A PROJECT REPORT MAJOR -II

ON

"Study and Analysis of 220KV sub station with solar grid integration"

Submitted in Partial fulfillment for the award of the Degree of

MASTER OF TECHNOLOGY

IN

RENEWABLE ENERGY TECHNOLOGY

By

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DECLARATION BY CANDIDATE

I **Shudhanshu Chaudhary**, hereby certify that the work which is being presented in the major project-II entitled "**Study and Analysis of 220KV sub station with solar grid integration"** is submitted in the partial fulfillment of the requirements for the degree of **M.Tech** at **Delhi Technological University** is an authentic record of my own work carried under the supervision of **Dr. K. Manjunath** Assistant Professor**,** Department of Mechanical Engineering **and Prof. R. S Mishra** Head of The Department, Department of Mechanical Engineering. I have not submitted the matter embodied in this major project-2 for the award of any other degree. Also it has not been directly copied from any source without giving its proper reference.

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CERTIFICATE

This is to certify that the project entitled "**Study and Analysis of 220KV sub station with solar grid integration**" is submitted by **Shudhanshu Chaudhary (Roll no. 2K13/RET/10)** to Delhi Technological University, Delhi for the evaluation of M.Tech Major Project- II as per academic curriculum. It is a record of bona fide research work carried out by the student under my supervision and guidance, towards the partial fulfillment of requirement for the award of the Master of Technology degree in Renewable Energy Technology.

The work is original as it has not been submitted earlier in part or full for any purpose before.

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ABSTRACT

The worldwide increasing demand of agricultural products is very much dependent on the proper irrigation of crops. Now a day's irrigation system is mainly driven by electric power and is operated using conventional resources. The main challenging problem in such system is that large amount of land is required for transmission of electricity through transmission lines, high KVA ratting transformers are required, higher conductor cost in AC transmission and large amount of protection equipment are required in A.C transmission. Now the limitations of such system using conventional resources can be alternatively handled by making systems using non-conventional resources (PV module), specifically targeted for rural areas of India where mainly agriculture and irrigation is major requirement.

In our project work study and feasibility of PV power generation at rural area of western India is performed. For this purpose, a 220KV sub-station in Laxmangarh, Rajasthan is chosen to find out the electricity consumption by rural feeder. Firstly the power consumptions of the specified rural area is measured, thereafter, the solar radiations of this area are computed with the help of software and then the behavior of PV module is checked by the software output. The month wise I-V characteristics and DC voltages are computed and an analytical study is performed. Finally, a 2MW solar power plant and desired DC to DC converter are designed theoretically. Although few limitations and challenges are found while performing analytical study of power plant with solar grid integration, but various advantageous features are obtained and thus make this project beneficial for making power plants using renewable energy resources.

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NOMENCLATURE USED

I_0	reverse saturation current of diode(Ampere)
q	charge of electron(1.602×10^{-19}C)
V_d	voltage across the diode (volt)
K	Boltzmann's constant in joule per kelvin (1.38×10^{-23} J/K)
T	junction temperature in kelvin(K)
I	load current(Ampere).
I_{sc}	short circuit current(Ampere).
I_{ph}	current due to photon(Ampere).
I_d	diode current(Ampere).
KV	rating of equipment in killo Volt
KA	rating of equipment in killo ampere
KVA	rating of equipment in killo volt ampere
G	Global solar radiation [W/m^2]
T	Average temperature at [°C]
W_{peak}	Peak power rating of solar array [Kilowatts]
V_{DC}	DC voltage.
W	WATTS (Unit of Power)
Wp	Energy produced by PV module under Standard Test Conditions
Wh	Units of Energy
Wh/m2	Energy produced per unit area
Wh/day	Energy Produced per day
MHz	Mega Hertz
D	Duty cycle

DC	Direct current
AC	Alternating Current
PV	Photovoltaic
P.F	power factor
C.U.F	capacity utilization factor
SPCU	Solar power Conditioning Unit
MPPT	Maximum Power Point Tracking
MOP	Ministry Of Power
MNRE	Ministry of New and Renewable Energy

Chapter 1
Introduction

Grid sub-station form important parts of transmission and distribution network of electrical system. A GSS controls the supply of power on various routs by means of transformers, circuit breaker, isolators etc. connected to a particular bus bar system. The physical arrangement of various equipment connected to one another in a GSS usually called the layout. One of the primary requirements of good sub-station layout is that it should be as economical as possible but should ensure the desired degree of flexibility and reliability, operation and maintenance and all requirement of safety of operation and maintenance personnel.

1.1 Structure of grid sub station

Usually, following type of buss arrangements are adopted for design of layout [1]

1. Single buss bar system
2. Single main with auxiliary bus system
3. Double main bus systems
4. Double main with auxiliary bus system
5. One and half breakers system
6. Ring bus bar and mesh bus bar system

According to above bus arrangements following type of structures are used in 220/132 kV sub stations.

1.2 Bus-Bar Scheme

1.2.1 One and Half Breaker Scheme

A breaker and a half breaker configuration has two buses, both buses are energized during normal operation. For every 2 circuits there are 3 circuit breakers with each circuit sharing a common center breaker. Any breaker can be removed for maintenance without affecting the service on the corresponding exiting feeder and a fault on either bus can be isolated with interrupting service to the outing lines. If a center breaker should fail, this will cause the loss of 2 circuits, while the loss of an outside breaker would disrupt only one. The breaker and a half scheme is a popular choice when upgrading a ring bus to provide more terminals.[1]

MERITS

1. Flexible operation for breaker maintenance.
2. Any breaker can be removed from maintenance without interruption of load.
3. Required one and half breaker per feeder.
4. All switching by breaker.
5. Selective tripping.

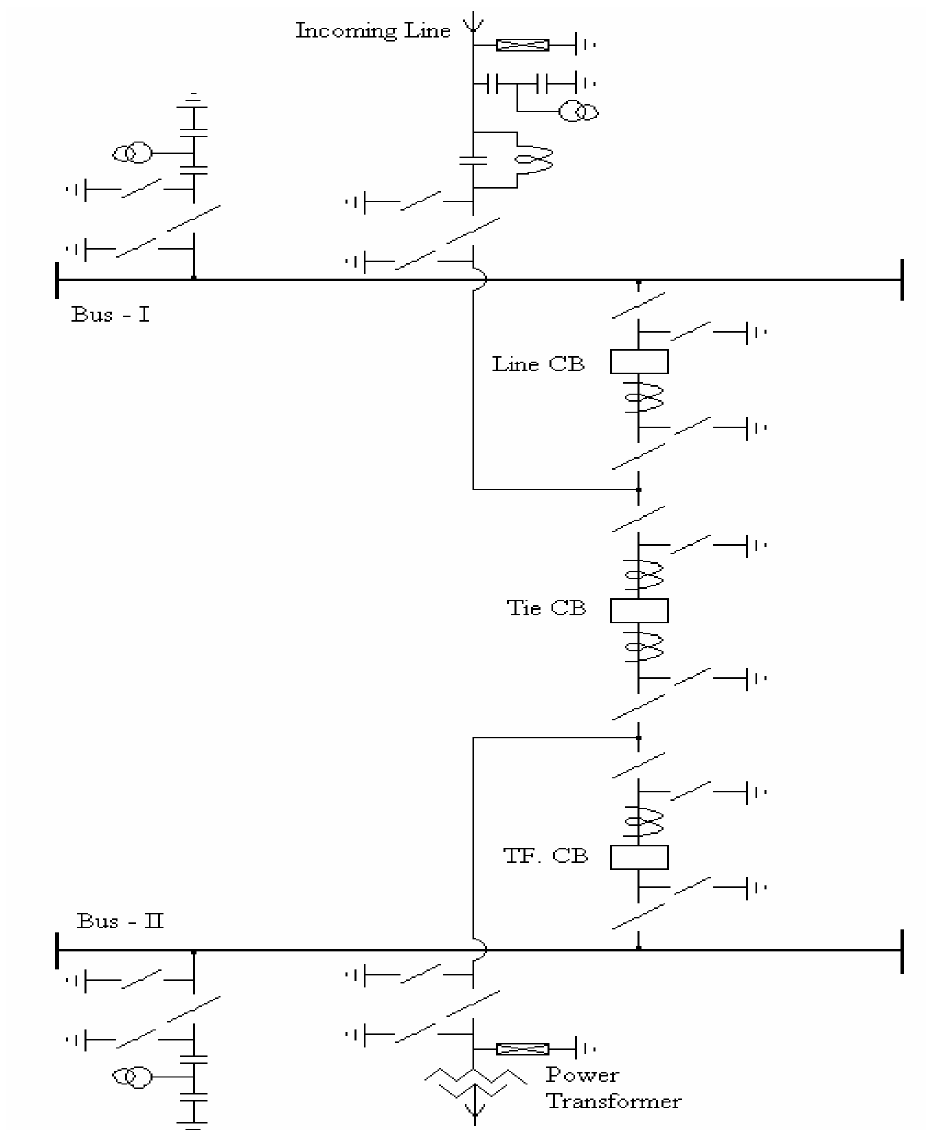


Figure 1.1: One and Half Breaker System [1]

1.2.2 TWO MAIN AND ONE TRANSFER BUS SCHEME

This scheme has the following arrangement:

- One main bus.
- One duplicate main bus(Bus-II)
- One transfer bus

Such a scheme preferred to an ordinary duplicate bus in case of important 220Kv and 400Kv substation.[1]

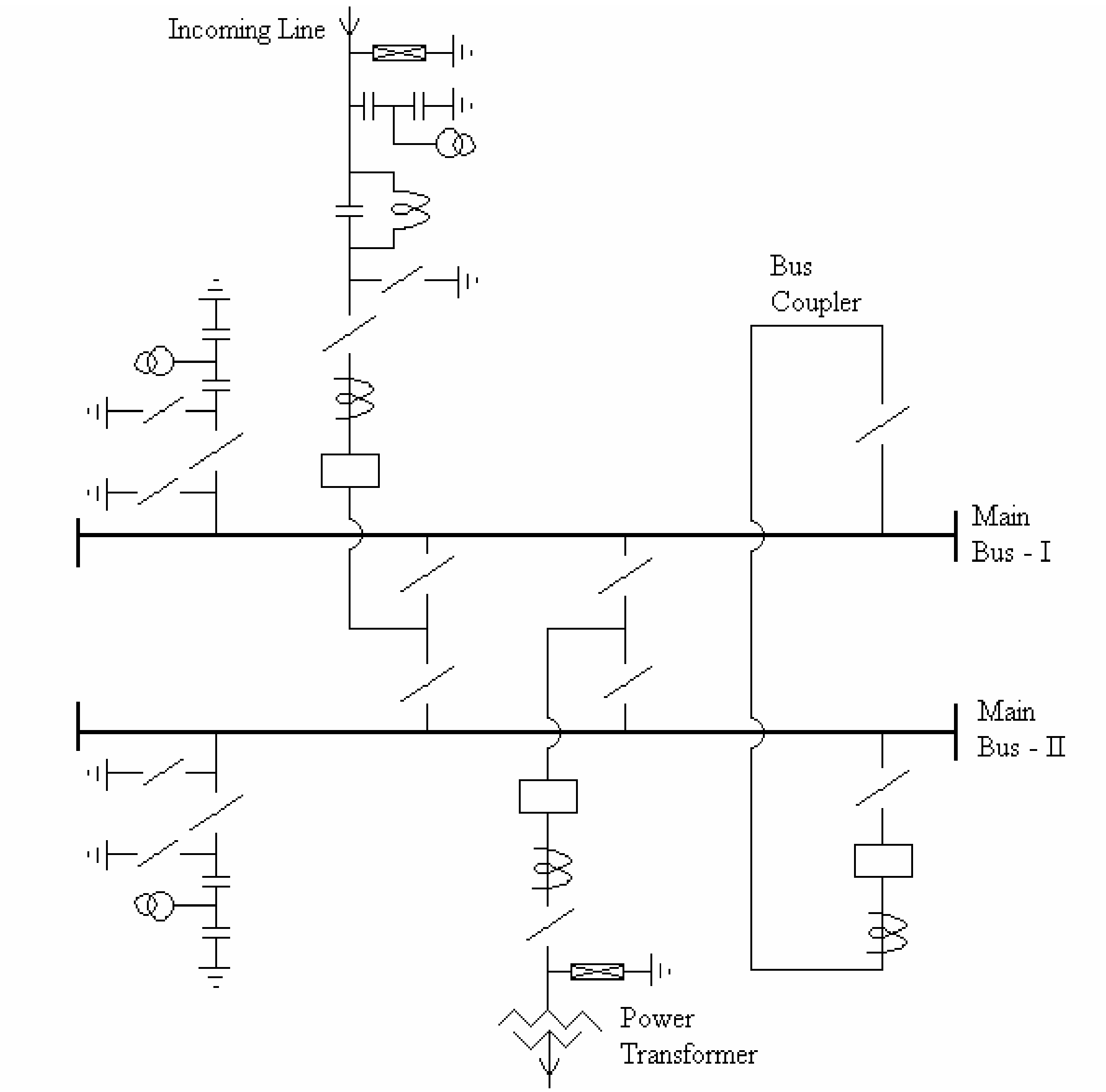


Figure 1.2: Double Main and Transfer (DMT) Bus Arrangement [1]

MEERITS:

1. Most flexible in operation.

2. Highly reliable.
3. Breaker failure on bus side breaker removes only one circuit from service.
4. All switching done with breakers.
5. Simple operation, no isolator switching required.
6. Either main bus can be taken out of service at any time for maintenance.
7. Bus fault does not remove any feeder from the service.

1.3Description of Equipments in Switch Yard

Figure 1.3: 220kV switch yard

1.3.1 Transformer

Transformer is the costliest and the most robust equipment in the substation. This is the mode by which we can transfer energy from one level to other. All transformers at an extra high voltage (EHV) grid substation are step down transformer.

A transformer is a static device comprising coils coupled through a magnetic medium connecting two ports at different voltage levels in an electrical system allowing the interchange of electrical energy between the ports in either direction via the magnetic field. The Transformer is one of the most components of variety of electrical circuits ranging from low power, low current, low current electronic and control circuit to ultra-high voltage power system. A circuit model and performance analysis of transformer is necessary for understanding of many electronics and control system and almost all powers systems. In brief a transformer is a device that:

(a) Changing voltage and current levels in power system
(b) Matching source and load impedance for maximum power transfer in electronic and control circuitry.
(c) Electric isolation.
(d) It does so without a change of frequency.

Figure 1.4: Transformer Installed at 220 kV Substation

Transformers are used extensively in ac powers system because they make possible power generation at the most desirable and economical level(25-50 kv) , power transmission at an economical transmission voltage(as high as 400-1000 Kv) and power utilization at most convenient distribution voltage(230/400V) for industrial and commercial and domestic purpose.[2]

If the secondary voltage is greater than the primary value, the transformer is called step up transformer, if it is less it is known by step down transformer. If primary and secondary voltages are equal, the transformers is said to have a one to one ratio. One to one transformers are used to electricity is a late to parts of a circuit.

1.3.2 Lightning Arrestor

Surge arrester is a device designed to protect electrical from high voltage surges and to limit the duration and amplitude of the follow current. Generally arresters are connected in parallel with the equipment to be protected, typically between phase and earth for three phase installation. The main element of a surge arrester is the ‘Non-linear resistor’, the part of the arrestor which offers a low resistance to the flow of discharge current thus limiting the voltage across the arrester terminal and high resistance to power frequency voltage, thus limiting the magnitude of follow current. There are two types of design available for EHV surge arrester. These are conventional gapped surge arrester and metal oxide surge arrester.[3]

1.3.3 Wave Trap:

Line trap is also known as wave trap. What is trapping the high frequency communication signals sent on the line from the remote substation and diverting them to telecom/ teleportation panel in the substation control room (through coupling capacitor and LMU). The signals are primarily teleprotections signals and in addition, voice and data communication signals. The line trap offers impedance to the high frequency communication signals thus obstructs the flow of these signals in to the substation bus bars.[4].

1.3.4 Current Transformer:

A current transformer (CT) is used for electric currents. Current transformers are also known as instrument transformers. When current in a circuit is too high to directly apply to measuring instrument, a current transformer produces a reduced current accurately proportional to the current in the circuit, which can be conveniently connected to measuring and recording instruments. A current transformer also isolates the measuring instruments from very high voltage in the primary circuit. Current transformers are commonly used in metering and protective relays in the electrical power industry.[5]

1.3.5 Capacitive Voltage Transformer (CVT):

A capacitive voltage transformer (CVT) is a transformer used in power system to step down extra high voltage and provide low voltage signals either for measurement or to operate a protective relay. In its most basis form the device consists of three parts: two capacitor across which the voltage signals is split, an inductive element used to tune the device to the supply frequency and a transformer used to isolate and further step down the voltage for the instrumentation or protective relay. The device has at least four terminals, high voltage terminals for connection to the high voltage signal, a ground and at least one set of secondary terminals for connection to the instrumentation or protective relay.[5] .

1.3.6 Isolator:

Isolators are disconnecting switches which are used for disconnecting the circuit under no load conditions. They are installed in such a way that a part of substation circuit can be isolated from other live parts for the purpose of maintenance. An isolator can be opened only after opening the circuit-breaker. An isolator should be closed before closing the circuit breaker. Single or double earth switches, as required, can be fitted to them. These isolators can be operated either manually or by motor. The earth switch of isolator is a mechanical switching device for providing safety earthing during maintenance. It is capable of withstanding short circuit current for a specified time.[6]

1.3.7 Conductors:

Materials commonly used in conductors are aluminium, copper, and steel. Galvanized steel wires are combined with aluminium in the most common type of overhead conductors – aluminium conductors steel reinforced (ACSR). “Standard” bare overhead conductors consist of round strands helically laid about a core in one or more layers. The most common type of transmission conductor is ACSR. ACSR consists of one or more layer of aluminium strands surrounding a core of 1,7,19, or 37 galvanized steel strands.[6]

1.3.8 Reactors:

When the line is energized but not loaded or only loaded with a small current, there is a voltage rise along the line (the Ferranti-effect). To stabilize the line voltage the line inductance can be compensated by mean of series capacitors and the line capacitance to earth by shunt reactors. Series capacitors are placed at different places along the line while shunt reactors are often installed in the station at the ends of line. In this way, the voltage difference between the ends of the line is reduced both in amplitude and in phase between the ends of the line is reduced both in amplitude and in phase angle.[6]

1.3.9 Neutral Earthing Reactor:

Neutral earthig reactor is one of the means to ground the neutral.in the transmission system which require single pole opening and reclosing of the EHV lines from the consideration of transient stability, successful single pole reclosing requires that extinction of secondary arc and the deionization of arc path in faulty phase should occur reclosing is affected. In EHV system this is achieved by installing a single phase shunt reactor (called neutral earthing reactor) between neutral point of EHV reactor and the earth.[6]

1.3.10 Power Line Carrier Communication:[7]

- Uses electrical conductors of EHV/HV transmission lines for propagation of carrier signals.
- Modulated communication signals on EHV phase conductors through coupling equipment.
- 4KHz Audio band is used for transmission of voice and data.
- VOICE: 0.3-2.0 KHz
- DATA: 2.1-3.4 KHz

1.3.11 Fire Fighting Equipment:

High Velocity Water (H.V.W) spray type fire protection essentially consists of a network of projectors and an array of heat detectors around the Transformer/Reactor to be protected. On operation of one or more of heat detectors, water under pressure is directed to the projector of one or more of heat detectors, water under pressure is directed to the projector network through a valve from pipe network laid for this system.[7]

1.3.12 Station Auxiliaries:

Auxiliary power is essential at sub-station for specific purpose. A storage battery of being charged at convenient rate, such that it can store enough quantity of readily available energy which can be delivered at any time at the required rate and place without delay suitable for these applications.[7]

Storage batteries are provided for the following functions.

- Supply to trip coils and closing coils of switchgears.
- For energising the holding and operating coils in control and interlock schemes, and in protection schemes.
- For power supply to communication including PLCC equipment and other supervisory equipment.
- For emergency DC lighting.
- Electric impulses for impulse clocks.

1.3.13 Substation Lighting

In substation the categories of lighting system can be described in number of ways[7]

- Switchyard lighting
- Control room lighting

A. AC NORMAL LIGHTING:
This includes street lighting and flood/spot lighting from towers. In this, AC light is connected to ac lighting panels.

B. AC EMERGENCY LIGHTING:
This system is available in control room building, switchyard and D.G room. Lighting panel of this system are connected to the emergency lighting board, which is feed from diesel generator during the emergency.

C. D.C LIGHTING:
This system is provided both indoor as well as at outdoor location.

1.4 *Circuit Breakers*

The function of a circuit breaker is to isolate the faulty part of power system in case of abnormal conditions. A circuit breaker has two contacts a) fixed contact b) moving contact. Under normal condition these two contacts remain in closed position when the circuit breaker is required to isolate the faulty part, the moving contact moves to interrupt the circuit. On the separation of contact the flow of current is interrupted, resulting in the formation of arc between the contacts. The contacts are placed in a closed chamber containing some insulating medium (liquid or gas) which extinguish the arc.[8]

1.4.1 Classifications of circuit breakers

Circuit breakers are classified into four types depending on the arc quenching medium as i) oil circuit breakers ii)air blast circuit breaker iii) sulphur hexafluoride (SF_6) circuit breaker iv) vacuum circuit breaker.

- ***Sulphur hexafluoride (SF_6) circuit breaker***: SF_6 is an inert and heavy gas having good dielectric and arc extinguishing properties. Due to these properties of this gas is used as an arc quenching medium in breakers. During the arc period, this gas blown axially along the arc. The gas removes the heat from the arc by axial convention and radial dissipation. As a result, the arc diameter reduces during the decreasing mode of the current wave. The diameter become small during the current zero and the arc is extinguished. Due to its electron negativity and low arc time constant, the SF6 gas regain its dielectric strength rapidly after the current zero.[8]

  - The pressure of the operating air produced by self-enclosed motor compressor unit is supervised by a pressure gauge and controlled by a pressure switch (located in the breaker control cabinet). The pressure switch has four set of contacts, each of which operates at a different pressure level for the following functions: start/stop, low pressure indication, closing and opening interlock .
  - For CB upto 245kV, spring operating mechanism is used. The closing spring gets charged by geared motor. During closing strock the closing spring is discharged. It closes the breaker and also charges the opening springs.

