar Power

PLS: Power loss with solar unit

PL: Power loss without solar unit

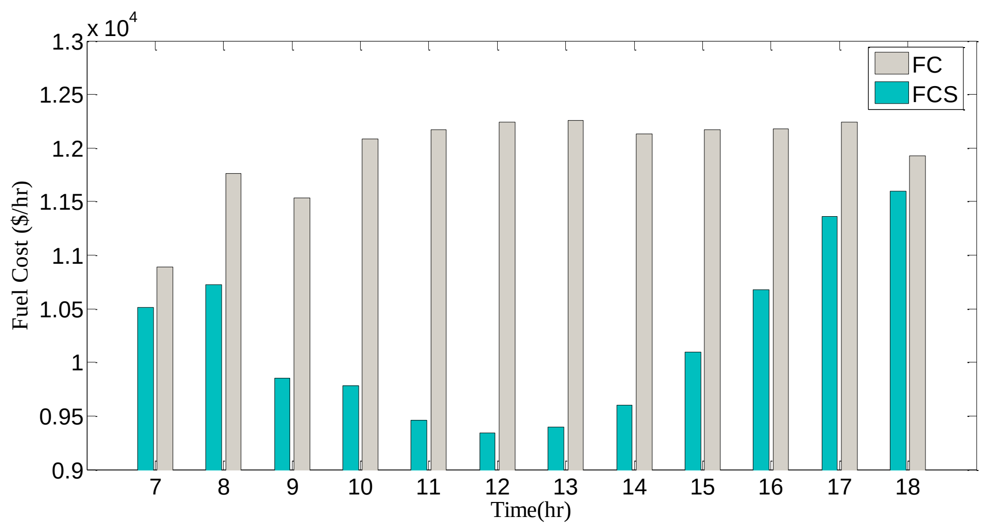


Fig.4.10 Fuel Cost With and Without Solar Power

FCS: Fuel cost with solar unit

FC: Fuel cost without solar unit

4.6.1.3 Optimum Solution for the Month of November

The simulated results of the generation scheduling are shown in Table 4.7. Here we considered two cases thermal units with solar unit and without solar unit. The rating of the PV module is 300W and the number of PV modules are 1000000. The load demand and solar radiation data of 12 hours for the November month is given in Table 4.2.

Table.4.7 Generation Scheduling With Solar Power System

TIME (hr)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	Psolar (MW)	P loss (MW)	Fuel Cost($/hr)
7	359.09	108.83	199.84	64.80	95.47	50.18	8.10	6.35	10393
8	353.17	93.88	190.08	63.57	88.47	51.20	47.40	5.80	9940
9	342.33	83.87	184.95	54.62	84.18	50.57	94.80	5.35	9466
10	325.69	82.50	172.22	52.06	71.50	50.76	135.00	4.75	8930
11	296.98	55.15	132.64	51.13	51.25	50.28	159.90	3.36	7600
12	313.21	74.29	159.57	50.66	60.78	50.58	173.10	4.20	8404
13	324.06	79.01	163.20	53.94	57.41	50.09	170.70	4.43	8618
14	324.02	80.99	172.07	50.82	72.37	50.53	153.90	4.72	8884
15	326.01	90.68	167.16	52.52	73.40	50.40	126.60	4.80	8994
16	342.87	91.12	176.75	51.01	83.39	50.98	88.20	5.35	9437
17	355.46	103.73	190.35	62.35	83.84	50.95	43.20	5.91	10015
18	367.45	100.14	195.24	65.38	105.16	50.52	6.60	6.45	10462

For six generation test system with solar power the results are obtained as

Total fuel cost is 111,143 $/hr and average fuel cost is 9261.91 $/hr

Total power loss is 61.44 MW and average power loss is 5.12 MW

Total solar power generated is 1207.4MW and average solar power generated is 100 MW

Table 4.8 Generation Scheduling Without Solar Power

TIME (hr)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P loss (MW)	Fuel Cost($/hr)
7	363.75	107.01	197.59	70.65	95.71	51.64	6.38	10493
8	357.37	116.65	196.02	69.30	99.01	50.04	6.42	10517
9	365.98	112.64	204.06	71.73	92.01	50.10	6.55	10615
10	360.33	115.01	190.47	74.25	100.56	50.73	6.39	10554
11	341.14	99.03	169.52	51.45	87.75	50.37	5.34	9452
12	366.33	106.87	191.60	70.67	68.12	50.73	6.35	10468
13	368.28	112.02	213.24	79.24	77.65	50.12	6.58	10671
14	368.45	114.46	197.73	73.45	102.32	50.22	6.66	10738
15	365.70	109.27	195.48	68.66	99.08	50.22	6.45	10516
16	359.52	118.84	196.39	67.56	95.02	50.07	6.44	10505
17	364.89	109.41	196.94	70.04	98.59	50.55	6.46	10541
18	365.82	106.47	204.33	70.11	93.64	50.08	6.48	10541