1.5Intelligent Electronics Devises(Relays)

A protective relay is device that detect the fault and initiate the operation of circuit breaker to isolate the defective element from the rest of the system. The relays detect the abnormal conditions in electric circuit by measuring the electric quantities which are different under normal and fault conditions. The electrical quantities which may change under fault condition are voltage, current, frequency and phase angle. In present days the numerical relays are widely used.[8]

1.6 Types Of Protection Systems:

1.6.1 Differential protection system

Differential protection is a unit scheme that compares the current on the primary side of a transformer with that on the secondary side. Where a difference exist (other than that due to the voltage ratio) it is assumed that the transformer has developed a fault and the plant is automatically disconnected by tripping the relevant breakers. Differential protection detects faults on the entire plant and equipment zone, including inter turn short circuit.[9]

1.6.2 Restricted earth fault protection (REF):

The REF protection method is a type of "unit protection" applied to transformers or generators and is more sensitive than the method as differential protection. An REF relay works by measuring the actual current flowing to earth from the frame of unit. If that current exceed a certain preset maximum value than the relay will trip to cut off the power supply to the unit. REF protection is applied on transformer in order to detect ground faults on a given winding more sensitively than differential protection.[9]

1.6.3 Over current protection

The purpose of protective devices is to detect the overcurrent and protect equipment during faulty condition. We use over current relay for this purpose.[9]

1.6.4 Distance protection

There are three major categories of protection scheme for transmission lines two are known as distance protection schemes. These are "pilot protection" and "non pilot protection". The term "pilot" referring to the use of a communication link between the ends of lines to be protected (allowing for instantaneous fault clearing). In pilot schemes, there is the advantage of "knowing" the condition of line at both ends. the third type of approach are differential in nature. Phase comparison relaying is one of these. This allows for on fairly common solution to the problem of series compensated transmission line protection which is successful in most cases. This solution does not use distance relaying principle, instead it compare the phase of currents at both ends of the line to see if there is a fault in the middle.[9]

1.6.5 Over flux protection:

The magnetic flux density in the transformer core is a function of voltage and frequency. Hence relay sense voltage and frequency for magnetic flux condition. Over fluxing relay is provided with enough time lags. In this protection scheme, a resistance and a capacitance are connected to the secondary of potential transformer (PT). The voltage drop across the resistance is a function of line to earth voltage and frequency. This voltage is fed to the "volts per Hz" relay.[9]

1.7 Solar Grid Integration

This section provides the fundamental details of Main components of grid connected photovoltaic power plant. The main components are Photovoltaic Modules (PV array), Power Conditioning Units (PCUs), inverters, LT (Low tension) panel, circuit breakers, transformers, isolators, metering panel and SCADA operated control room.

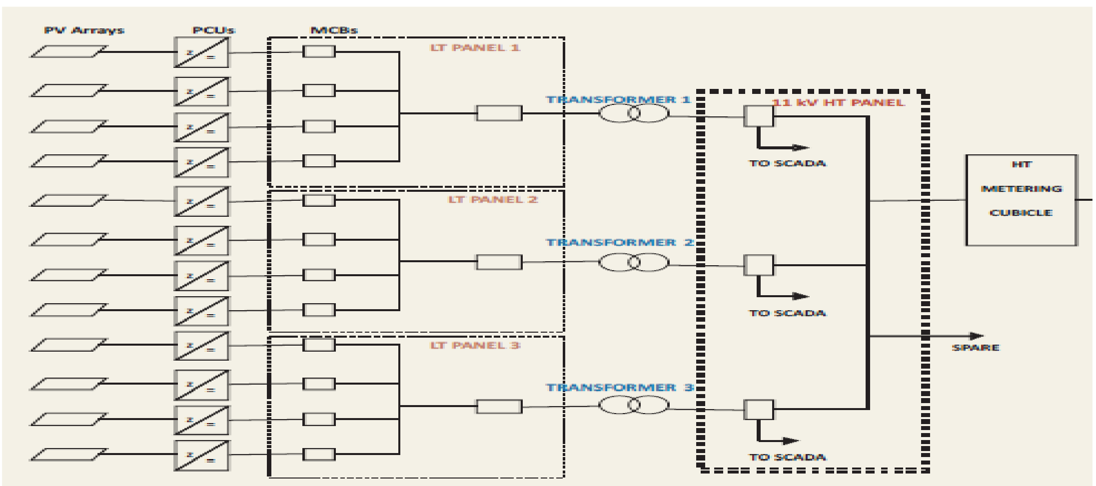


Figure1.5: Simple block diagram of the grid connected PV Plant[33]

1.7.1 Solar Energy:

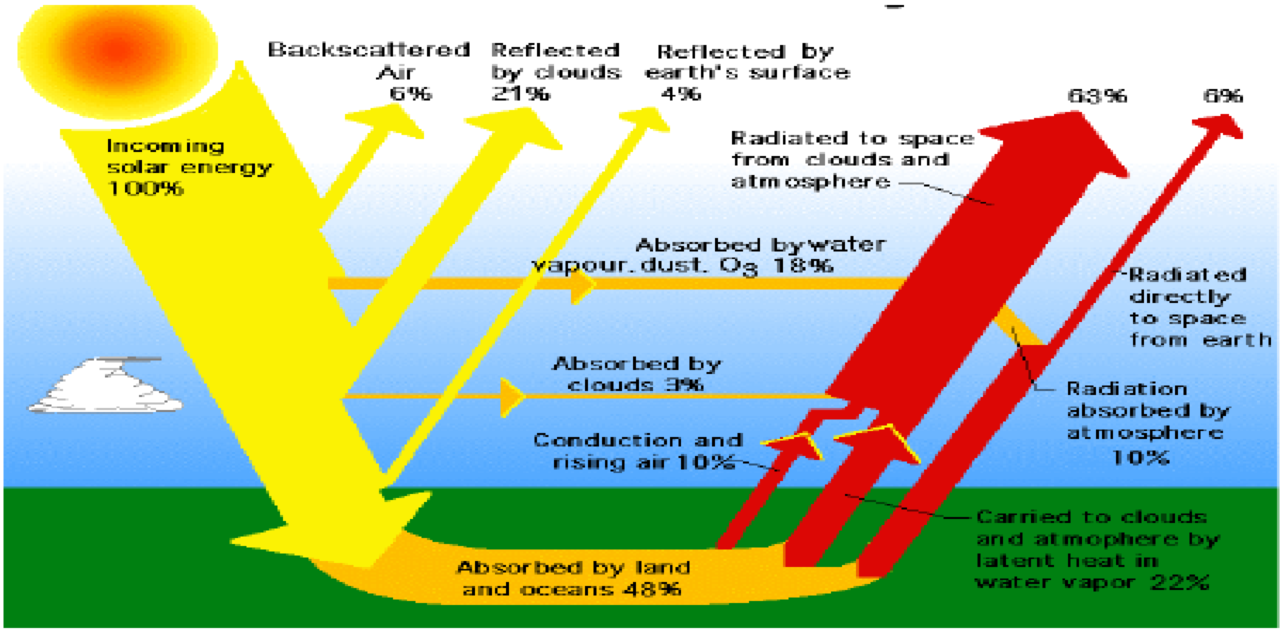


Figure1.6 : solar energy distribution on earth [34]

Source:

The sun is the energy source that drives the climate and weather on entire earth. The earth receives radiant energy from the sun in the form of solar radiation. Solar radiation is the intensity of sun rays expressed in Watts per square meter (W/m^2). Variation of the solar radiation falling per unit time per unit area depends on temperatures, latitude and longitude of the place, wind speed, time of day, orientation, atmospheric conditions and season. Pyrometer is used for measurement of solar radiation.[10]

Figure1.7: main features of sun [35]

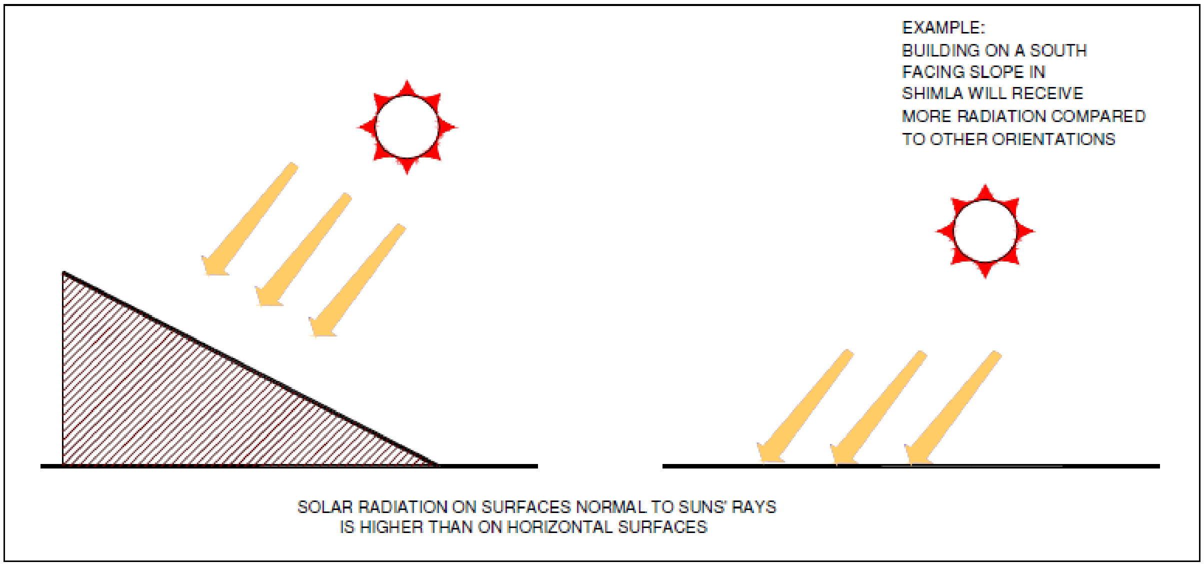


Figure1.8: effect of orientation [11]

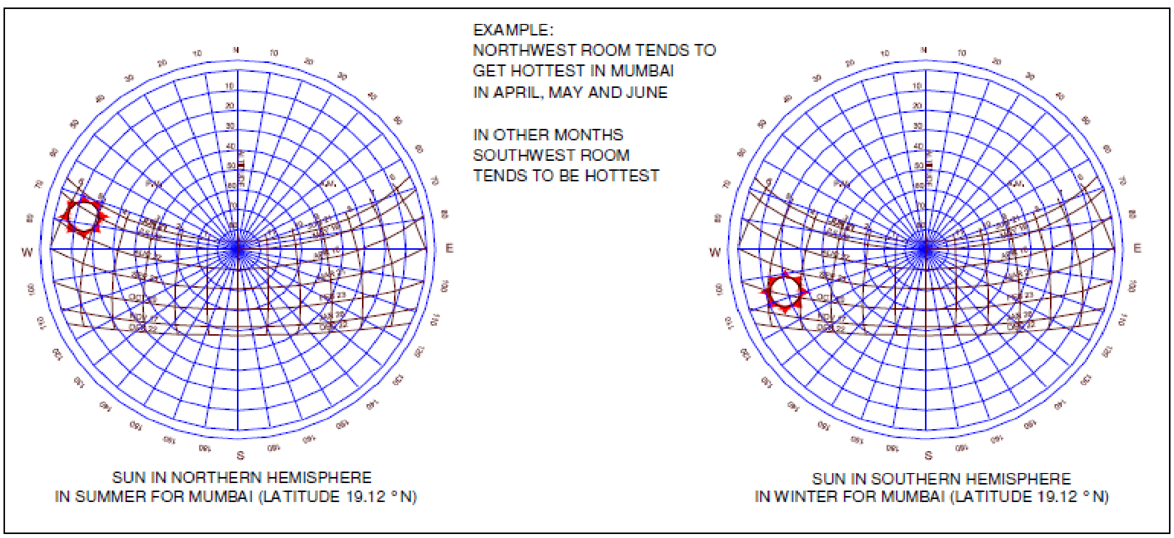


Figure1.9: effect of season [11]

1.7.2 Photovoltaic Modules:

The French scientist Edmund Becquerel discovered the first photovoltaic effect in 1839. In 1876 British scientist William Adams and his student Richard Day discovered first photovoltaic material. Selenium was first discovered photovoltaic material. Scientist William Adams also made a solid cell with 2 % efficiency.[12]

The first semiconductor (silicon) based PV cells was born in 1954 which were soon widely adopted in space application. The efficiency of first generation PV cell was only 6%. Today, the production of PV cells with technological advancement has improved efficiency and reduced cost. Traditional photovoltaic panels consist of a number of solar cells usually made of silicon. Crystalline Silicon based flat plate solar cells are efficient (11-19%) and are widely used (around 90% used). Thin film solar cells are second generation with very thin and flexible silicon wafers with lower efficiencies ranging from 7-14% but are cheaper. Third generation technologies tries to tackle the Shockley Queisser efficiency limit, which is the theoretical maximum efficiency limits around (40-45%) depending on solar spectrum and band gap of material used. Third generation cells uses alternatives like cadmium, gallium, indium, organic solar cells and various multi junction models which are most successful. A record efficiency of 44% is obtained with metamorphic triple junction cells. These researches clearly indicates that the price of the solar panels will continue to drop without compromising the efficiency in years to come, will make them widely acceptable. [12]

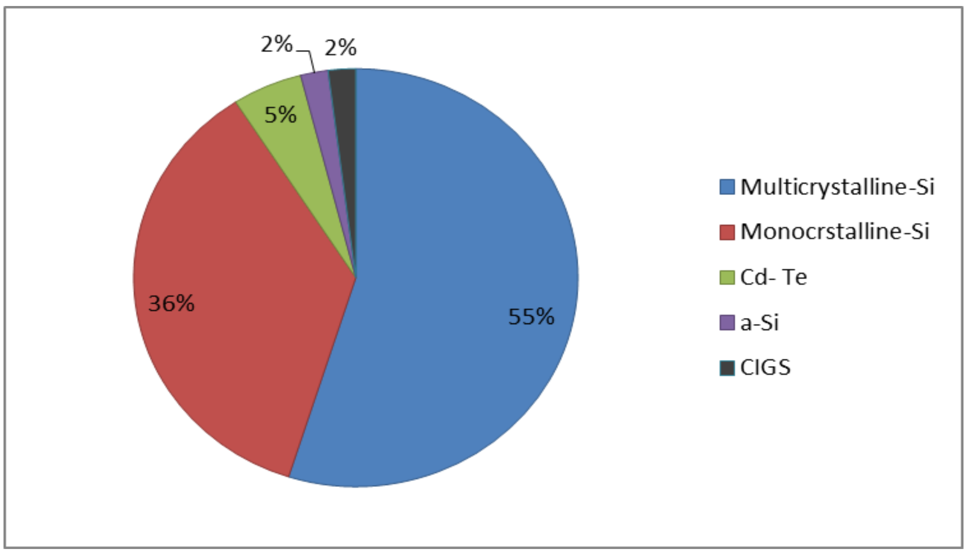


Figure 1.10: Solar cell technologies market share [37]

Solar photovoltaic array (PV array) comprises of a number of solar photovoltaic modules essentially sized to satisfy the energy requirement of the customer. A number of solar photovoltaic modules, connected in series as well as parallel depending on the voltage and load requirements makes solar array. Solar arrays installed in a field can be a fixed type or tracking one. Tracking system will considerably improve the efficiency although it adds additional cost of tracking equipment. Photovoltaic panels makes up to 40 to 60% of the overall system costs, thus proper sizing of the panel as per requirement is a crucial as well as difficult process as power output of the PV array varies according to differences in location, solar radiation, temperature and other atmospheric factors.

The sizing of the PV array is to be done by considering the daily energy requirement, the daily average radiation on the photovoltaic array and the overall system efficiency. This approach makes the system more precise and reliable.[12]

1.7.3 SPV cells:

SPV cells typically measure 5 by 5 inches or 6 by 6 inches, have an output of 3 to 4.5 watts, and have a positive layer, a negative layer, and a positive-negative junction ("p/n junction").SPV cells use either monocrystalline silicon or multicrystalline silicon to convert sunlight into electricity. In order to achieve the desired wattage and power requirements, SPV cells are connected in strings in parallel connection or in series connection to form solar array. Monocrystalline cells are made from a single grown crystal, have a single crystal lattice, and tend to have higher conversion efficiency than multicrystalline cells, which have a random crystal structure, a variable crystal lattice pattern, and lower conversion efficiency. [12]

1.7.4 Solar Power Conditioning Unit (SPCU)

The power conditioning unit is an interface between the PV modules and the transformer with the crucial function of improving coupling performances. The SPCU is a DC-AC inverter. the.MPPT (Maximum Power Point Tracking) device is usually equipped in both converter and inverters to maximise the power extraction from the solar panels. Usually the SPCU efficiency varies between 85% to 95% depending on power availability and the working temperature.

The main functions of the SPCU are matching the input power from solar panels to the output power , providing protection against too low and too high voltages by switching off the system thus increasing the lifetime of the equipments and reducing maintenance.[13]

1.7.5 Maximum Power Point Tracker and Sun tracker

The maximum power point tracker (MPPT) is now prevalent in grid-tied PV power systems and is becoming more popular in stand-alone systems. It should not be confused with sun trackers, mechanical devices that rotate and/or tilt PV modules in the direction of sun. MPPT is a power electronic device interconnecting a PV power source and a load, maximizes the power output from a PV module or array with varying operating conditions, and therefore maximizes the system efficiency. MPPT is made up with a switch-mode DC-DC converter and a controller. For grid-tied systems, a switch-mode inverter sometimes fills the role of MPPT. Otherwise, it is combined with a DC-DC converter that performs the MPPT function. In addition to MPPT, the system could also employ a sun tracker. The single-axis sun tracker can collect about 40% more energy than a seasonally optimized fixed-axis collector in summer in a dry climate . In winter, however, it can gain only 20% more energy. In a climate with more water vapor in the atmosphere the effect of sun tracker is smaller because a larger fraction of solar irradiation is diffuse. It collects 30% more energy in summer, but the gain is less than 10% in winter. The two-axis tracker is only a few percent better than the single-axis version. Sun tracking enables the system to meet energy demand with smaller PV modules, but it increases the cost and complexity of system. Since it is made of moving parts, there is also a higher chance of failure. Therefore, in this simple system, the sun tracker is not implemented. [13]

1.7.6 String Inverters:

Simplicity is one of the most crucial things about photovoltaic power. All components are almost completely solid state, from the PV cell to the electricity delivered to the consumer. All equipments that are required between the solar array and the load are electronic and electrical components. Compared to other renewable sources of energy PV is the most suitable, scalable and modular to make electricity. More electrical fusing, bussing and wiring are required in larger PV systems. While the most complex component between the solar array and the load is inverter that converts and processes the electricity. Basically inverter is an electronic device that changes direct current (DC) to alternating current (AC) by using electronic circuit. In the reference of grid-tied PV, the only electronics component needed between the array and the grid is the inverter. [13]

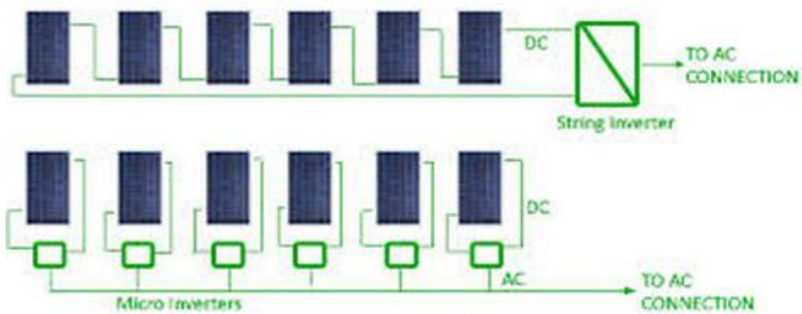


Figure 1.11: String Inverter [13]

Functions of inverter:

- Inversion
- Maximum power point tracking
- Grid disconnection
- Integration and packaging.

Applications of inverter

- Fuel cells
- Wind turbine and micro turbine
- Variable frequency drives
- Uninterruptible power supply
- Induction heaters
- HVDC power transmission

To form a string, inverters are connected in parallel or in series. String inverters offer the major advantages such as high DC system voltage range and three-phased output while still maintaining the high efficiencies. The most crucial advantage of string inverter is reducing losses in both AC and DC cabling. Furthermore, string combiners and external string monitoring are not required thus making simple cabling possible.

Chapter 2
Literature review

This chapter deals with theoretical background and the published research work that is related to the project work.

2.1 Theoretical background

Chen *et al.* [14] proposed an artificial neural network (ANN), to solve the load forecasting of distribution substations and to investigate the temperature sensitivity of substation loading. Hourly substation load data were collected by the supervisory control and data acquisition system (SCADA). Substation load data were then integrated with weather information to form a training set of supervisory neural network with back propagation function link. To verify the performance of the proposed method, actual substation load data and weather data were used as the recall data sets of the ANN to perform the distribution substation load forecasting for the next year. To demonstrate the effectiveness of the proposed ANN method, the conventional multi-variable linear regression technique had been applied to solve substation load forecasting for the purpose of comparison.

Kulesz [15] demonstrated the results of the investigation of different designs of these transformer-rectifier sets - namely, 12- and 24-pulse systems. The comparison of electrical quantities such as ripple content, harmonic content of supply current and output voltage and utilization of transformer secondary windings was provided.

Murakami *et al*. [16] developed a new SCADA system for 500-kV substations. To apply existing LAN-based SCADA system for unmanned 275-kV or 77-kV substations, they developed three functions. Firstly, the new SCADA system enables that 500-kV substation was supervised and controlled from multiple operating sites. Secondly, the database of the new SCADA system can be downloaded the maintenance data from the SCADA system for 500-kV control center via an IP network. Finally, the new SCADA system had supervisory control capability for manned 500-kV substations.

Adaramola *et al.* [17] examined the feasibility of solar PV-grid tied energy system for electricity generation in a selected location in the northern part of Nigeria using HOMER energy optimization software. The technical and economic performance of a combination of 80 kW solar PV-grid connected was investigated. At base case of solar PV cost of $2400/kW and average global solar radiation of 6.0 kW h/m2/day, it was found that this energy system can generates annual electricity of 331,536 kW h with solar PV contributing 40.4% and the levelized cost of energy is $0.103/kW h. Based on the findings from this study, the development of grid-connected solar PV system in the north-eastern part of Nigeria could be economically viable. The effects of the cost of PV system and global solar radiation were also investigated.

Franceschi *et al.*[18] identified off-grid solar Photovoltaic (PV) and solar PV hybrid packaged systems that are applicable to emergency relief activities, refugee camp activities and micro-grid development. The paper's concentration on offgrid power, the description of these engineered systems by humanitarian activity and the identification of the different engineered packaged solutions was aimed at stimulating a discussion to help scale more appropriate technologies for humanitarian action. The paper concluded with a discussion of present and future private sector business strategies to support scalability of this new and growing market.

Li *et al.* [19] suggested a generalized model, the ARMAX model, to allow for exogenous inputs for forecasting power output. The suggested model takes temperature, precipitation amount, insolation duration, and humidity that can be easily accessed from the local observatory as exogenous inputs. As the ARMAX model does not rely forecast on solar irradiance, it maintains simplicity as the conventional ARIMA model. On the other hand, it was more general and flexible for practical use than the ARIMA model. It was shown that the ARMAX model greatly improves the forecast accuracy of power output over the ARIMA model. The results were validated based on a grid-connected 2.1 kW PV system.

Yong *et al.* [20] presented an integrated modeling scheme of smart substation and dispatch master station; the modeling range contains coordination and share of grid model, integrated maintenance of grid graph and seamless communication between smart substation and dispatch master station. That scheme followed IEC61970 and IEC61850 standards, combined with CIM/E (common information model based efficient model exchange format), CIM/G（common information model/graph）and power grid equipment common model naming specification to formulate model/graph sharing standard of smart substation and dispatch master station.

Balcombe *et al.* [21] presented the results of a simulation of 30 households with different energy demand profiles using this system, in order to determine: the degree of household electricity self-sufficiency achieved; resultant grid demand profiles; and the consumer economic costs and benefits. The results indicated that, even though PV and SECHP collectively produced 30% more electricity than the average demand of 3300 kWh/yr, households still had to import 28% of their electricity demand from the grid with a 6 kWh battery. This work shown that SECHP was much more effective in increasing self-sufficiency than PV, with the households consuming on average 49% of electricity generated (not including battery contribution), compared to 28% for PV. The addition of a 6 kWh battery to PV and SECHP improved the grid demand profile by 28% in terms of grid demand ramp-up requirement and 40% for ramp-downs. However, the variability of the grid demand profile was still greater than for the conventional system comprising a standard gas boiler and electricity from the grid. These moderate improvements must be weighed against the consumer cost: with current incentives, the system was only financially beneficial for households with high electricity demand (>4300 kWh/yr). A capital grant of 24% of the installed cost of the whole micro-generation system was required to make the system financially viable for households with an average electricity demand (3300 kWh/yr).

Bessa *et al.* [22] proposed a new forecasting algorithm for 6 h ahead based on the vector auto regression framework, which combines distributed time series information collected by the Smart Grid infrastructure. Probabilistic forecasts were generated for the residential solar photovoltaic (PV) and secondary substation levels. The test case consisted of 44 micro-generation units and 10 secondary substations from the Smart Grid pilot in Évora, Portugal. The average improvement in terms of root mean square error (point forecast evaluation) and continuous ranking probability score (probabilistic forecast evaluation) for the first 3 lead-times was between 8% and 12%, and between 1.4% and 5.9%, respectively.

Gonzalez *et al.* [23] proposed a methodology, which is capable of finding the sizing that leads to a minimum life cycle cost of the system while matching the electricity supply with the local demand. The methodology was tested by means of a case study in which the actual hourly electricity retail and market prices have been implemented to obtain realistic estimations of life cycle costs and benefits. A sensitivity analysis that allows detecting to which variables the system is more sensitive had also been performed. Results presented show that the model responds well to changes in the input parameters and variables while providing trustworthy sizing solutions. According to these results, a grid-connected HRES consisting of photovoltaic (PV) and wind power technologies would be economically profitable in the studied rural township in the Mediterranean climate region of central Catalonia (Spain), being the system paid off after 18 years of operation out of 25 years of system lifetime. Although the annual costs of the system were notably lower compared with the cost of electricity purchase, which was the current alternative, a significant upfront investment of over $10 M – roughly two thirds of total system lifetime cost – would be required to install such system.

Marrekchi *et al.* [24] presented a PV-grid connected system and proposed a practical and efficient method for coupling a photovoltaic generator (PVG) on a single-phase electric grid throughout two conversion stages namely DC–DC boost converter and voltage source inverter (VSI). The DC–DC converter ensures that a maximum power extraction from the PVG and that the VSI matches the grid requirement for the energy produced. In fact, before discussing the injection of the produced power by the PVG into the electric grid, connection requirement have to be met. The proposed method has been simulated revealing the ability of our system to highlight the coupling instance. The obtained results show the transient analysis of coupling and the efficiency of the proposed technique.

Mpholo *et al.*[25] presented the performance of a newly installed 281 kWp first grid-connected photovoltaic solar farm in Lesotho. The performance parameters selected were those that mainly indicate the suitability of a site for solar power development. Using normalised values, a brief comparison with other farms across the globe was made to assess the relative performance of the farm. The results show that its performance was satisfactory, with a weighted performance ratio of 0.70 compared to the global average of 0.70e0.80 for sufficiently well performing farms.

Sundaram and Babu *et al* [26] presented the validated annual performance analysis with the monitored results from a 5MWp grid connected photovoltaic plant located in India at Sivagangai district in Tamilnadu. The total annual energy generated was 8495296.4 kW h which averages around 707941.4 kW h/month. In addition to the above, real time performance of the plant was validated through system software called RETscreen plus which employs regression analysis for validation. The measured annual average energy generated by the 5 MWp system is 24116.61 kW h/day which was appropriately close to the predicted annual average which was found to be 24055.25 kW h/day by RETscreen. The predicted responses were further justified by the value of statistical indicators such as mean bias error, root mean square error and mean percentage error. The annual average daily array yield, corrected reference yield, final yield, module efficiency, inverter efficiency and system efficiency were found to be 5.46 h/day, 5.128 h/day 4.810 h/day, 6.08%, 88.20% and 5.08% respectively. The overall absolute average daily captures loss and system loss of the particular system under study is 0.384 h/day and 0.65 h/day respectively. A comparison was also made between the performance indices of solar photovoltaic system situated at other locations from the literature's published. Furthermore the effect of input factors over the output of the system was emphasized by regression coefficients obtained through regression analysis. In-depth analysis dealing with energy and exergy of the system were also included to strengthen the study.

Tripathi *et al.*

[27] designed a LCL filter interfaced grid which is connected to a photovoltaic system using power balance theory. The desired results for evacuation of PV power were attained and by giving compensating reactive power from PV system, grid was operated under unity power factor. It improved the power factor of the system. The system was investigated and analyzed for unbalanced load and non-linear load condition also. The performance of the system was maintained according to IEEE-519 standards for THD and under unbalanced and non-linear load conditions as the PV inverter generates the compensating current. This system does not require PLL as the synchronization is achieved through templates.

2.2Problem statement

The Indian economy is mainly dependent on the agriculture but the main problem of agriculture is irrigation. Today's irrigation equipment's are mainly driven by electric power and which are operated on conventional sources. But it has some limitation as follows:

- Large amount of land is required for transmission of electricity through transmission lines.

- High KVA ratting transformers are required.
- Higher conductor cost in AC transmission.
- Large amount of Protection equipment are required in A.C transmission.

To deal with these limitations with conventional sources, an attempt is made to check the feasibility of the non-conventional source (PV module) in the rural area of India.

2.3Objective

The main aim of this study is to check the feasibility of PV power generation at rural area of western India. For the above purpose, a 220KV sub station Laxmangarh is chosen, to find out the electricity consumption by rural feeder.

2.4Organisation of report

The report has been organised in the following sequence. Introduction of the report is presented in the first chapter, which is followed by the related literature review in chapter 2. Research methodology used is described in the chapter 3. Chapter 4 provides results & discussion of this project. Finally the report is concluded in the last chapter.

Chapter 3
Methodology

The entire project work can be broadly classified into two major sections. First section deals with study and analysis of 132KV side of 220KV sub station which includes one year energy consumption with power factor and efficiency of plant studied. Second section consists of designing of 2MW PV power plant which includes testing of PV (photovoltaic) module at different months' solar radiation and temperature, also includes I-V (current-voltage) characteristic and DC power output of PV cell and design of DC to DC converter for battery charging.

3.1 Introduction to 220 KV sub station

It is a project to distribute the power generated by suratgarh thermal power plant. A 220 KV transmission line is constructed from reengus to laxmangarh substation and another 220KV transmission line is constructed from ratangerh to laxmangarh substation to achieve its transmission target. A 220/132/33 KV substation is also constructed to step down the voltage level and also to transmit it to other 33 KV substation via 33KV transmission line. Hence this substation is an important link for system strengthening in north east part of Rajasthan. This substation is situated at laxmangarh near NH11 25 KM from Sikar railway station.

3.2 Energy Requirements:

A substation feeds different types of consumers-domestic, commercial, industrial, agricultural etc. The present day power station invariably feed a grid which delivers power to the load centres. The design of a substation must take into account the future increase in load. For this purpose load forecasting studies have to be made to predict the increase in load in the next 30 years or so. A modern substation takes 2 to 3 years for completion. As such the power system planning must be done about 20 years in advance .The estimate of power and the increase in generation capacity depend on maximum demand, the distribution and variation in demand and the energy requirements.

3.3 Types Of Load:

The main types of load on a system are domestic, commercial, municipal, traction, agriculture etc. [28]

- Domestic or Residential load: Residential load consists of lights, fans and appliances like radios, heaters, electric irons refrigerators, coolers, electric water heaters, washing machines etc.
- Industrial load
- Commercial load:

This load mainly consists of lighting, fans and small electric appliances. The load is fairly constant from 9 AM to 8 PM.during nights the load may consist of some lighting load.

- Urban traction load: this load consist of tram cars, suburban trains and associated railway station etc.
- Municipal load: This includes load for street lighting, water supply etc.
- Irrigation load:

3.4Economic factors:

- *Maximum demand*: The maximum demand of a consumer means the maximum power that his circuit is likely to draw at any time.
- *Connected Load*: Each device at the consumer terminal has its rated capacity. The connected load of a consumer means the sum of the continuous rating of all devices and outlets installed on his distribution circuit.
- *Demand factor*: Demand factor for system is the ratio of the maximum demand to the connected load.

$$\text{Demand factor} = \frac{\boldsymbol{Maximum\ Demand}}{\boldsymbol{Connected\ Load}}$$

- *Base load*: The unvarying load which occurs almost whole day on the sub station is called base load.
- *Peak load*: The various peak demand of the load over and above the base load of the substation is called peak load.
- *Load Factor*: Load factor for a system is the ratio of the average load to the peak load, for a certain period of time.

$$\text{Load factor} = \frac{Average\ load}{peak\ load}$$

Load factor can also be defined as the ratio of the energy consumed in a certain time to the energy which would be consumed if the load is maintained at the maximum value throughout that time:

$$\text{Load factor} = \frac{Energy\ consumed\ during\ a\ time\ of\ t\ hours}{(Peak\ load)(\ t)}$$

Here” t” = time in hours

Load factor is practically less than one and in ideal condition it is equal to one. If the maximum demand on the substation is low than the load factor is increases so that the cost of initial investment on the electrical equipment is minimum hence cost of generation is reduced.[28]

3.5 Solar Radiation Data for India:

The annual distribution of solar radiation falling per unit time per unit area (kWh/m^2) and hours of sunshine in India are presented in figure3.6 and figure3.7. As far as the availability of bright sunshine hours concerned more than 3000 to 3200 hours of bright sunshine in a year are received by Rajasthan, Gujarat and north Maharashtra. Figure also show that Jammu and Kashmir, north eastern states and Kerala receive below 2600 hours of bright sunshine in a year and average availability of bright sunshine hours for India is 2600 to 2800 hours in a year. In Jammu and Kashmir the maximum duration of sunshine occurs in June and July and minimum in January where a significant decrease in sunshine occurs during June to August over the whole country.[29]

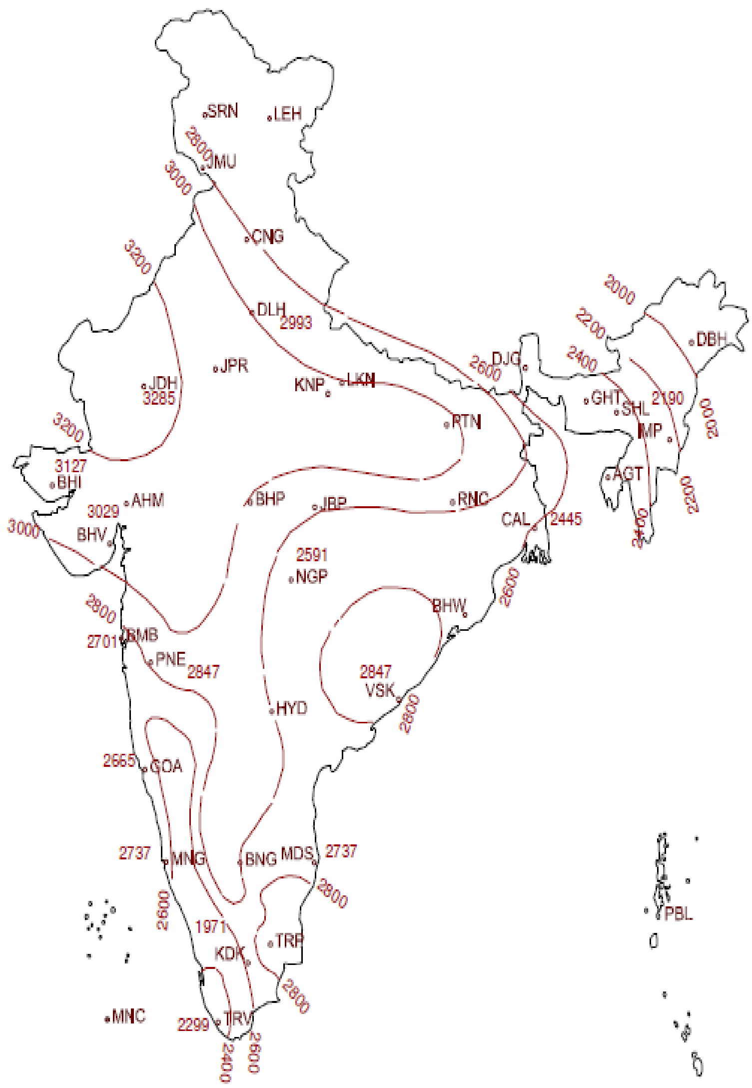


Figure3.1: Distribution of Annual Sunshine Hours in India [11]

Figure3.7 shows that the availability of global solar radiation (kWh/m^2) over the whole country. It can be seen from figure that Rajasthan and Gujarat receive more than 2000 kWh/m^2 of global solar radiation while North West Bengal, east Bihar and the north-eastern states receive less than 1700 kWh/m^2.

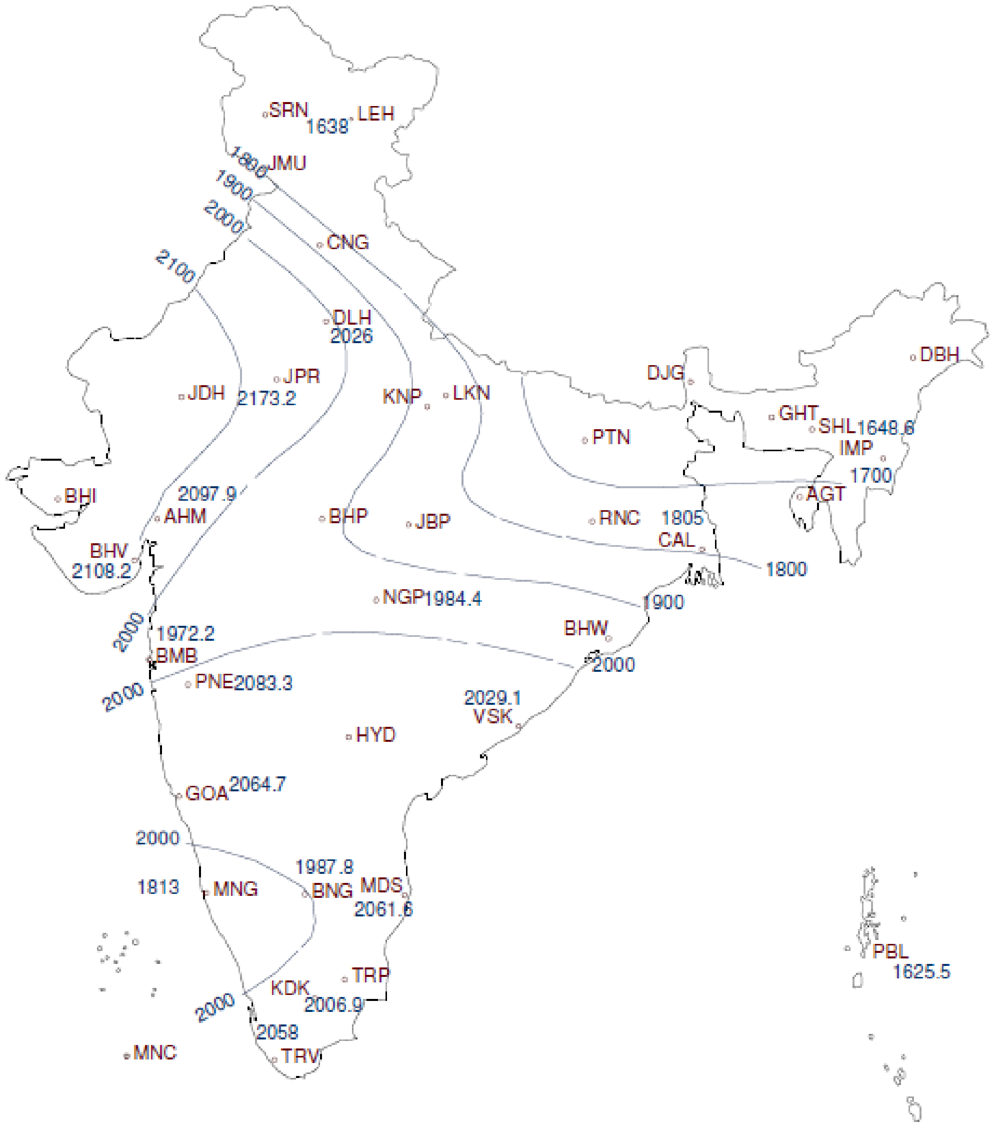


Figure3.2: Availability of solar radiation (in kWh/m^2-year) in the country [11]

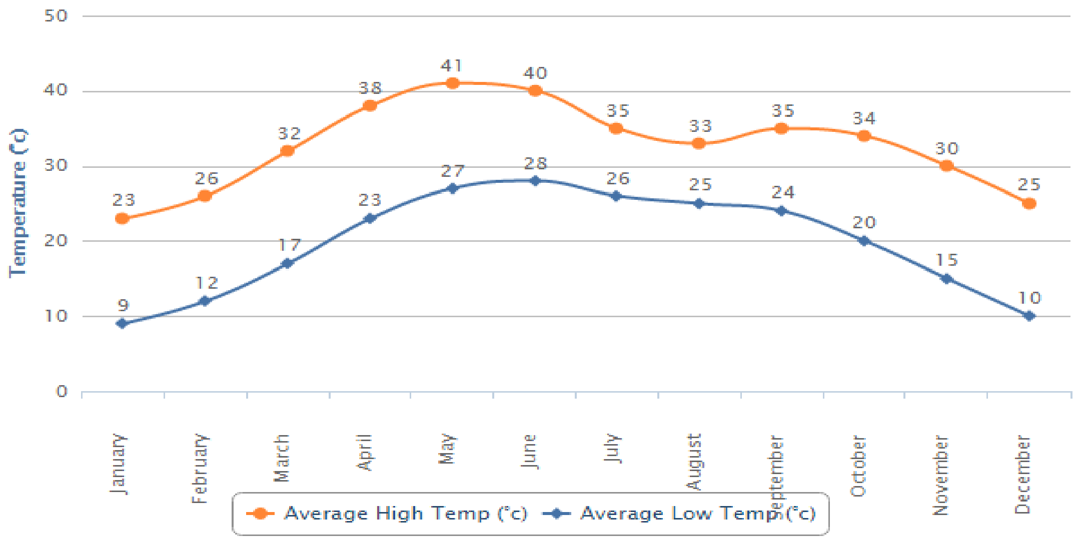
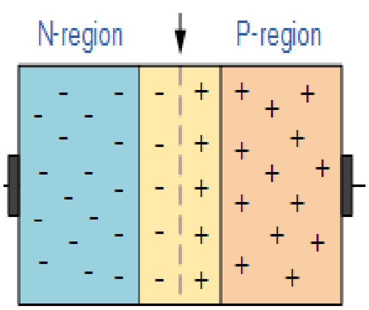


Figure3.3: Monthly Temperature Distribution [36]

3.6 Photovoltaic cell:

When a Photons of light with energy higher than the band-gap energy of semiconductor material fall on the semiconductor material, make electrons free from atoms and create holes and these electrons will soon fall back into holes when charge carriers disappear. If an electric field is applied across semiconductor material it can supply free electrons and holes with the extra energy they require to cross the junction. The photoelectric effect is define as the emission of electrons from the surfece of a metal due to incident light.[12]



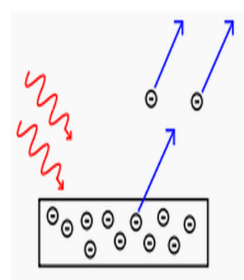


Figure3.4: semiconductor device [12] **Figure3.5: photoelectric effect [12]**

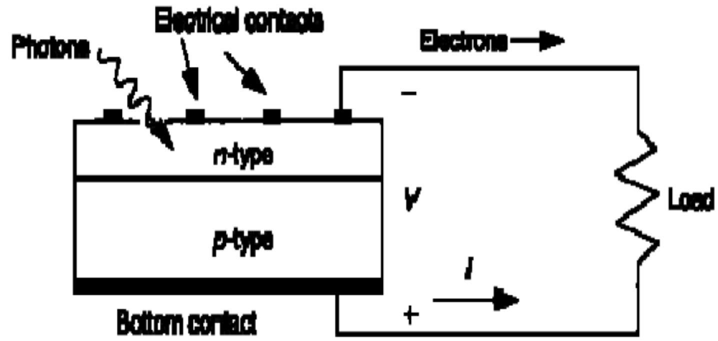


Figure3.6: equivalent circuit diagram of PV cell when connected to load [12]

There are two electrical contacts in PV cell on its top and bottom to capture the electrons.When the load is connected across the PV cell, the PV cell delivers power to the load . Electrons starts flowing from n-side, through connecting wire and load, and back to the p-side where they recombine with holes. The current starts flowing in the opposite direction from electron.