For six generation test system without solar power the results are given below
Total fuel cost is 125611$/hr and the average fuel cost is 10467 $/hr
Total power loss is 76.5 MW and average power loss is 6.37 MW

It has observed from the above Table 4.7 and Table 4.8 that when solar power system operating with six generator systems then there is a reduction in total and average fuel cost and power loss. The average fuel cost when solar power is in system is 9261.91 $/hr whereas the without solar unit the average fuel cost is. 10467 $/hr.

The Figure 4.11 reflects the power generation output during the month of June. The thermal power output is lower when system is operated with solar unit as some part of load demand is shared by solar unit.

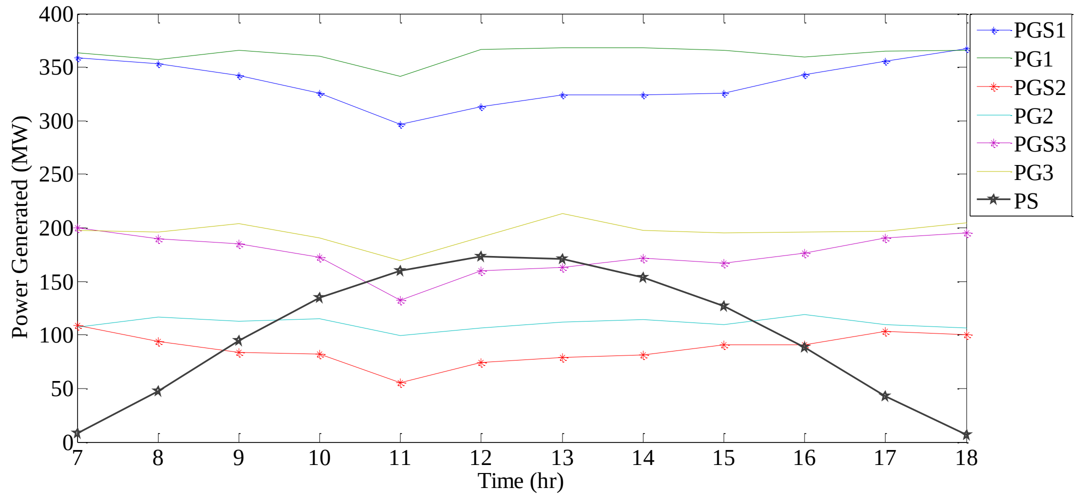


Fig 4.11(a) Power Generated With And Without Solar Power

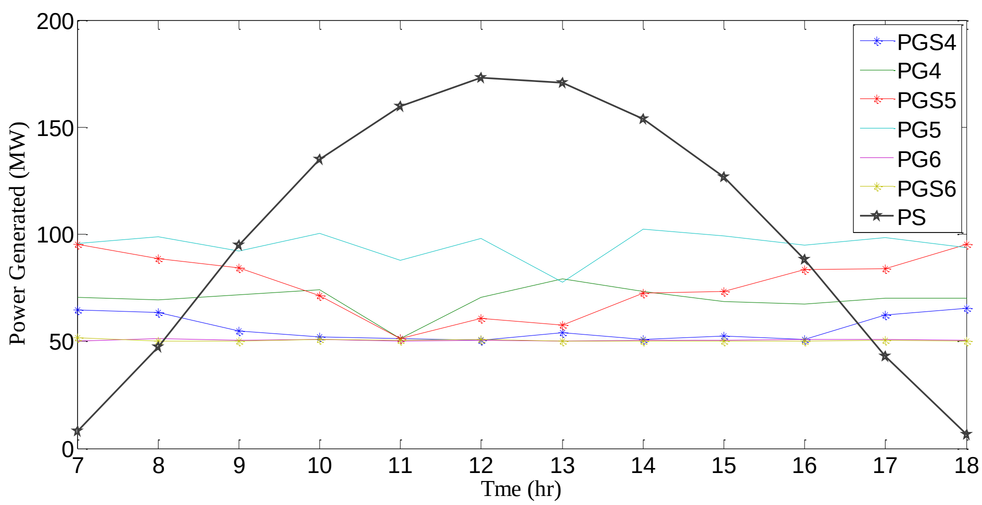


Fig.4.11(b) Power Generated With And Without Solar Power

PGS: Power generated with solar unit

PG: Power generated without solar unit

the Figure 4.12 and 4.13 presented the reduction in power loss and fuel cost when the power system comprises the solar unit.At noon hours this reduction is maximum.