The PV cell consists of an ideal current source in parallel with an ideal diode. The curent generated by photons is represented by the current source generated and its output is remain constant under constant incident radiation of light andconstant temperature .

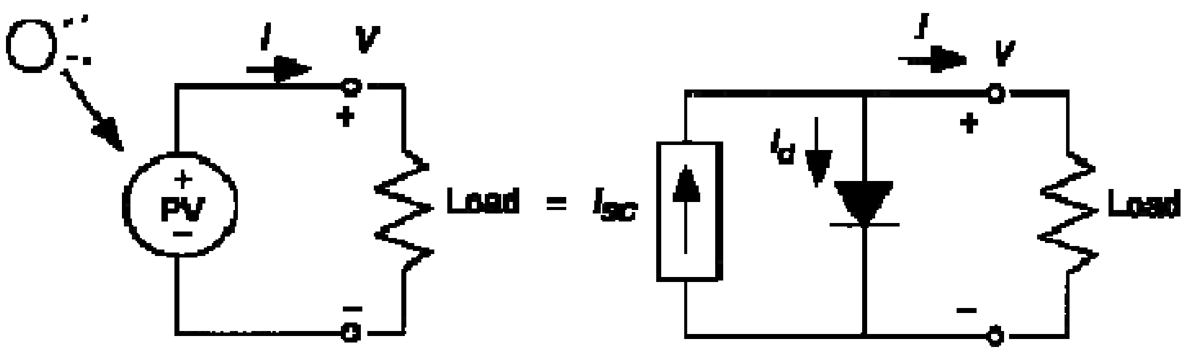


Figure3.7: equivalent circuit of PV cell [12]

To found the output current of PV cell apply kirchoff's current law on the circuit diagram

$$I = I_{sc} - I_d \quad (1)$$

And $$I_{sc} = I_{ph} \quad (2)$$

Where:

I = load current(A).

I_{sc} = short circuit current(A).

I_{ph} = current due to photon(A).

I_d = diode current(A).

The current is measured in ampere and the diode current is represented by following equiation.

$$I_d = I_0\,(e^{qVd/kT} - 1) \qquad (3)$$

Where:

I_0 = reverse saturation current of diode(A)

q = charge of electron(1.602×10^{-19}C)

V_d = voltage across the diode (volt)

K = Boltzmann's constant in joule per kelvin (1.38×10^{-23} J/K)

T = junction temperature in kelvin(K)

So eqution of output current can be written as

$$I = I_{sc} - I_0\,(e^{qVd/kT} - 1) \qquad (4)$$

The I-V plot of ideal PV cell at constant temperature of 25^0C shows that the cell current is directly proportional to the solar radiation.[12]

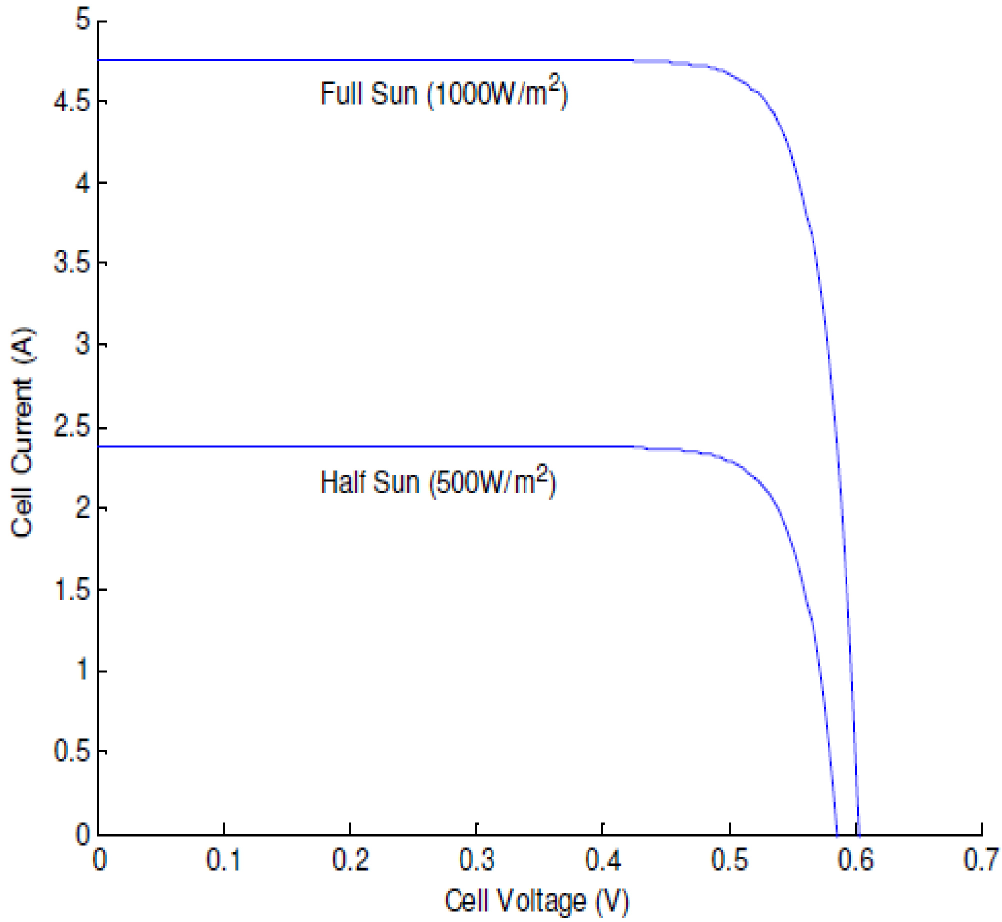


Figure3.8: I-V curve of ideal PV cell under two different levels of irradiancet, temperature of 25^{0}C [12]

3.7 Photovoltaic Module:

The output voltage of a single PV cell is less than 1V and for crystallinesilicon(Si) cell it is about 0.6V. Thus to achive a desired output voltage, number of PV cells are connected in series. These series connected cells are placed in a frame to make a PV module. Two types of PV modules either have 36 series connected crystalline Si cells or have 72 series connected crystalline-Si cells are available in the market for commercial use. A 36 cell module is suitable for 12V battery and 72 cell module is suitable for 24V battery.[12]

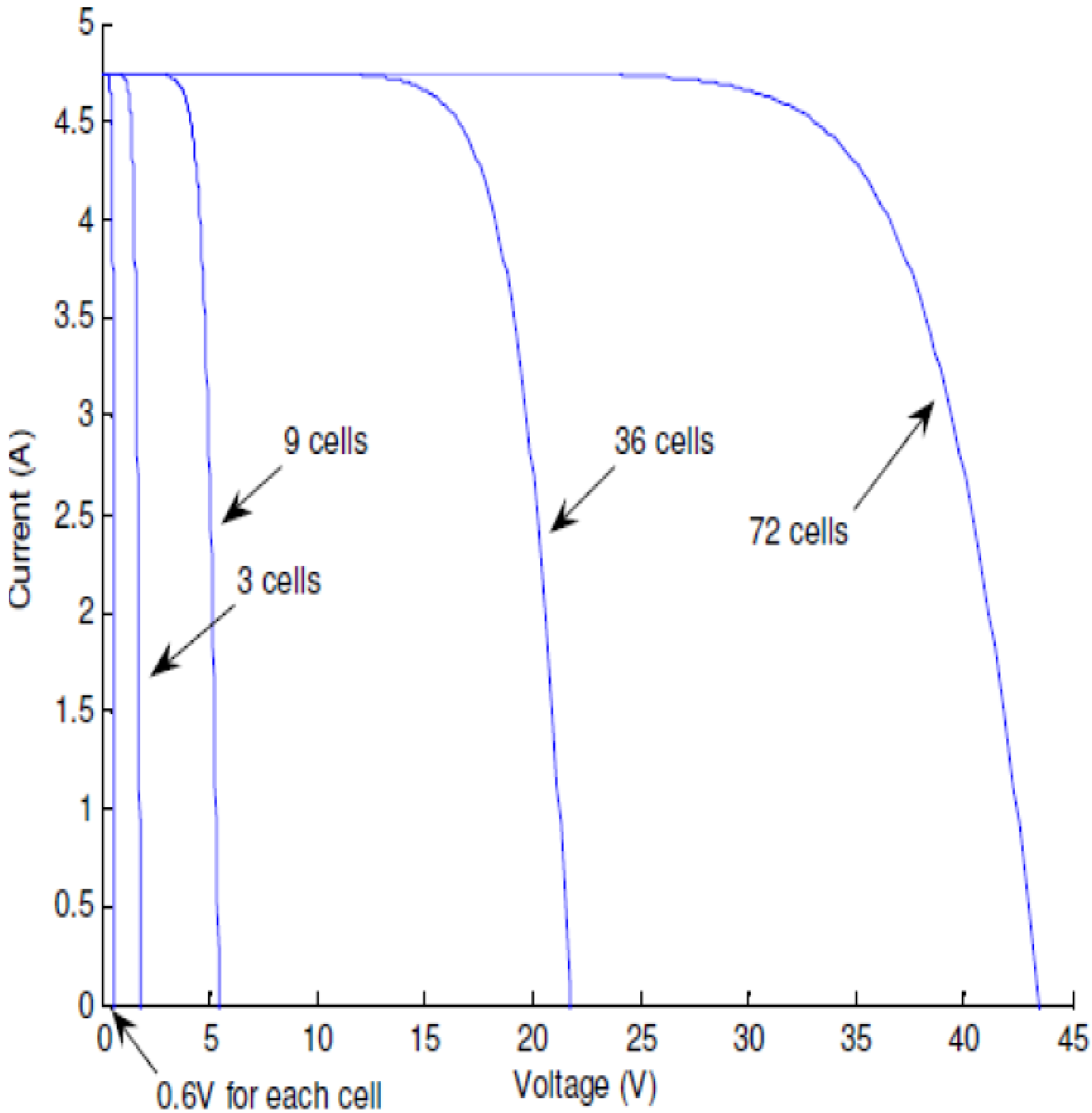
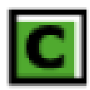
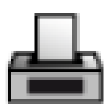


Figure3.9 : PV cells are connected in series to make up a PV module [12]

3.8 Testing of PV module at Different Environmental Conditions using INSEL:

About Insel: INSEL (Integrated Simulation Environment language) provides an integrated environment and a graphical programming language for the creation of simulation applications. INSEL was originally developed for modeling of renewable energy systems at the faculty of physics of Oldenburg University, Germany.[30]

Table3.1 INSEL block details[30].

S.No.	Name of block	symbol	Use in SIMULINK model
1	PVI block		The PVI block is used for calculation of temperature and output current of a crystalline Photovoltaic generator (SM 55 Siemens module). The output of PV generator depends on voltage, global radiation on the generator plane, wind speed and ambient temperature.
2	DO BLOCK		The DO block is used for giving voltage input to the PIV module. DO block vary the voltage in a range between 0 to 25 volt with a constant increment of 10 millivolt.
3	CONST BLOCK		The CONST block defines a constant. In this circuit diagram two CONST blocks are used to provide values for the global radiation and the module temperature.
4	MUL BLOCK		The MUL block multiplies its inputs
5	GOH BLOCK		The block GOH calculates the solar radiation the Earth's atmosphere radiation
6	CLOCK BLOCK		The CLOCK block generates date and time of the actual simulation time step with constant increment.
7	DOY BLOCL		The DOY block returns the day of the year.
8	PLOT BLOCK		The PLOT block generates graphical output of its connected input data via GUNPLOT.

For testing of photovoltaic module at different environmental condition of laxmangarh (sikar) town SM 55(Siemens module) PV module is selected which is available in blocks directory of INSEL. INSEL blocks directory contain more than five thousand parameter sets for all Modules that are available in the market. The PVI block(SM 55 module) is selected to simulate the behavior of solar cells at different temperature (in degrees Celsius) and solar radiation (in W/m^2). In Photovoltaic, electromagnetic radiation is directly converted to electricity.

Table3.2 Block and their perameters[30]

S.No.	Name of block	Input parameters	Output paramrters
1	PVI block	Minimum three inputs are required for PVI Block simulation • PV cell voltage(V) • Global radiation on the generator plane G (in W/m^2) • Temperature (degrees Celsius)	• Current(in Ampère) • Cell temperature (degree Celsius).
2	DO BLOCK	• Initial valve of voltage: 0V • Final value of voltage: 25V • Increment in voltage: 0.1V	• The output signal of DO block runs from 0V to 25V in steps of 0.1v
3	CONST BLOCK	• Global radiation and temperature	• Global radiation G (in W/m^2) and temperature(degrees Celsius)
4	GOH BLOCK	• Year a • Month(1 to 12) • Day (1 to 31) • Hour (0 to 23)	Global radiation G (in W/m^2)

5	PLOT BLOCK	• X axis • Y axis	• The curve
6	MUL BLOCK	The MUL block multiplies its inputs	
7	CLOCK BLOCK	The DOY block returns the day of the year.	
8	DOY BLOCL	The CLOCK block generates date and time of the actual simulation time step with constant increment	

Table3.3: technical specification of SM 55 module[30]

S.NO	Parameters	details
1	Number of cells in series per module	36
2	Number of cells in parallel per module	1
3	Single cell area(in m^2)	0.01
4	Single module area(in m^2)	0.494
5	Band gap(eV)	1.14
6	Coefficient of short-circuit current density(Volt)	0.2841
7	Temperature coefficient of short-circuit current($V^{-1}K^{-1}$)	0.000164
8	Coefficient of saturation current density (Shockley diode)(Am^{-2} K^{-3})	14589
9	Coefficient of saturation current density(Recombination diode)(Am^{-2} $K^{-5/2}$)	1.189
10	Series resistance(Ω m^2)	0.00013041
11	Parallel resistance (Ω m^2)	0.0899
12	Diode ideality factor α	1
13	Diode ideality factor β	2
14	Bishop parameter a	0
15	Bishop parameter m	0
16	Bishop parameter V_{br}/V	0
17	Module tolerance plus (%)	5
18	Module tolerance minus (%)	-5
19	Characteristic module length(in meter)	0.459
20	Module weight(in kg)	6.65
21	Absorption coefficient	0.7
22	Emission factor	0.85
23	Specific heat of a module(in Jk$g^{-1}K^{-1}$)	900
24	Nominal operating cell temperature(degree Celsius)	47
25	Single cell voltage error tolerance	0.001

3.9 Software modelling

The Simulink model for calculation of solar radiation is shown in figure 3.15. Figure 3.16 and 3.17 are used to plot I-V characteristics and DC power output of PV module. Similarly figure3.18 is used to find out the behaviour of PV module at different values of solar radiation while the temperature kept constant at 25^0C. The details of blocks which are used in Simulink model are given in table 3.9. Table 3.10 provides the technical specification of PV module which is selected for testing. The output current and the temperature of a crystalline photovoltaic generator are calculated by using PVI block. The behavior of PV generator is depending on voltage, global radiation on the generator plane, ambient temperature, and wind speed.

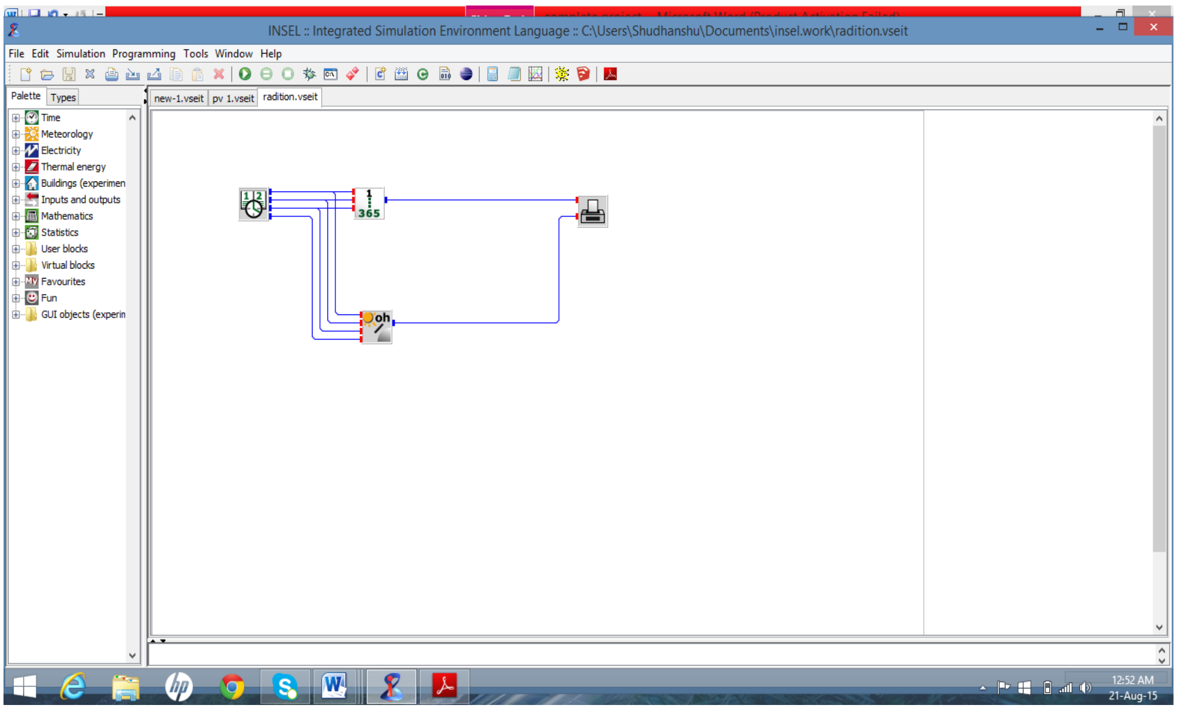


Figure 3.10: SIMULI NK model for calculation of solar radiation

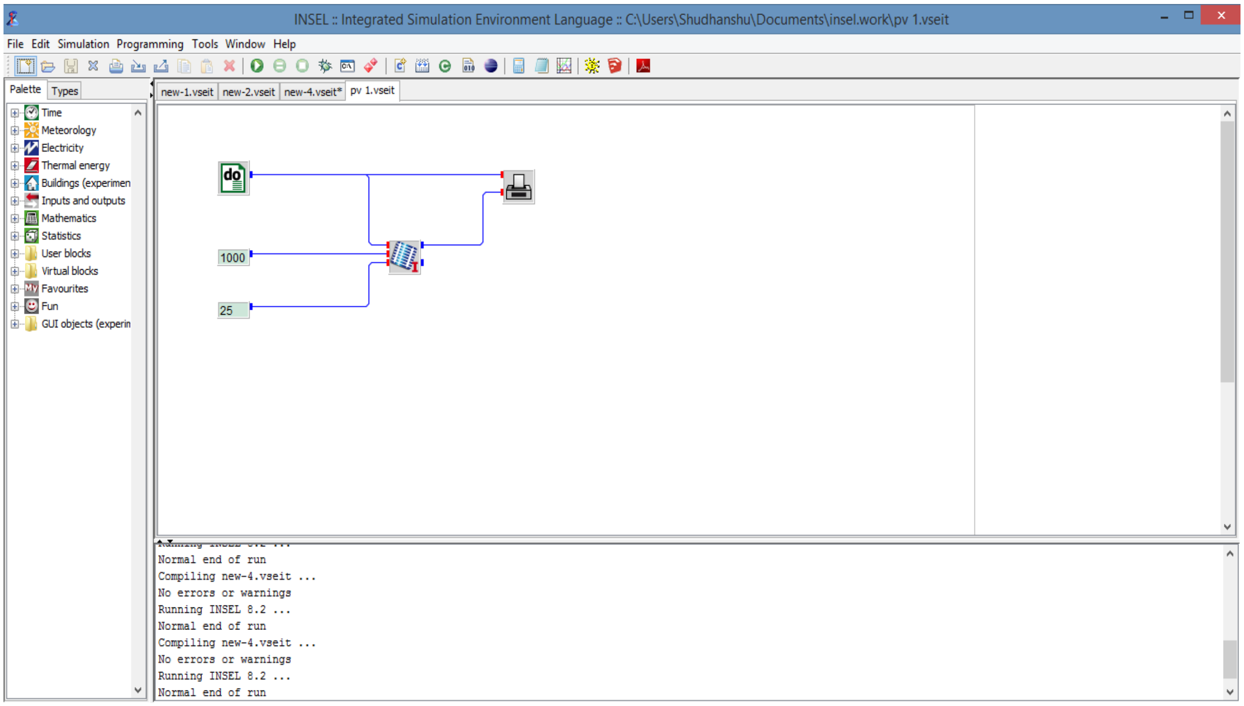


Figure 3.11: SIMULI NK model for I-V characterstics

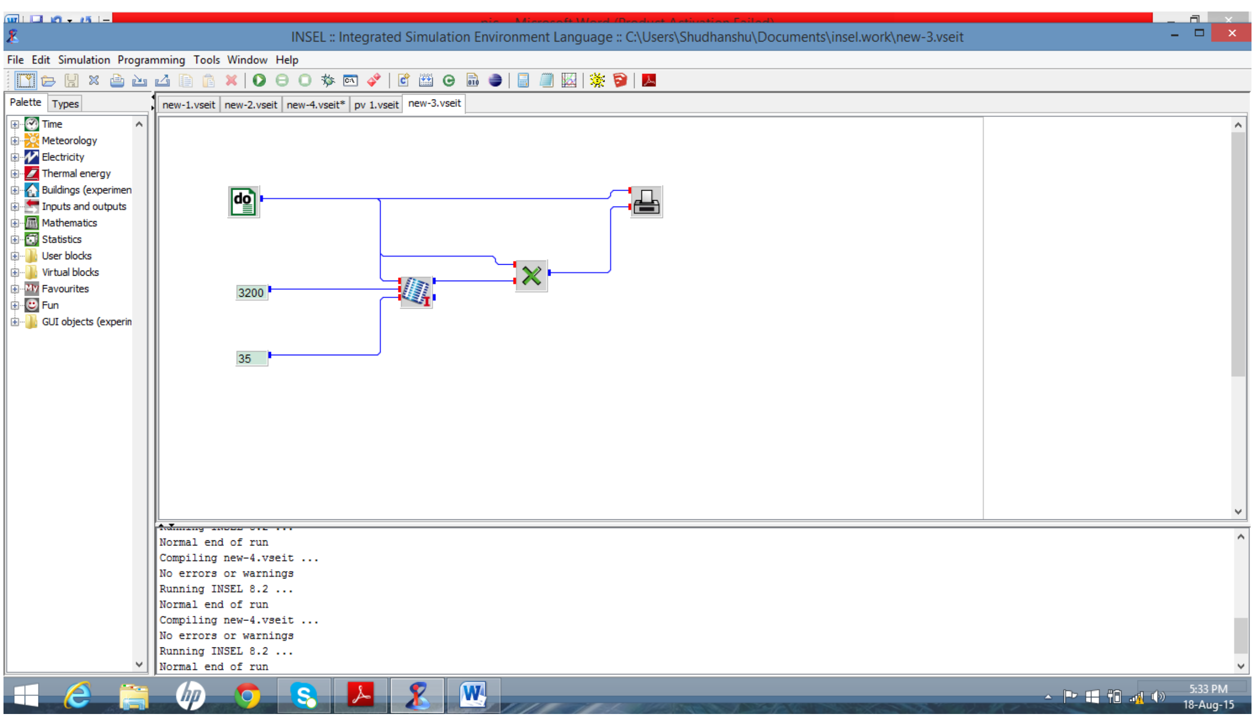


Figure 3.12: SIMULI NK model for calculation of DC power output

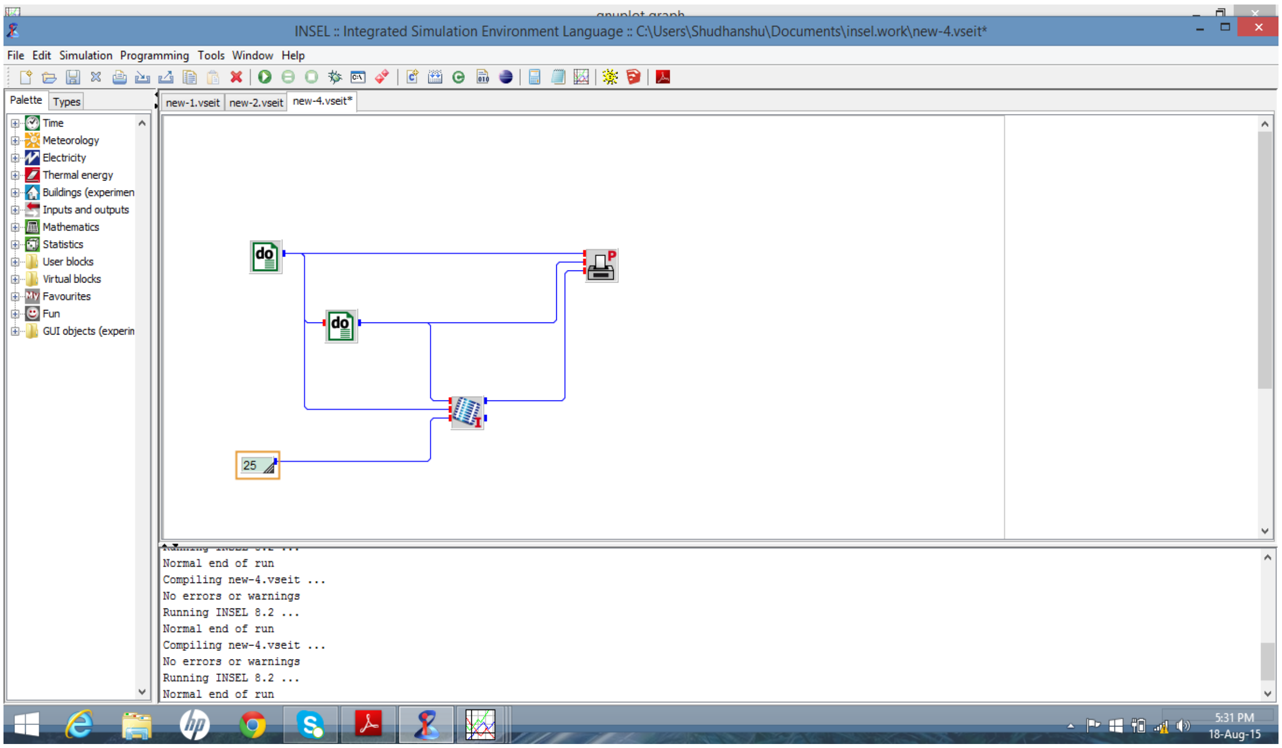


Figure 3.13: SIMULI NK model forI-Vcharacterstics at different solar radiation

3.10 DC to DC converter

For charging of battery, the output voltage needs to be stepped down to provide required starting current for battery charging. The buck converter is used for this purpose.[31]

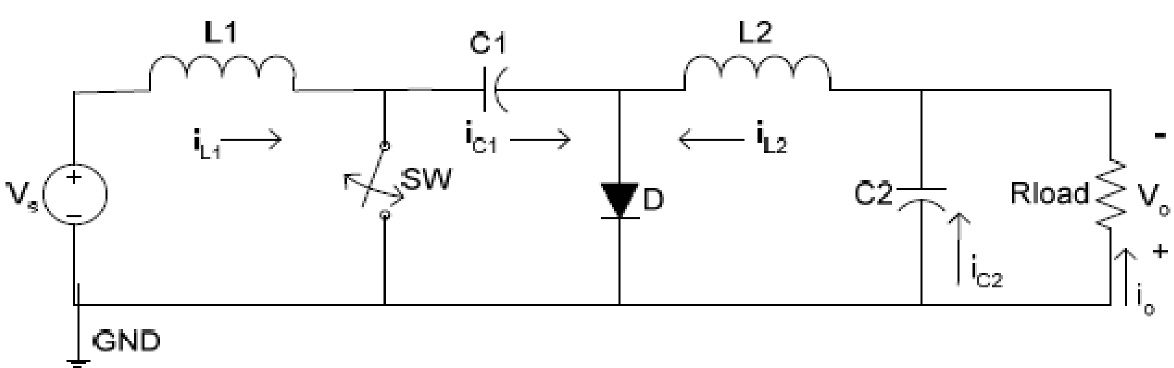


Figure 3.14: Circuit diagram of the basic buck converter

3.10.1 Buck Converter Design:

Buck converter is designed based on the specification shown in the table below.

Table 3.4: Design Specification

specification	
Input voltage (V_s)	25-50 V
Input current (I_s)	0-5 A
Output voltage (V_o)	15-30 V (<5% ripple)
Output current (I_o)	0-5 A (<5% ripple)
Maximum output power (P_{max})	150 W
Switching frequency (f)	50KHz
Duty cycle (D)	$0.1 \leq D \leq 0.6$

3.10.2 Component Selection

a) Inductor Selection[31]

The sizes of inductor are decided using following equations:

$$\Delta I_L = \frac{Vs.D}{L.f} \qquad (5)$$

$$L = (Vs.D) / (\Delta I_L.f) \qquad (6)$$

The inductor sizes are decided such that the change in inductor currents is no more than 5% of the average inductor current. where: Vs is the input voltage, D is the duty cycle, and f is the switching frequency

b) Capacitor selection[31]:

The sizes of input capacitor are decided using following equations:

$$C_1 = \{(V_0.D)\} \div \{(R.f.\Delta V_c)\} \qquad (7)$$

The value of output capacitor (C_2) is calculated using the output voltage ripple equation

$$\Delta V_0 / V_0 = \{(1 - D)\} \div \{(8.L_2.C_2.f)\} \qquad (8)$$

Where: V_0 is the out put voltage , D is the duty cycle, f is the switching frequency and ΔV_o is ripple voltage.

$$C_2 = \{(1- D)\} \div \{(\Delta V_0 / V_0).L_2.f^2\} \quad (9)$$

The following transfer function is used for duty cycle(D) calculation[32]

$$\Delta V_0 / V_0 = D/ (1- D)$$

- If $0 < D < 0.5$ the output is smaller than the input.
- If $D = 0.5$ the output is the same as the input.
- If $0.5 < D < 1$ the output is larger than the input.

Chapter 4
Results and discussion

4.1Energy consumption by various feeder of Laxmangarh

To verify the feasibility of PV power the first step is find the consumption of electricity at laxmangarh town which is situated at the Sikar district of Rajasthan state of India. For this purpose, we have studied with the data of one year energy consumption in the town. Feeder 1 is purely urban feeder which consumes approximately 50% of total consumption of sub-station. The main consumers of this feeder are small industries, railways, public hospital, educational institutes, offices, domestic user, etc. Similarly, feeder 2 is a rural feeder which consumes approximately 16-17% of total consumption of the sub-station. The main load of this feeder is due to agriculture. However, feeder 3 is semi urban which consumes approximately 33% of total consumption of the sub-station. The main consumers of this feeder are public hospital, educational institutes, domestic user, etc. As we can see that feeder 1 and feeder 3 need continuous supply of electricity whereas feeder 2 does not. That's why feeder 2 may be a possible alternative to consume the solar power. Table 4.1 shows the energy consumption in KWh for incomer and all three feeders respectively. Similarly table 4.2 presents monthly load details of feeder 2.

Table 4.1: Energy consumption in KWh at 132 KV sub station

Months	33KCV I/C	33 KV feeder-1	33 KV feeder-2	33KV feeder-3	Avg Power factor
July-14	2178030	1159019	254060	764933	0.96
Aug-14	2179035	1159511	254231	765273	0.97
Sep-14	2321042	1160500	394568	765921	0.95
Oct-14	2322039	1161027	344751	766271	0.96
Nov-14	2322029	1176563	389298	765100	0.95
Dec-14	3085029	1542513	516738	1048900	0.97
Jan-15	3185036	1624352	525525	1051043	0.93
Feb-15	2882034	1469820	461120	951060	0.96
Mar-15	2985043	1492531	507453	985057	0.97
April-15	3248037	1656481	519682	1006883	0.94
May-15	3254049	1561921	520644	1203978	0.97
June-15	2991040	1465590	508465	1046847	0.94

A graph showing the variation of system load during the days of month is known as the system chronological load curve. A load duration curve is a rearrangement of all the load elements of a chronological curve in a descending order thus it shows the variation in demand with time. The area under a load curve which the energy consume (i.e. kwh) during the month. Figure 4.1presents the chronological load curve for incomer, feeder 1, feeder 2 and feeder 3.

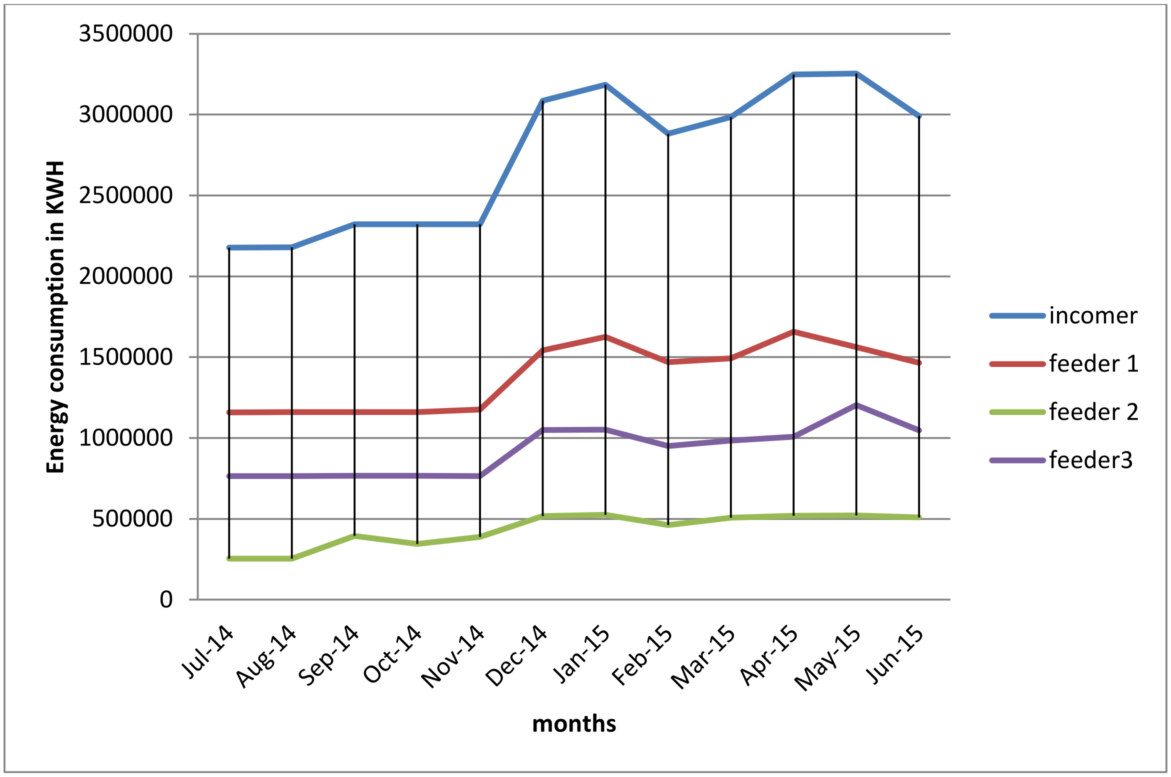


Figure 4.1: Chronological Load Curve

TABLE 4.2: Feeder 2 monthly load details (in ampere)

Months	Monthly Avg load (ampere)	Maximum load during month(ampere)	Minimum load during month(ampere)	Avg irrigation load(ampere)	Domestic load(ampere)
July-14	20	29	2	16	4
Aug-14	23	36	3	18	5
Sep-14	28	37	2	22	6
Oct-14	22	35	4	19	3
Nov-14	21	33	3	17	4
Dec-14	27	36	3	24	5
Jan-15	26	37	3	23	4
Feb-15	28	36	4	22	6

Mar-15	27	37	2	22	5
April-15	30	36	2	25	5
May-15	31	33	5	25	6
June-15	28	37	5	23	5

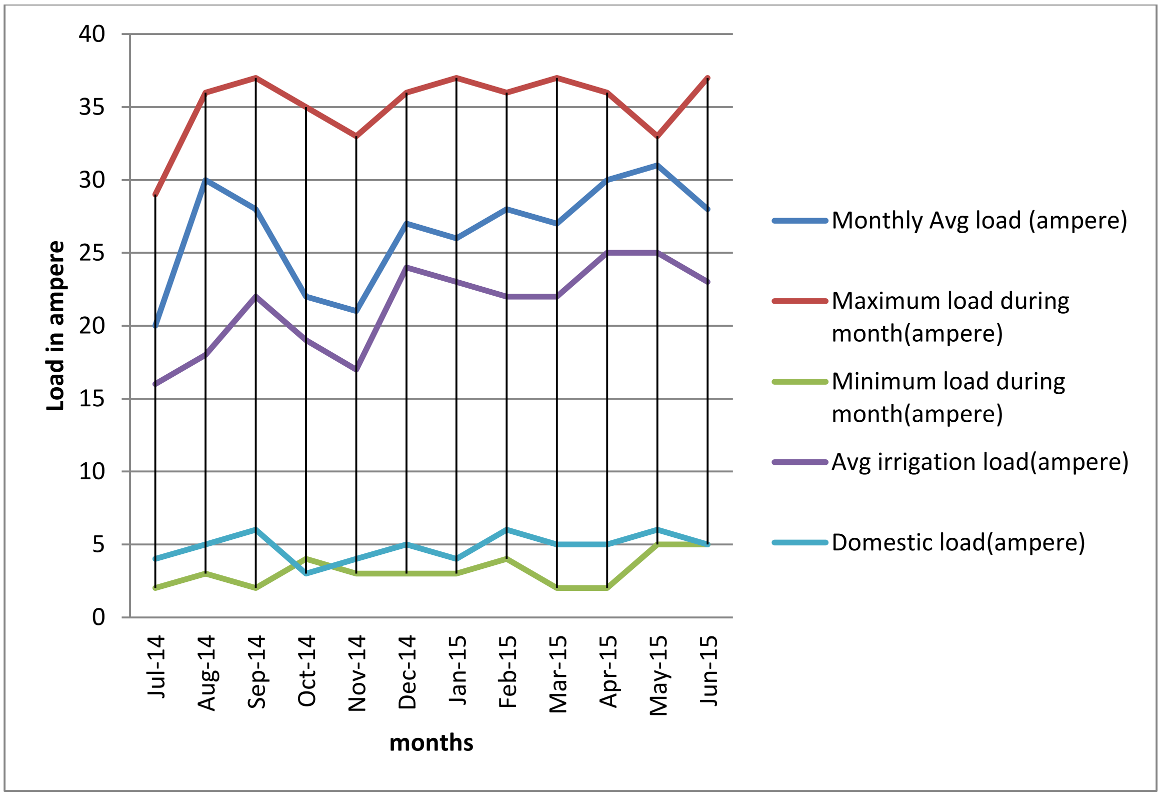


Figure 4.2 Chronological Load Curve

Hence the solar energy may be an alternative source of power at the rural feeder. To check the feasibility of this alternative firstly we will find out the solar radiation at Laxmangarh using INSEL software. Then we will find out the I-V behaviour and DC power out of PV module. Specifications of the PV module are presented in the previous chapter.

4.2 Calculation of annual distribution of solar radiation (W/m^2):

To find out the solar radiation at laxmangarh, we have software named as INSEL. For calculation of solar radiation longitude, latitude and time zone of place are required which are presented in table 4.3 and the interface of the software is shown in figure 4.4 and 4.5. For the calculation of solar radiation SIMOLI NK model is shown in figure 4.3.

Table 4.3: longitude, latitude and time zone of Laxmangarh

S.NO	Parameters	Value
1	latitude	27.8225^0N
2	longitude	75.025278^0E
3	Time zone	GMT+5:30

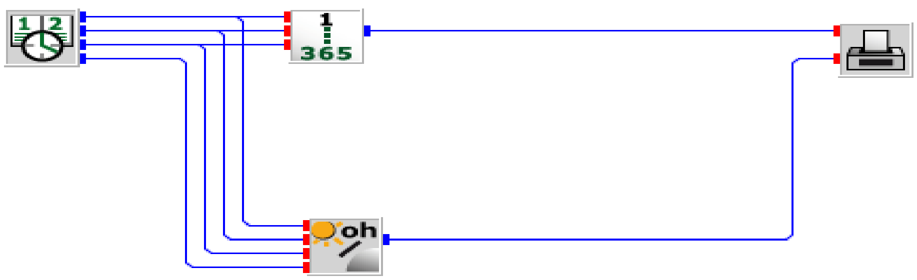


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Figure 4.3: SIMULI NK model for calculation of solar radiation

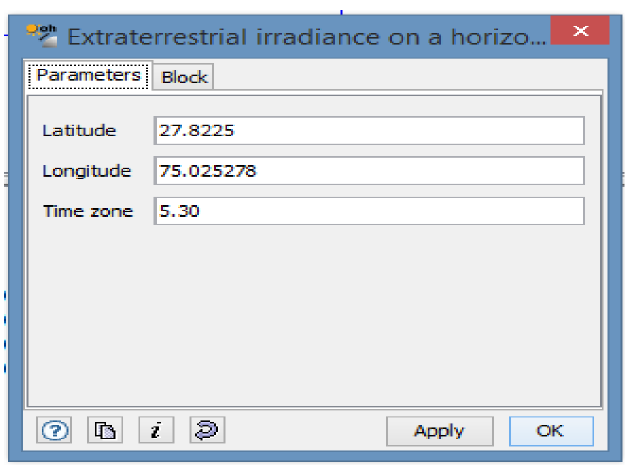


Figure 4.4: simulink solar radiation block parameters

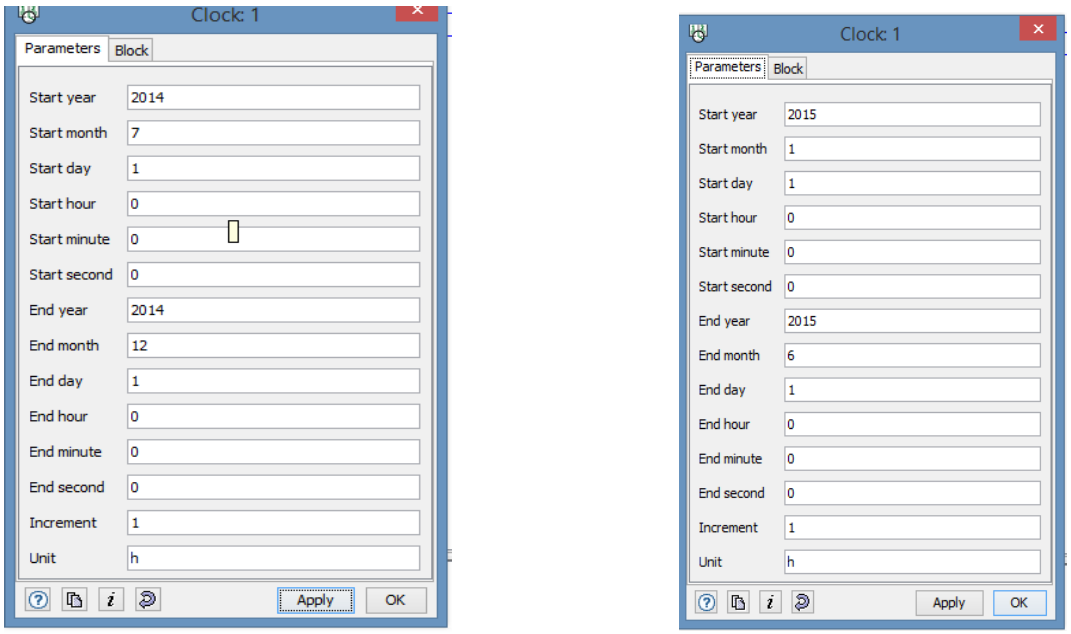


Figure 4.5: clock block parameters

The latitude and longitude are applied to GOH block then variation in the solar radiation with respect to time (in day) are ploted. Figure 4.6 shows the solar radiation during july 2014 to december 2014 while figure 4.7 shows the same for january 2015 to june 2015. In these figures the horizontal axis consist time (in days) while vartical axis have solar radiation (W/m^2)