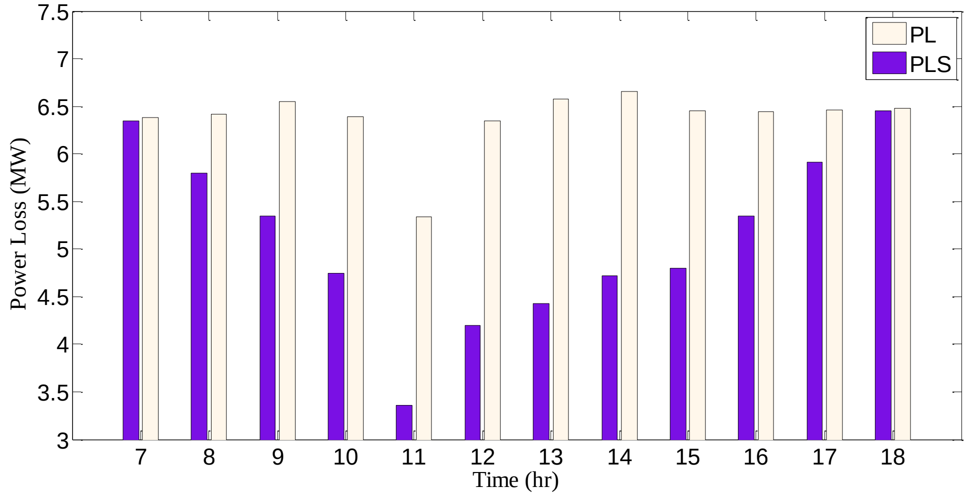


Fig.4.12 Power Loss With And Without Solar Power

PLS: Power loss with solar unit

PL: Power loss without solar unit

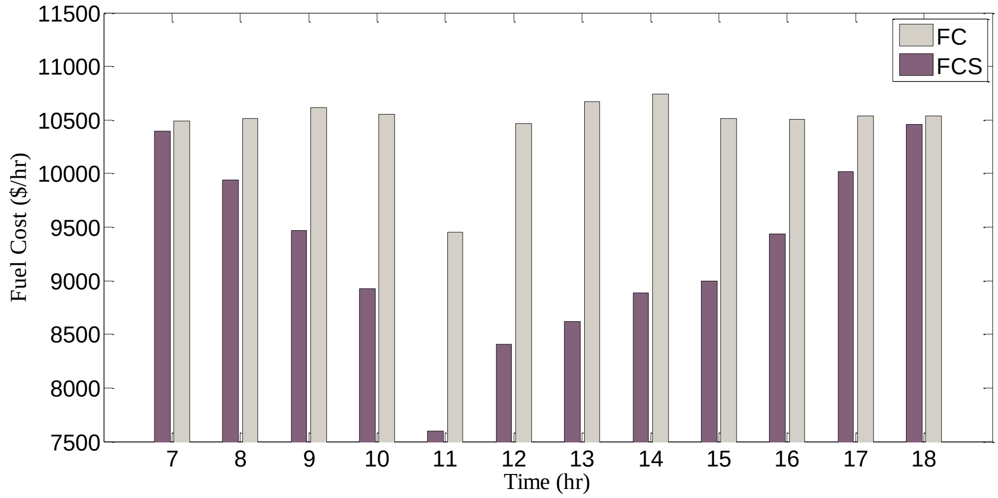


Fig.4.13 Fuel cost With And Without Solar Power

FCS: Fuel cost with solar unit

FC: Fuel cost without solar unit

4.6.2 CASE II- 3 GENERATOR UNITS

The specifications of 3 generator test system are detailed given below. The coefficients of fuel cost and the maximum and minimum power limits are given in Table 4.9 and Power loss equation is given below. The global solar radiation data has taken of February month which is given in Table 4.2.