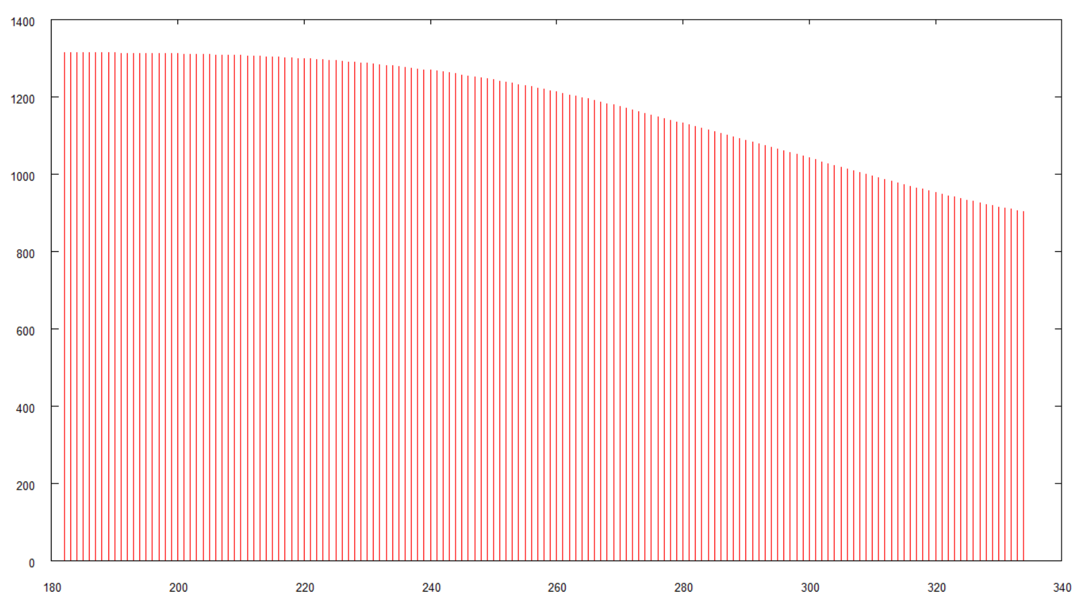


Figure 4.6: simulink plot of solar radiation (july 2014 to december 2014)

{At X axis Number of Days, At Y axis Solar Radiation(W/m^2)}

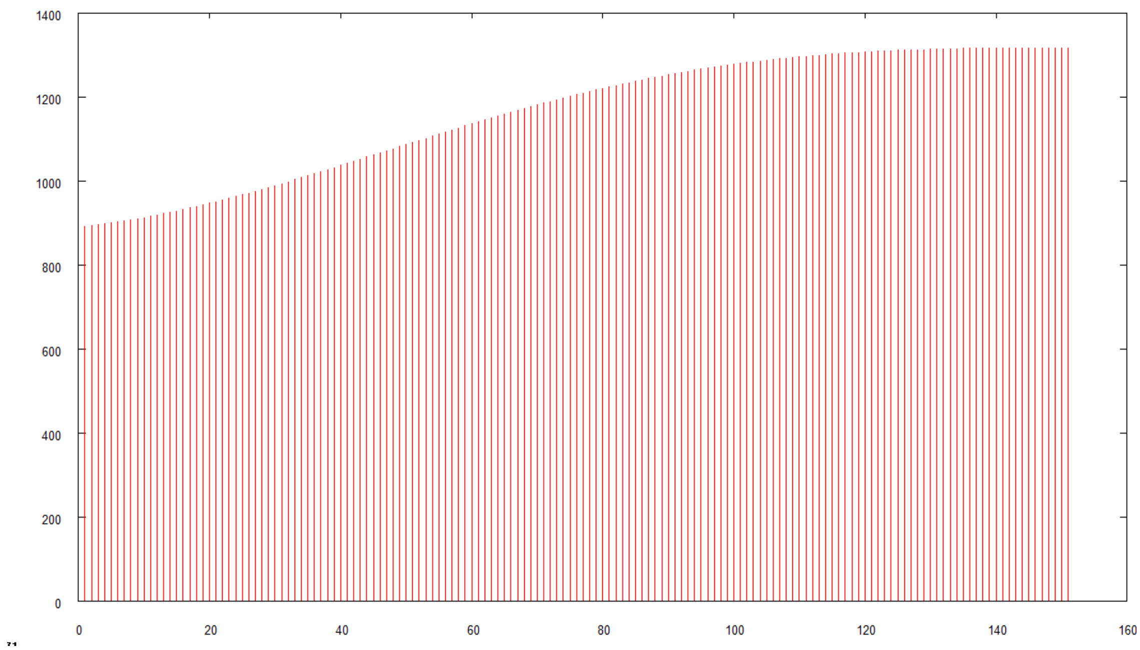


Figure 4.7: simulink plot of solar radiation (january 2015 to june 2015)

{At X axis Number of Days, At Y axis Solar Radiation(W/m^2)}

The INSEL simulation results are shown in table 4.4, where third column provides monthly solar radiation in W/m^2 while the maximum, minimum and the average monthly temparatures are shown in next three column respectivly. As we know that ideal value of globle solar radiation for PV module is 1000W/m^2 and in our study it varies in between 910-1320W/m^2. Hence it is a good environmental condition for solar powwer generation.

Table 4.4: Solar radiation data

S.No	Months	solar radiation (W/m^2)	Maximum Temperature (^{0}C)	Minimum Temperature (^{0}C)	Average Temperature (^{0}C)
1	July-14	1310	35	26	30
2	Aug-14	1280	33	25	31
3	Sep-14	1210	35	24	29
4	Oct-14	1100	34	20	27
5	Nov-14	970	30	15	23
6	Dec-14	940	25	10	15
7	Jan-15	910	23	9	14
8	Feb-15	1080	26	12	18

19	Mar-15	1165	32	17	24
10	April-15	1250	38	23	31
11	May-15	1300	41	27	34
12	June-15	1320	42	30	36

4.3 Behaviour Of PV module At Different solar radiation and temperature Using INSEL

A simulink model is preseted in figure 4.8 to find I-V characterstics of a PV at different temperature and solar radiations. To do so we require three parameters namely voltage, temparature and solar radiations.Similarly figure 4.9 shows the Simulink model to find the DC power output. After making these models, months wise I-V characteristics and DC power outputs are compute.

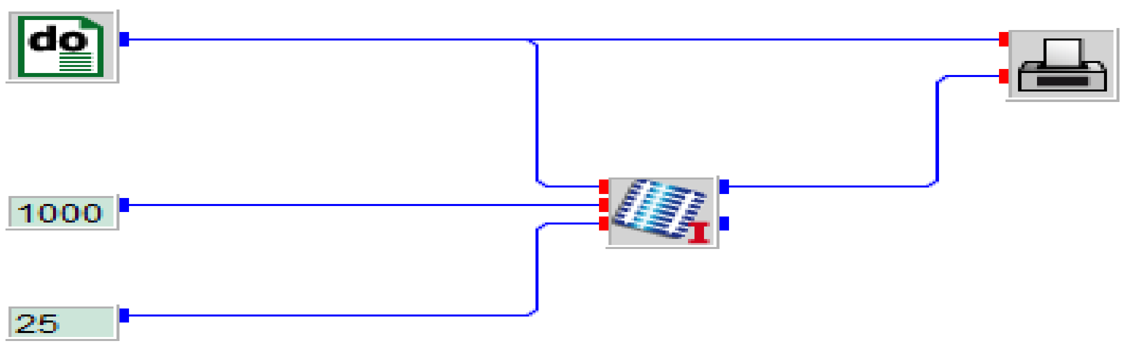


Figure 4.8: SIMULINK model for I-V charcterstics of PIV module

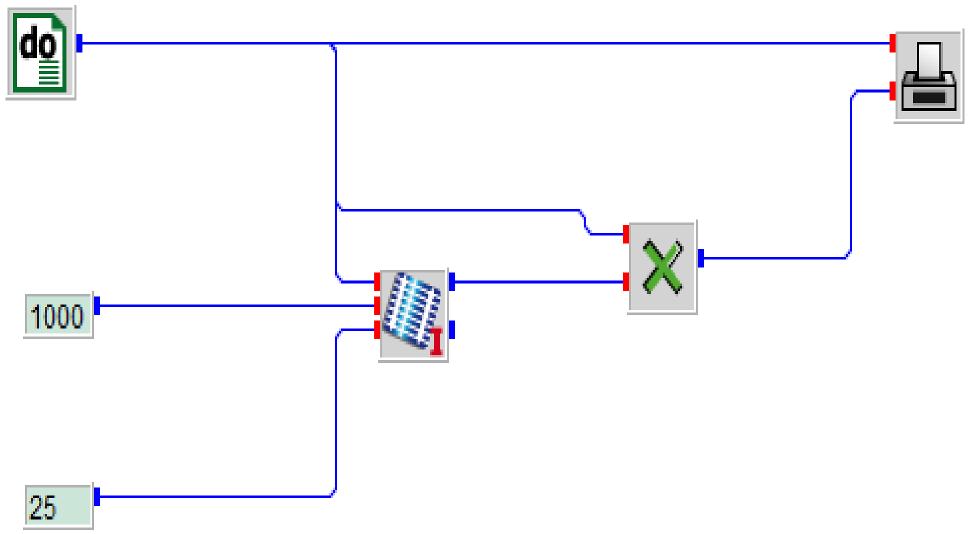


Figure 4.9: SIMULINK model for D.C power output

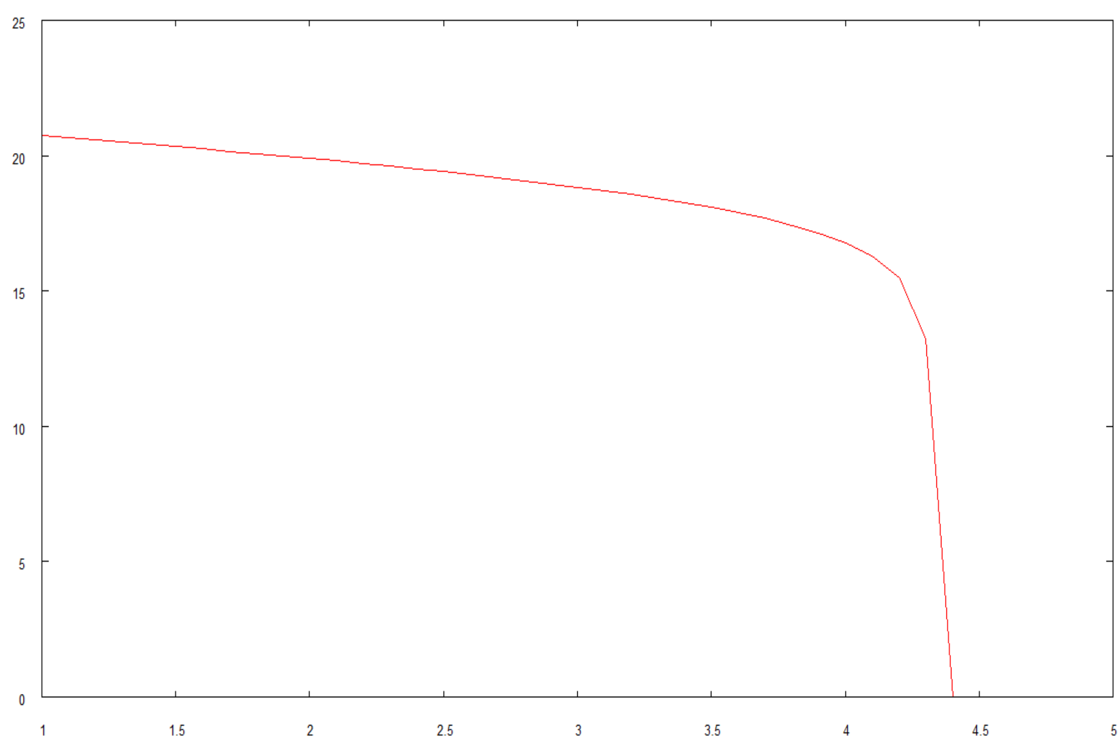


Figure4.10:simulink plot of I-V characterstics for july-2014 at 30^{0}C temperature and solar radiation of 1310(W/m^2) {At X axis Current (A), At Y axis Voltage (V)}

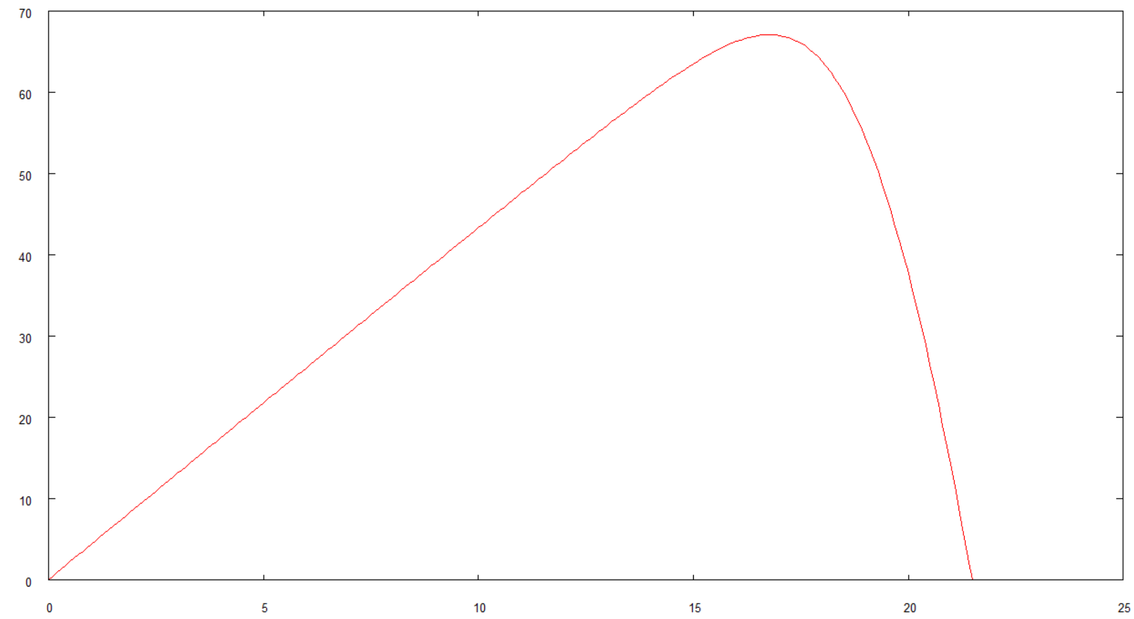


Figure4.11:simulink plot of D.C power output for july-2014 at 30^{0}C temperature and solar radiation of 1310(W/m^2) {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

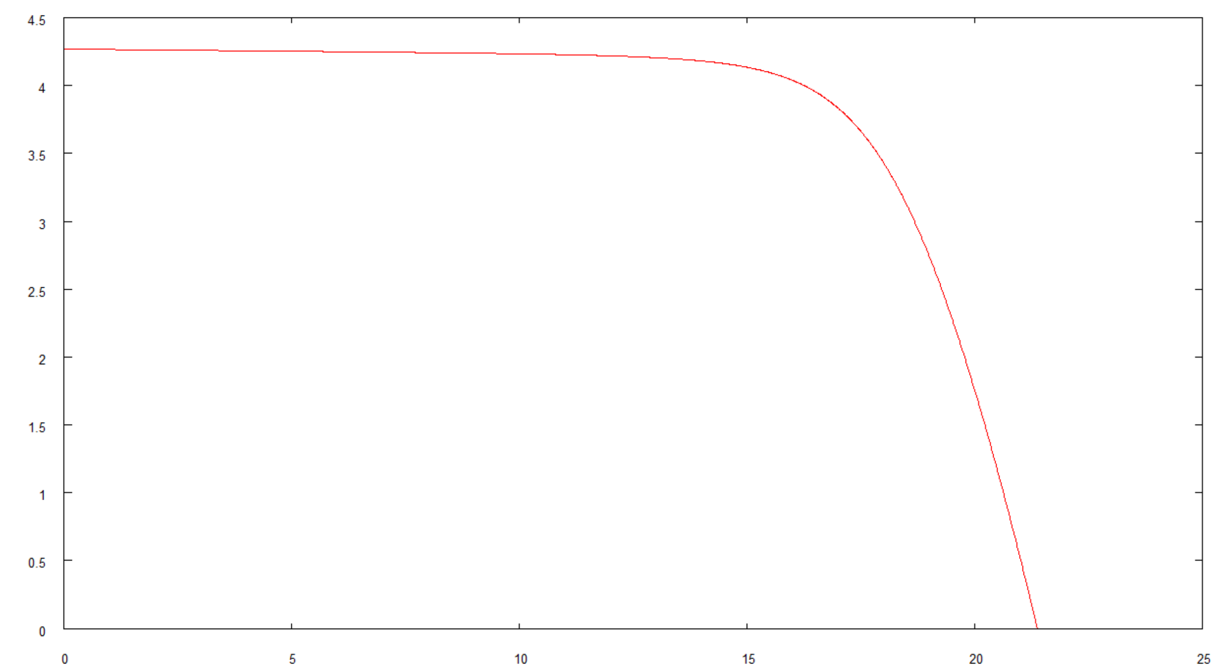


Figure4.12: simulink plot of I-V characterstics for august-2014 at 31^{0}C temperature and solar radiation of 1280(W/m^2) {At X axis Voltage (V), At Y axis Current (A)}

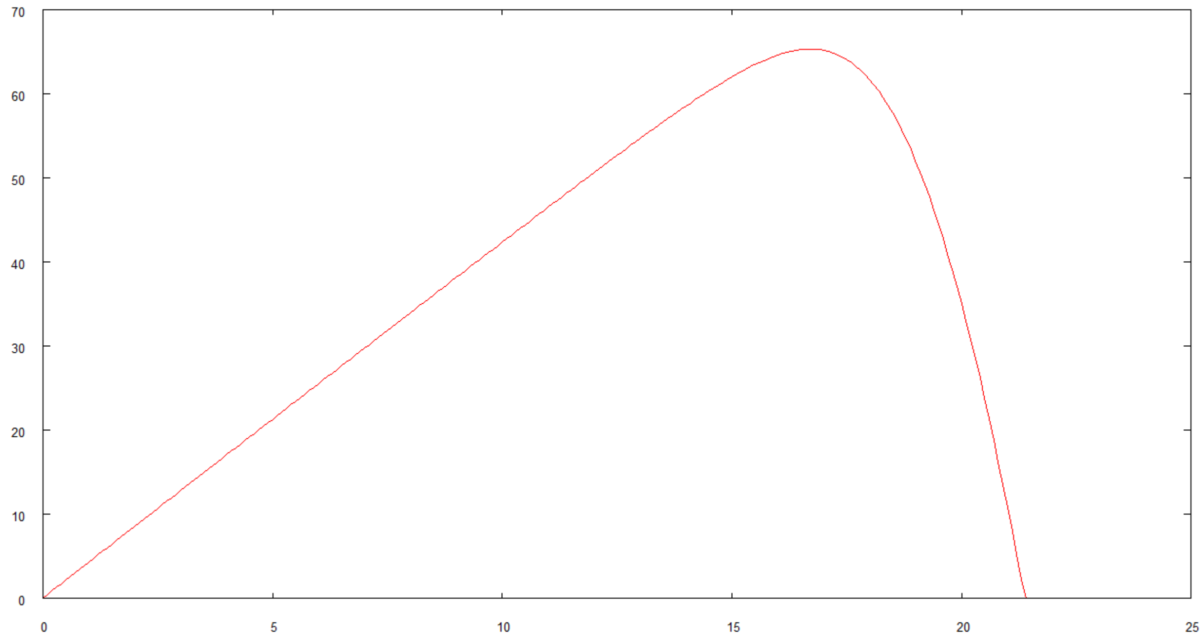


Figure4.13: simulink plot of DC power output for august-2014 at 31^{0}C temperature and solar radiation of 1280(W/m^2) {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

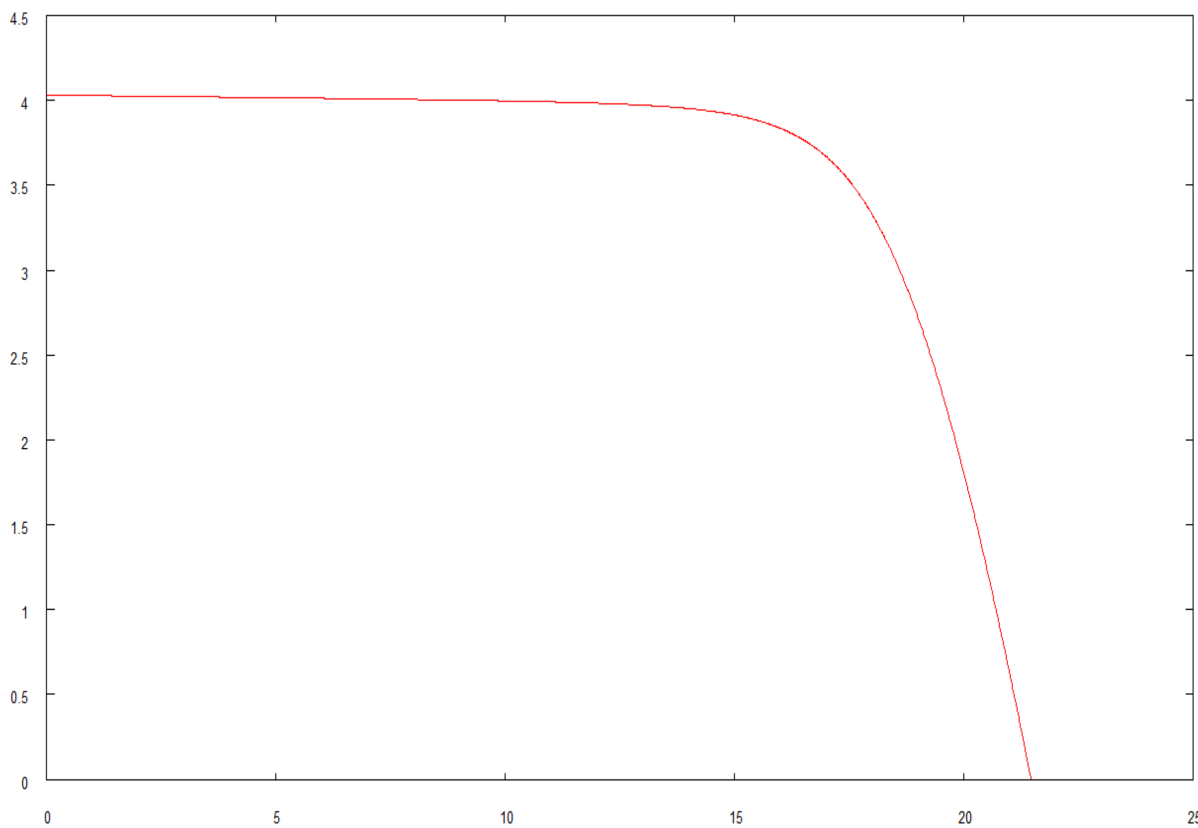


Figure4.14: simulink plot of I -V characterstics for septmber-2014 at 29^{0}C temperature and solar radiation of 1210(W/m^2) {At X axis Voltage (V), At Y axis Current (A)}

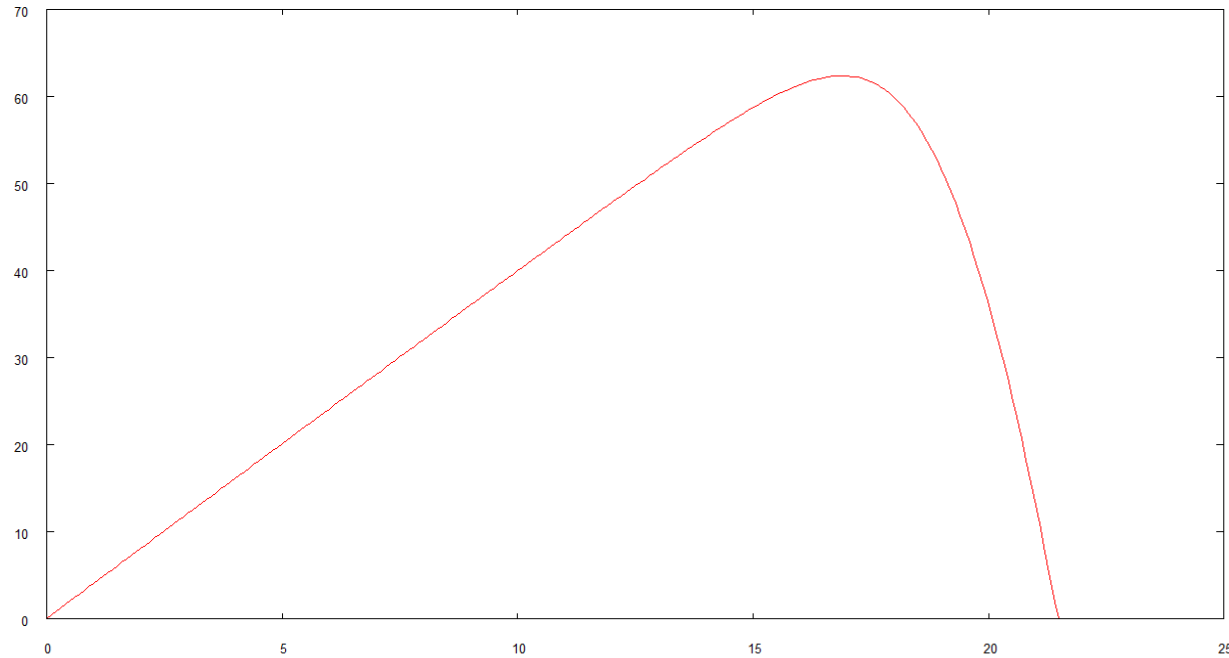


Figure4.15: simulink plot of DC power output for september-2014 at 29^0C temperature and solar radiation of 1210(W/m^2) {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

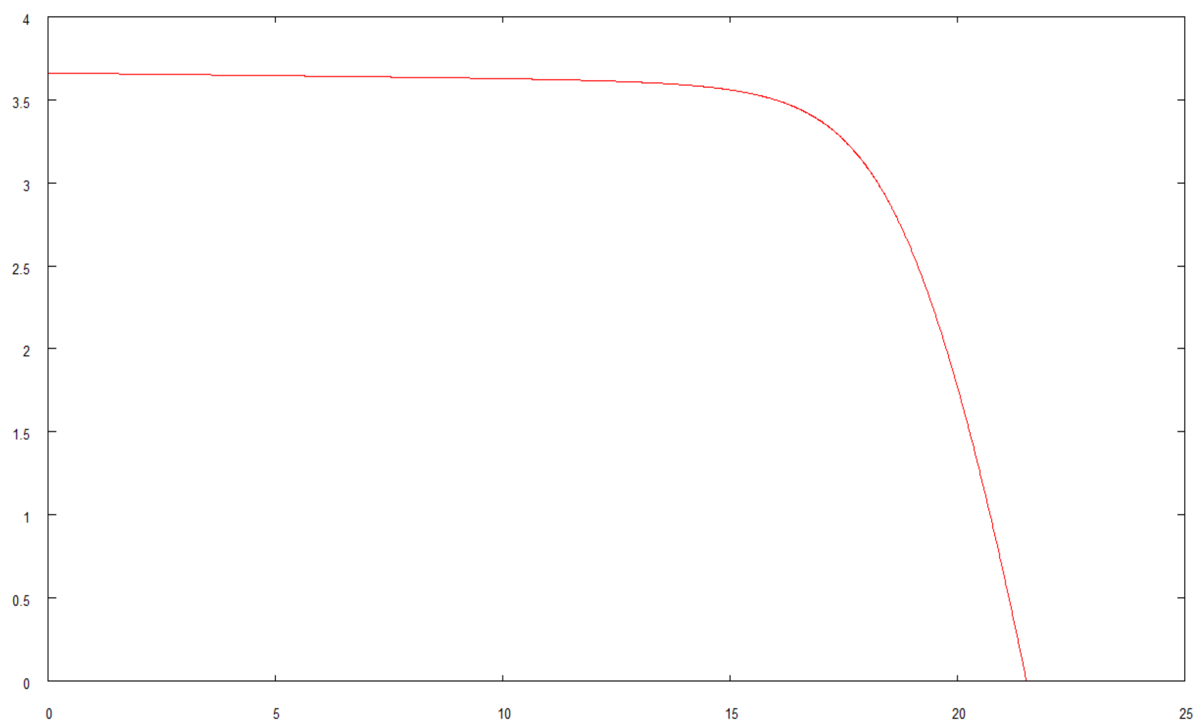


Figure4.16: simulink plot of I-V characterstics for October-2014 at 27^0C temperature and solar radiation of 1100(W/m^2) {At X axis Voltage (V), At Y axis Current (A)}

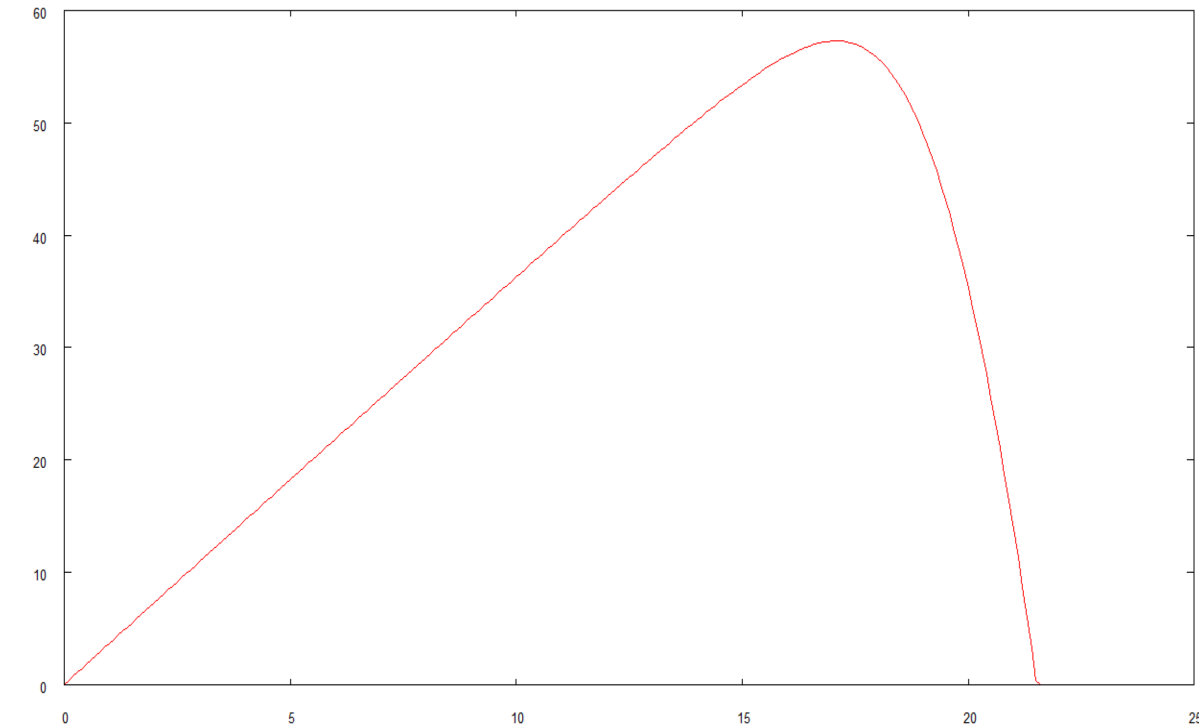


Figure4.17: simulink plot of DC power output for october-2014 at 27^0C temperature and solar radiation of 1100(W/m^2) {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

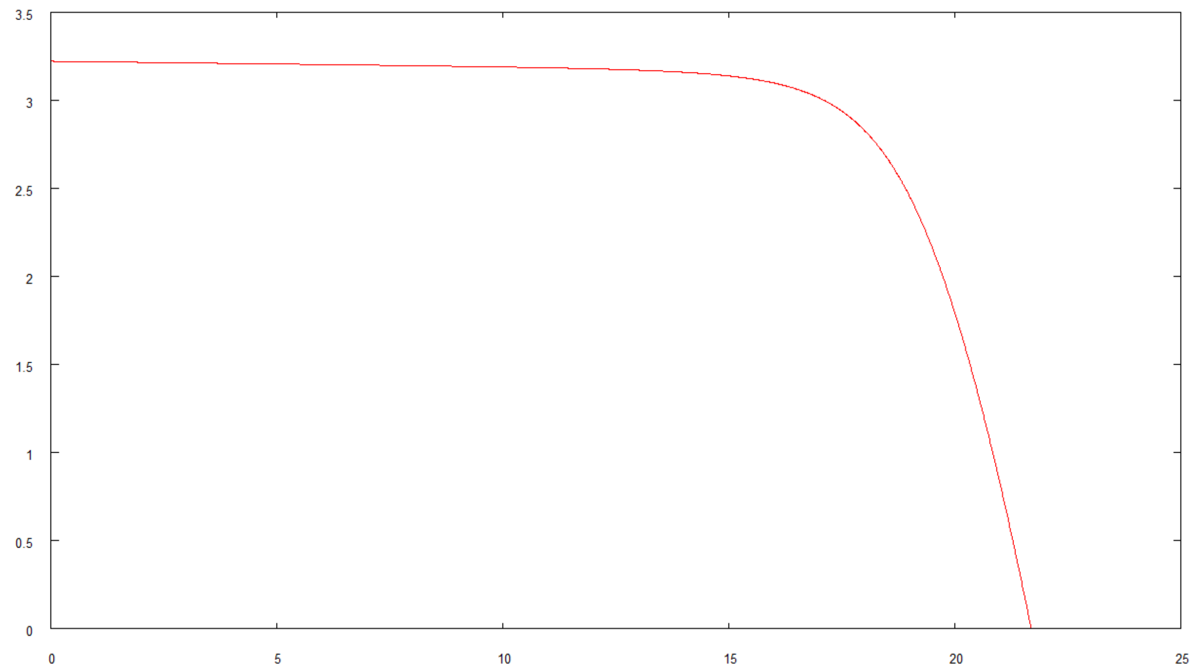


Figure4.18: simulink plot of I-V characterstics for november-2014 at 23^{0}C and solar radiation of 970(W/m^2) {At X axis Voltage (V), At Y axis Current (A)}

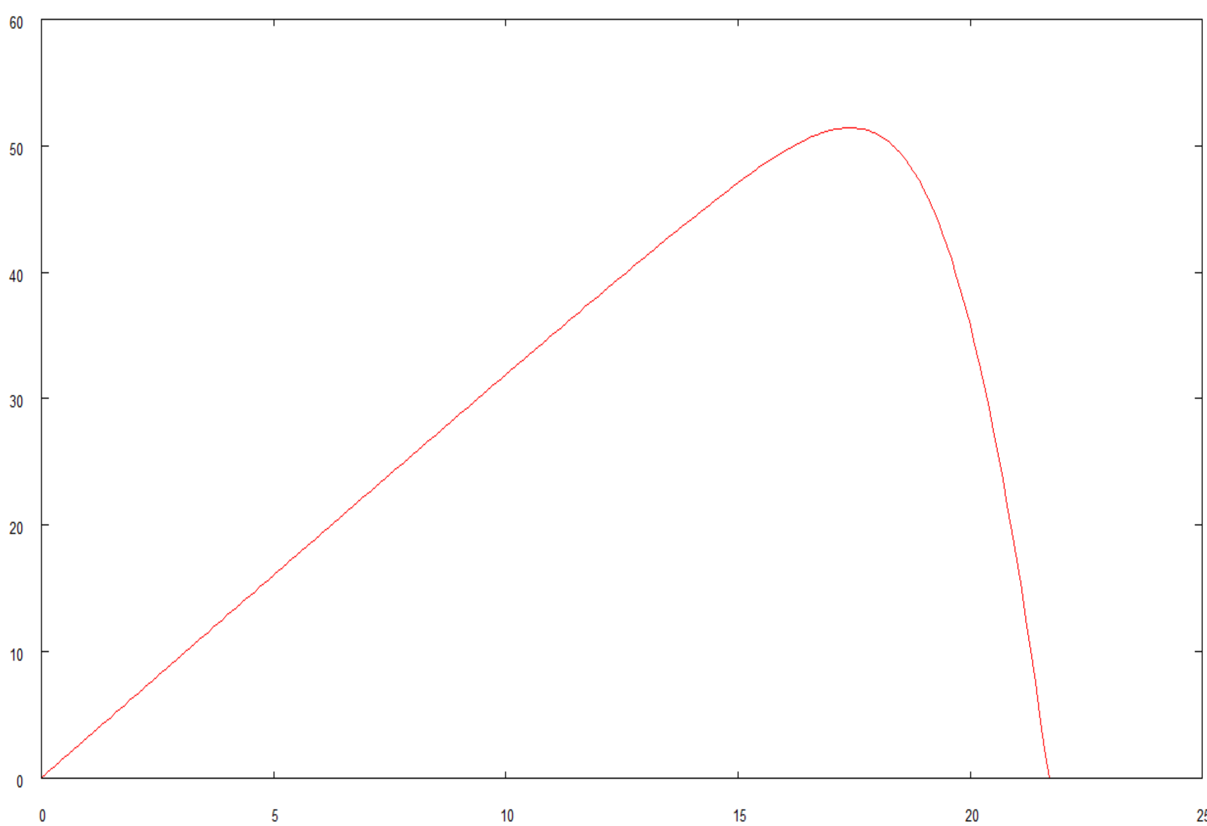


Figure4.19: simulink plot of DC power output for november-2014 at 23⁰C temperature and solar radiation of 970(W/m²) {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

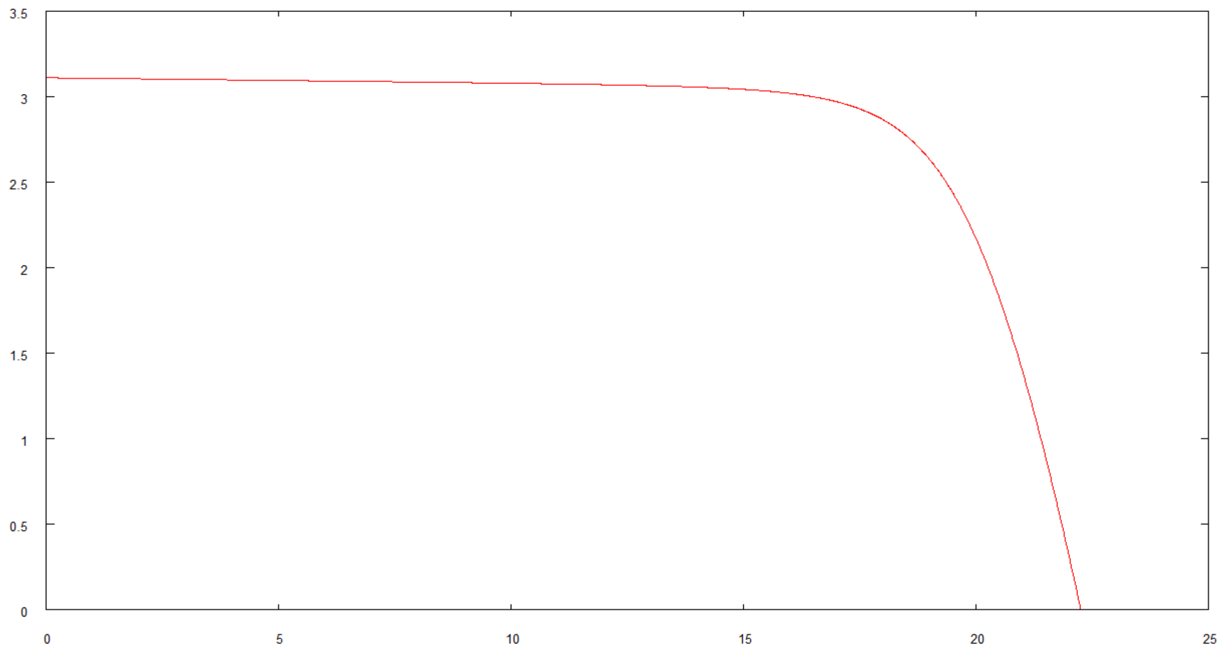


Figure4.20: simulink plot of I-V characterstics for december-2014 at 15⁰C temperature and solar radiation of 940(W/m²) {At X axis Voltage (V), At Y axis Current (A)}

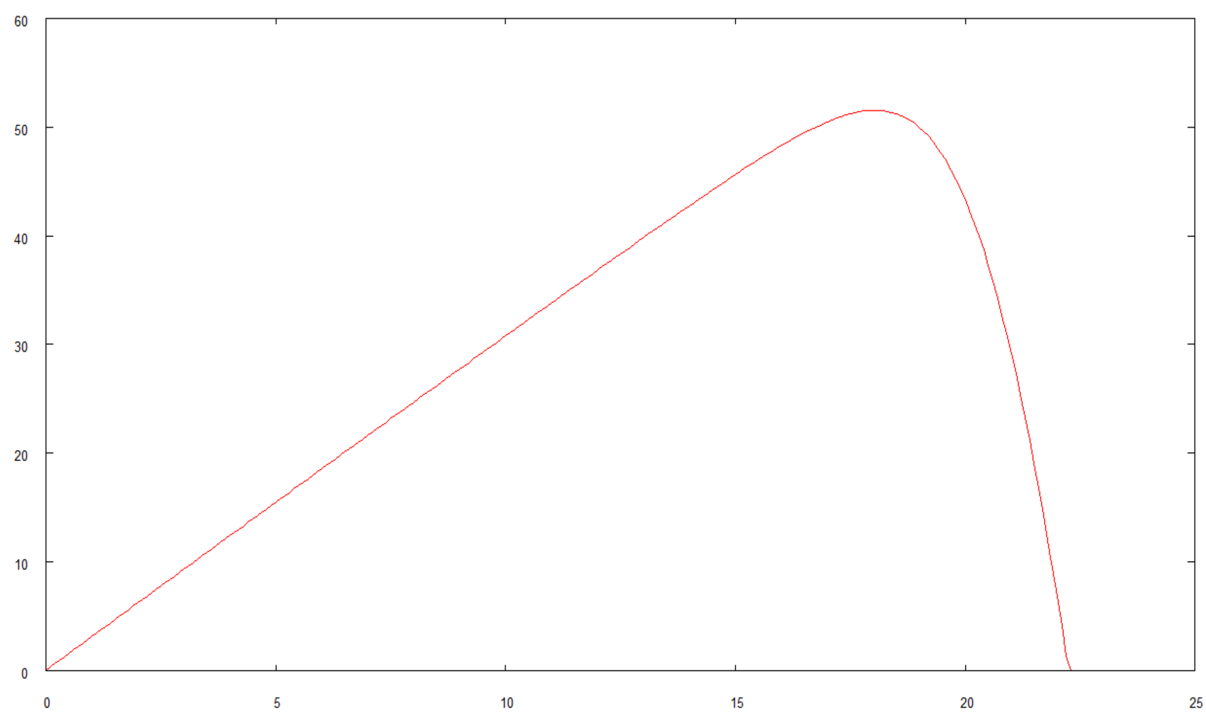


Figure4.21: simulink plot of DC power output for december-2014 at 15⁰C temperature and solar radiation of 940(W/m²) {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