The result of the generation scheduling of three generator unit with solar unit corresponding to the constant power demand of 900 MW and for the step load pattern are detailed in section (4.6.2.1), and (4.6.2.2) respectively.

$$P_{LOSS} = 0.00003P_1^2 + 0.00009P_2^2 + 0.00012P_3^2$$

Table 4.9 Cost Coefficients and Maximum, Minimum Power Limits

UNIT	P_i^{min} (MW)	P_i^{max} (MW)	a_i (Rs)	b_i (Rs/MW)	c_i (Rs/MW^2)
1	150	600	561	7.92	0.001562
2	100	400	310	7.85	0.00194
3	50	200	78	7.97	0.00482

4.6.2.1 Optimum Solution for Constant Load Demand

In this case load demand is 900 MW for 12 hours i.e. from morning to evening. The behavior of the generated power output is observed with respect to varying solar radiation of the February month. The generated power output with solar unit is given in Table 4.10.

Table 4.10 Power Generated With Solar Unit

Time (hr)	PG1 (MW)	PG2 (MW)	PG3 (MW)	PSOLAR (MW)	PLOSS (MW)	Fuel cost (Rs/hr)
7	454.10	313.9	136.99	12.3	17.30	8705
8	425.32	295.04	128.26	66.6	15.23	8186
9	391.25	272.76	121.53	127.50	13.06	7612
10	369.98	252.52	110.59	178.20	11.313	7139
11	343.12	241.16	102.53	223.20	10.02	6724
12	329.59	231.53	97.29	250.80	9.21	6471
13	328.35	234.15	95.91	249.90	9.315	6479
14	338.89	239.90	99.40	231.60	9.81	6647
15	359.12	250.9	106.77	194.10	10.90	6992
16	391.59	268.65	115.96	136.50	12.70	7527
17	425.82	294.38	125.93	69.0	15.14	8163
18	452.89	310.75	142.22	11.40	17.27	8714

For three generator test system the average power loss with solar unit is 12.60 MW and the average fuel cost is 7440Rs/hr. While the generated power output, power loss and fuel cost without solar unit of 12 hours as follows

PG1=464.01 MW

PG2=315.92 MW

PG3=137.78MW

P_{LOSS}=17.72MW

FUEL COST= 8823 Rs/hr

From Figure 4.14 it has observed that for constant load demand of 900MW the generators power output is not constant as there is a contribution of solar power. The average solar power output is 145 MW.

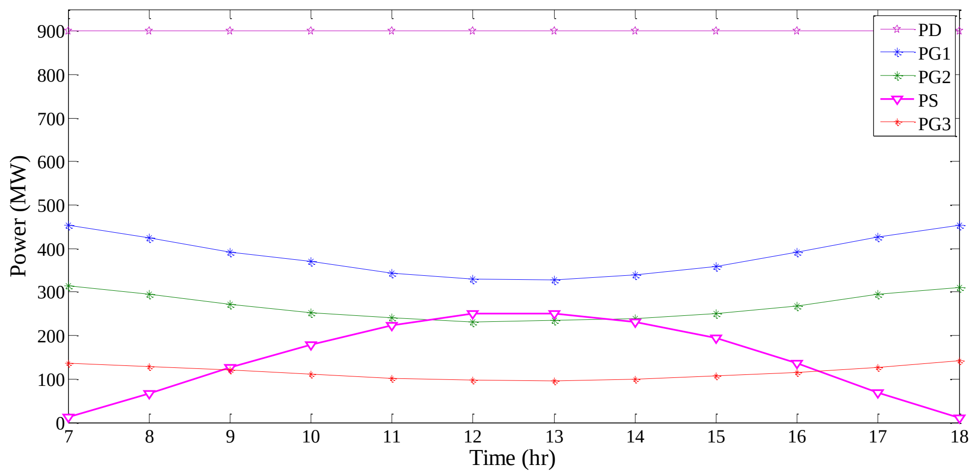


Fig.4.14 Generated Power Output With Solar Power System

PGS: Power generated with solar unit

PG: Power generated without solar unit

PD: Power demand

The reduction of power loss can be observed from the given Figure 4.15. The average fuel cost with solar unit is 7440Rs/hr while without solar unit it is around 8823Rs/hr.

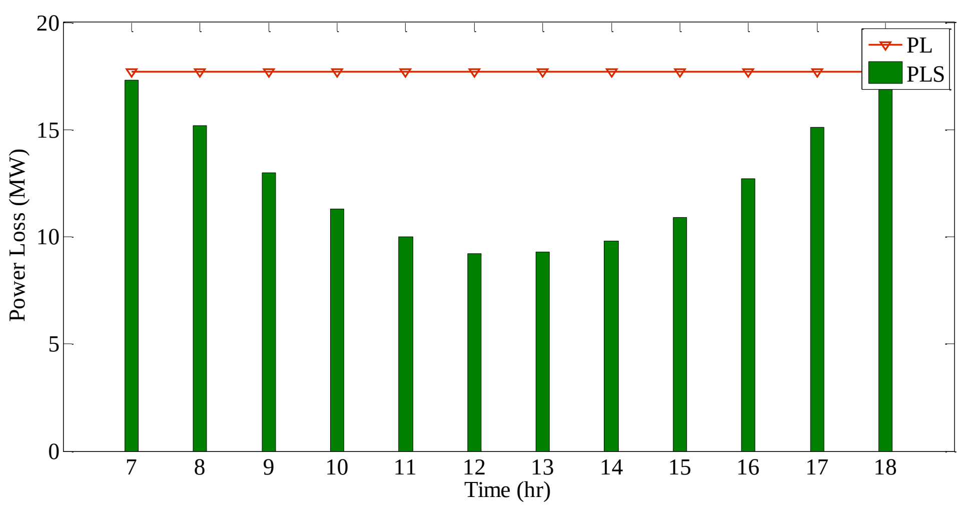


Fig.4.15 Power Loss Curve With and without Solar Power System

PLS: Power loss with sola

PL: Power loss without solar unit

4.6.2.2 Optimum Solution for Steps Load

The load demand patterns for different time period is given in Table 4.11. For three hours time period the power demand is constant. The load pattern curve and the generated power output curve with and without solar is shown in Figure 4.16.

Table 4.11 Load Pattern

Time Period	Load Demand
0700-1000	800
1000-1300	950
1300-1600	1050
1600-1800	900

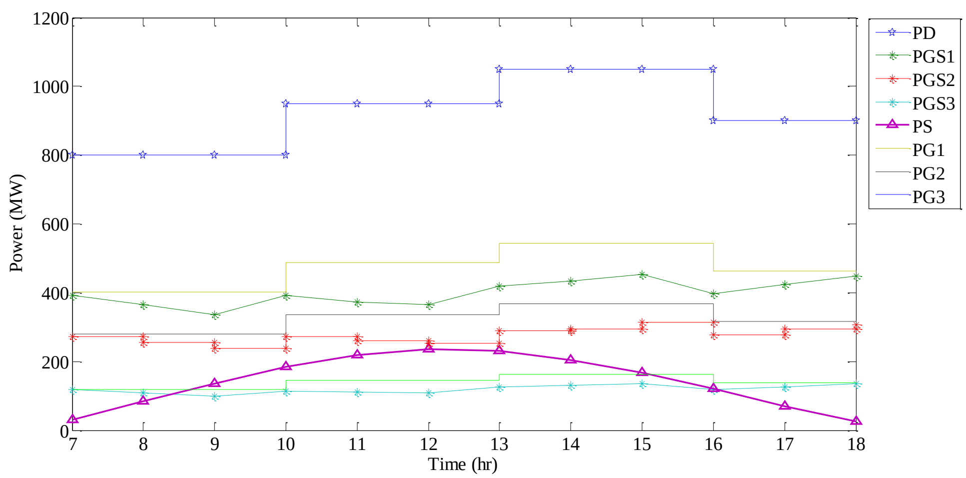


Fig.4.16 Generated Power Output With Solar Power System

PGS: Power generated with solar unit

PG: Power generated without solar unit

PD: Power demand

The Figure 4.17 and 4.18 reflects the impact of the solar unit operating with the thermal unit in the form of reduction in power loss and fuel cost.

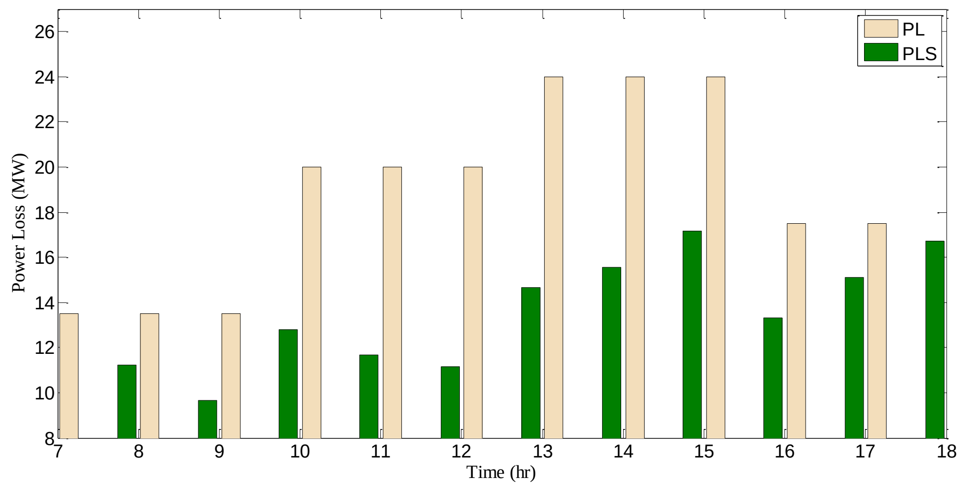


Fig.4.17 Power Loss Curve With and without Solar Power System

PLS: Power loss with solar unit

PL: Power loss without solar unit

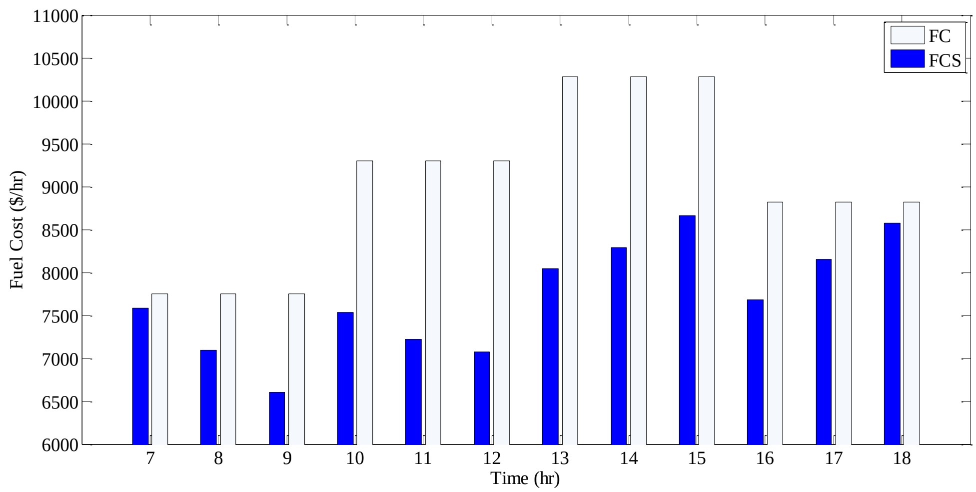


Fig.4.18 Fuel cost with and without Solar Power

FCS: Fuel cost with solar unit

4.7 CONCLUDING REMARK

The algorithm for solar radiation forecasting has been developed which is useful for the generation scheduling with solar power. It has been observed that that there is a reduction in power loss and fuel cost in all the three months. In the month of February the solar radiation is maximum and hence the solar power output is more, thus it shared reasonable amount of load demand. The solar generation in the month of June and November is less because in these months the solar radiation is relatively lower. The further investigation is performed for three generator unit having a constant load demand and step load demand. Therefore, the system losses depends on the solar radiation, which is varying during the day. The fuel cost is also depending on the solar radiation.

CHAPTER 5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusions

In this work, the formulation and implementation of the generation scheduling with solar energy is carried out. As the solar power output is depend on the solar radiation, algorithm for the forecasting of solar radiation has developed. Thee PV cell and PV module simulation has performed in MATLAB/SIMULINK environment, as they are the basic element of the solar power system. The following conclusions are drawn -

- The system loss and the fuel cost are varying even for constant load due to varying solar power generation caused by varying solar radiation.
- The developed algorithm is suited for short term forecasting at different location without the help of any measuring instruments.

5.2 Scope for the Future Work

- Implementation of inverter system to have an interface between solar and utility load.
- Integration of other renewable systems in optimal power flow solution.
- The minimization of cost can be attempted by considering the investment and rate of return due to solar system.

APPENDIX -A

Constant of a and b for Indian cities

Location	A	B
Ahmedabad	0.28	0.48
Bangalore	0.18	0.64
Calcutta	0.28	0.42
Goa	0.30	0.48
Pune	0.31	0.43
Delhi	0.25	0.57
Chennai	0.30	0.44
Nagpur	0.27	0.50
Srinagar	0.35	0.40
Minicoy	0.26	0.39

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