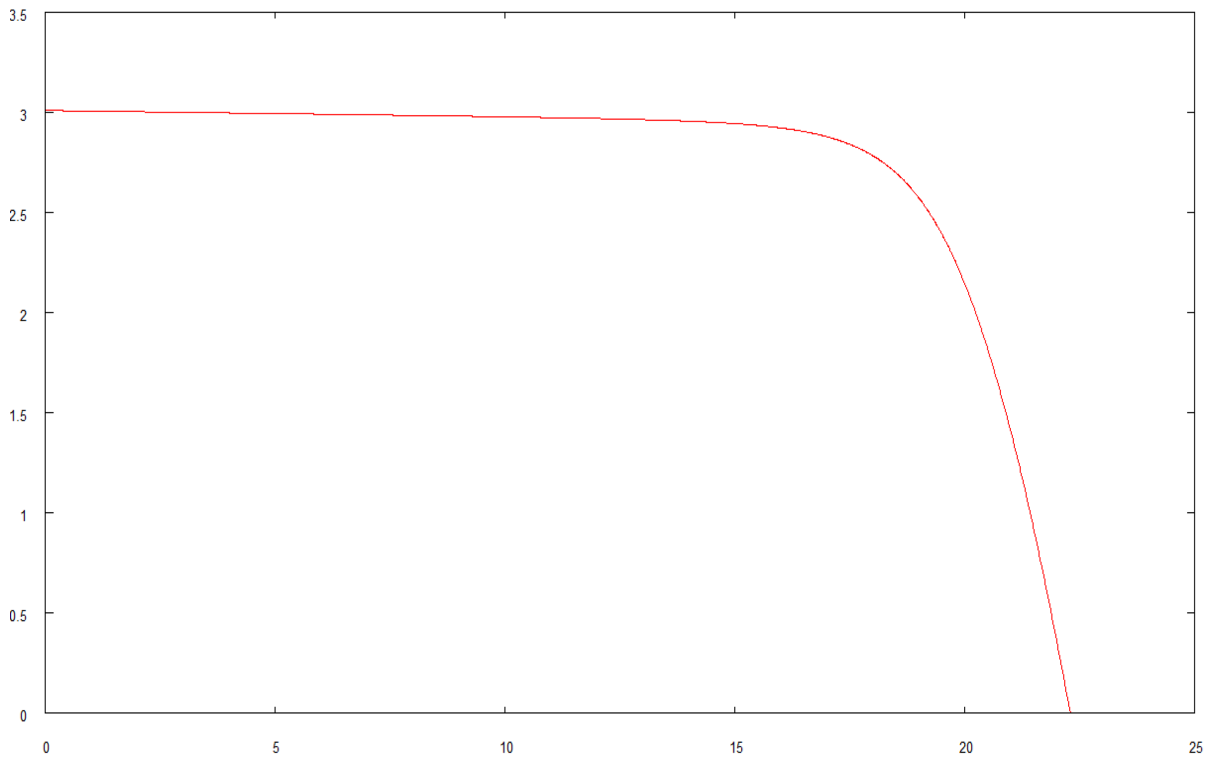


Figure4.22: simulink plot of I-V characterstics for january-2015 at 14^{0}C temperature and solar radiation of 910(W/m^2) {At X axis Voltage (V), At Y axis Current (A)}

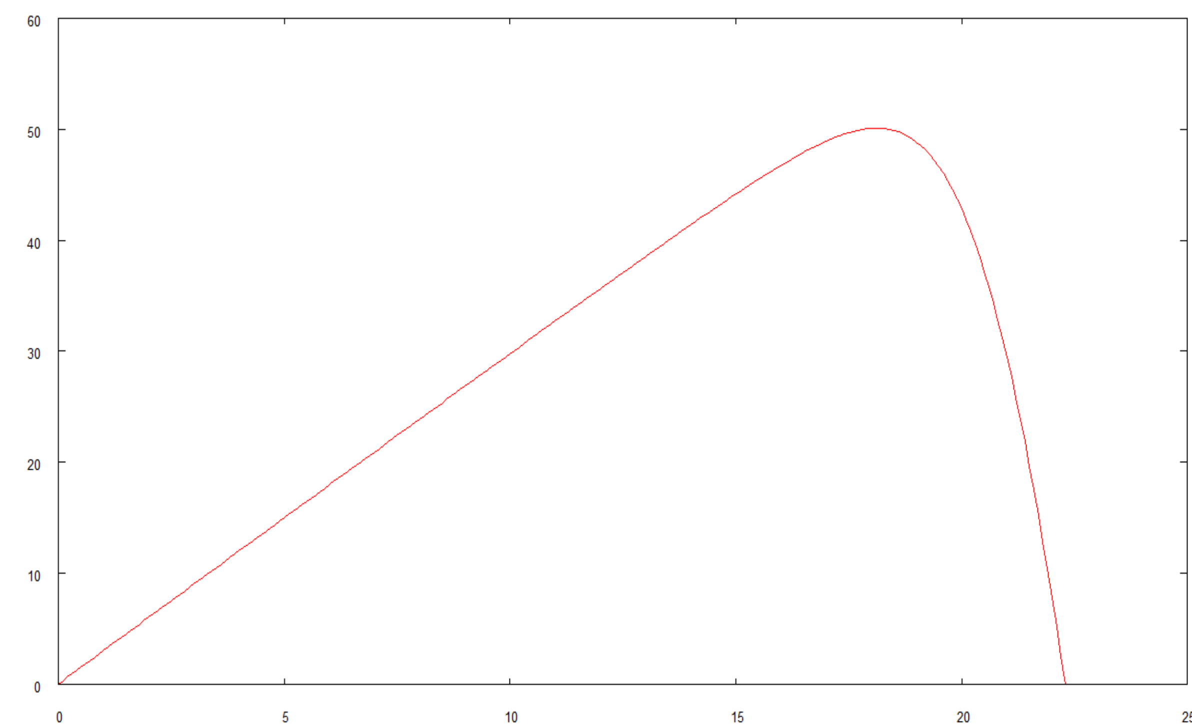


Figure4.23: simulink plot of DC power output for january-2015 at 14^{0}C temperature and solar radiation of 910(W/m^2) {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

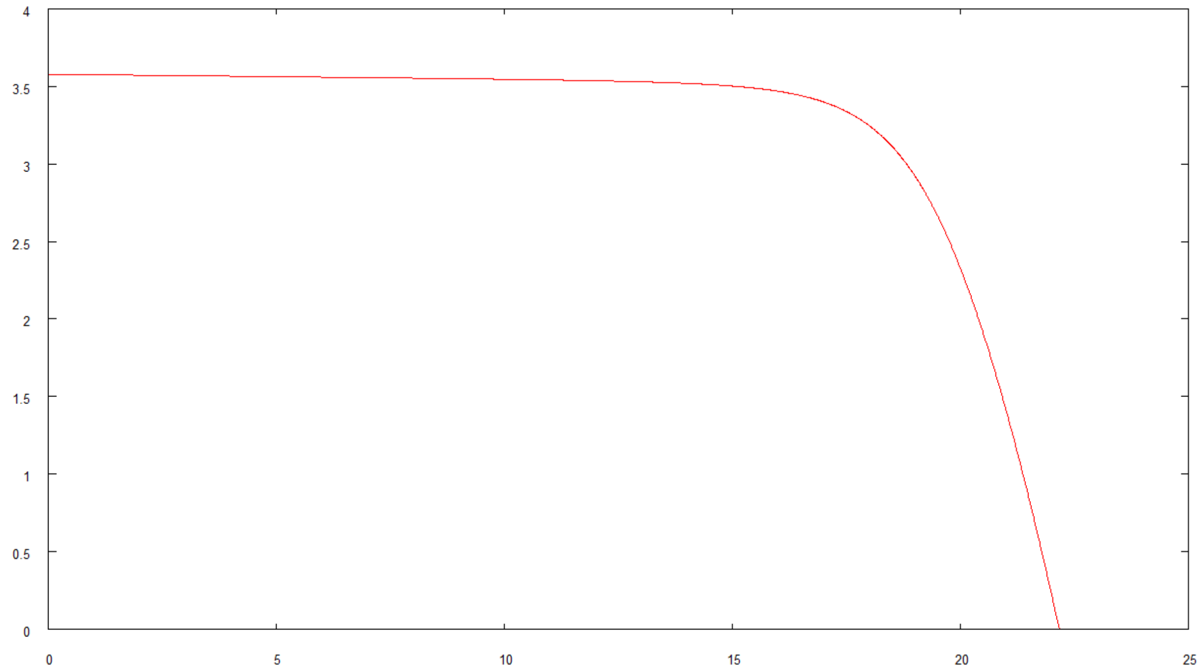


Figure4.24: simulink plot of I-V characterstics for febuary-2015 at 18^{0}C temperature and solar radiation of 1080(W/m^2) {At X axis Voltage (V), At Y axis Current (A)}

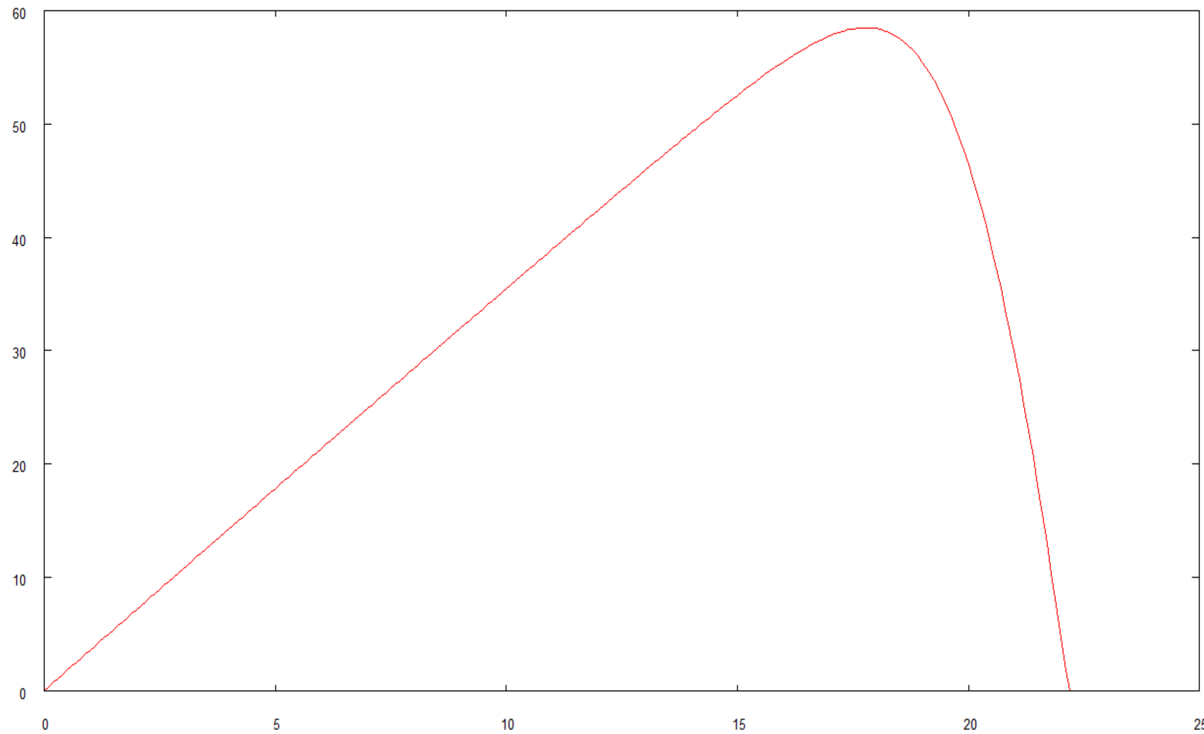


Figure4.25: simulink plot of DC power output for febuary-2015 at 18^0C temperature and solar radiation of 1080(W/m^2) {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

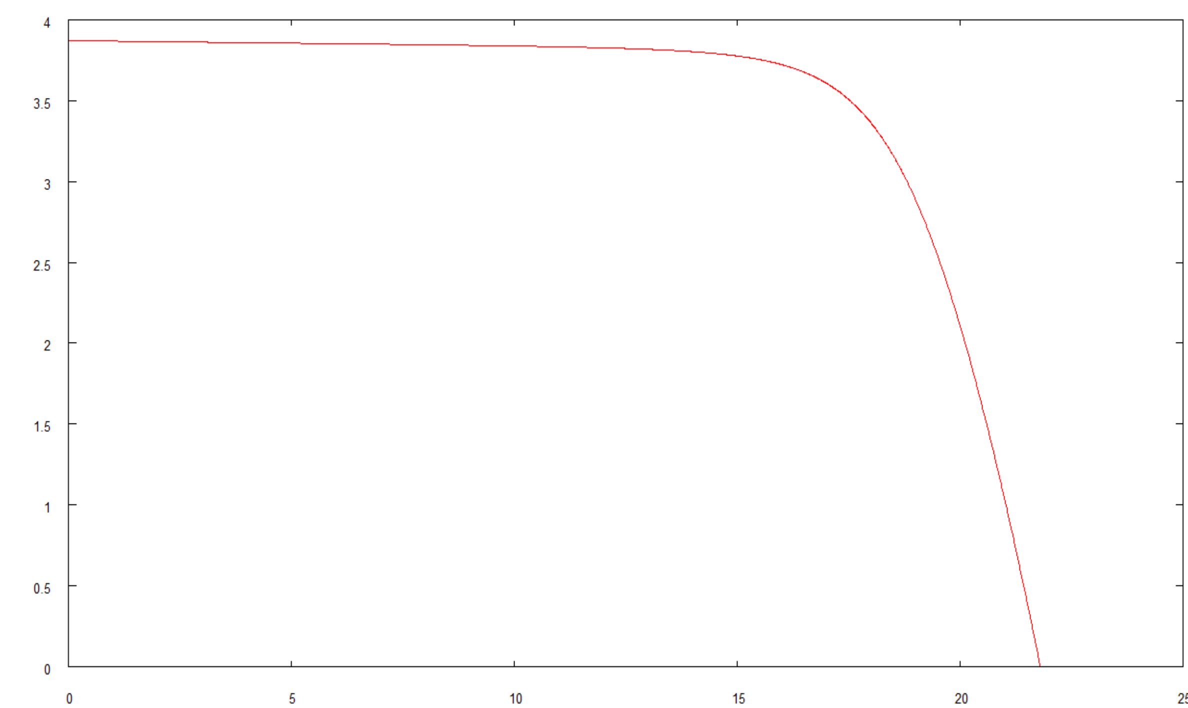


Figure4.26: simulink plot of I-V characterstics for march-2015 at 24^0C temperature and solar radiation of 1165(W/m^2) {At X axis Voltage (V), At Y axis Current (A)}

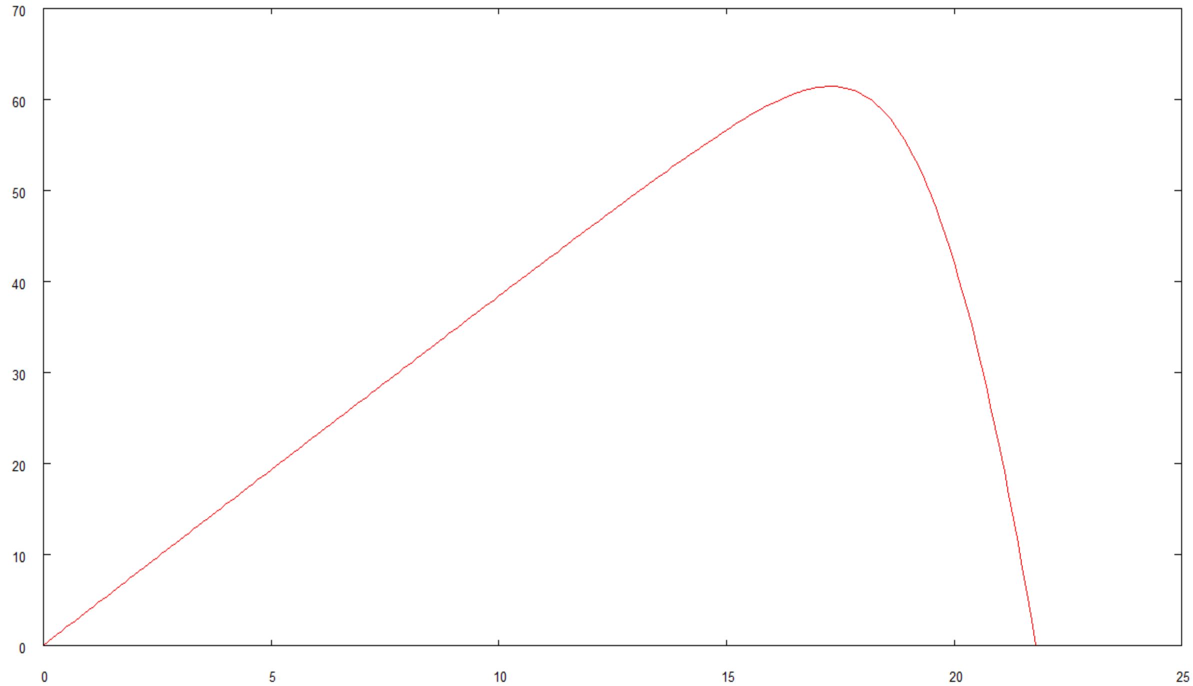


Figure4.27: simulink plot of DC power output for march-2015 at 24^0C temperature and solar radiation of 1165(W/m^2) {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

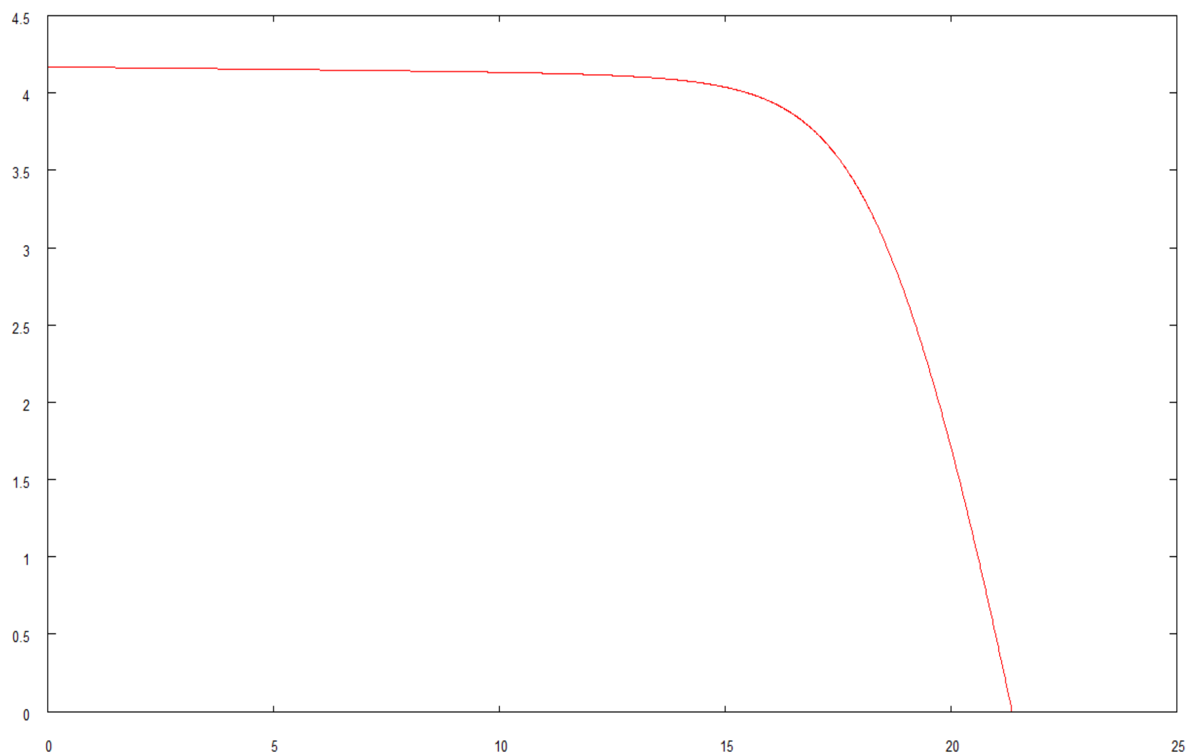


Figure4.28: simulink plot of I-V characterstics for april-2015 at 31^{0}C temperature and solar radiation of 1250(W/m^2) {At X axis Voltage (V), At Y axis Current (A)}

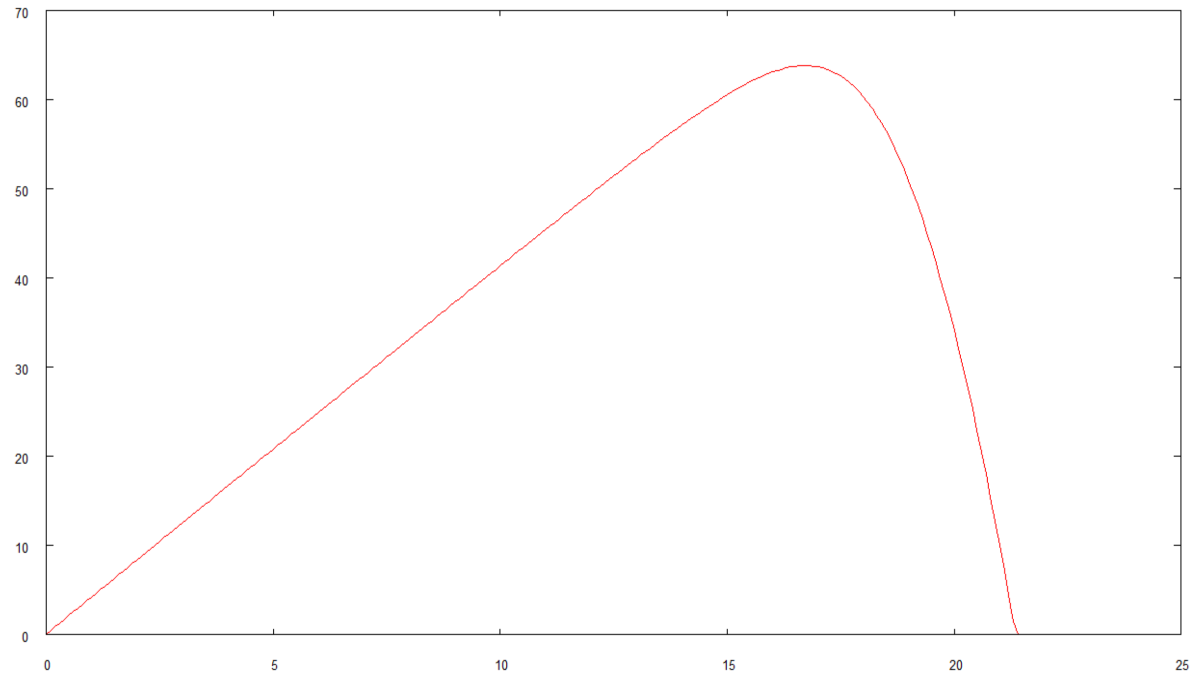


Figure4.29: simulink plot of DC power output for april-2015 at 31^{0}C temperature and solar radiation of 1250(W/m^2) {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

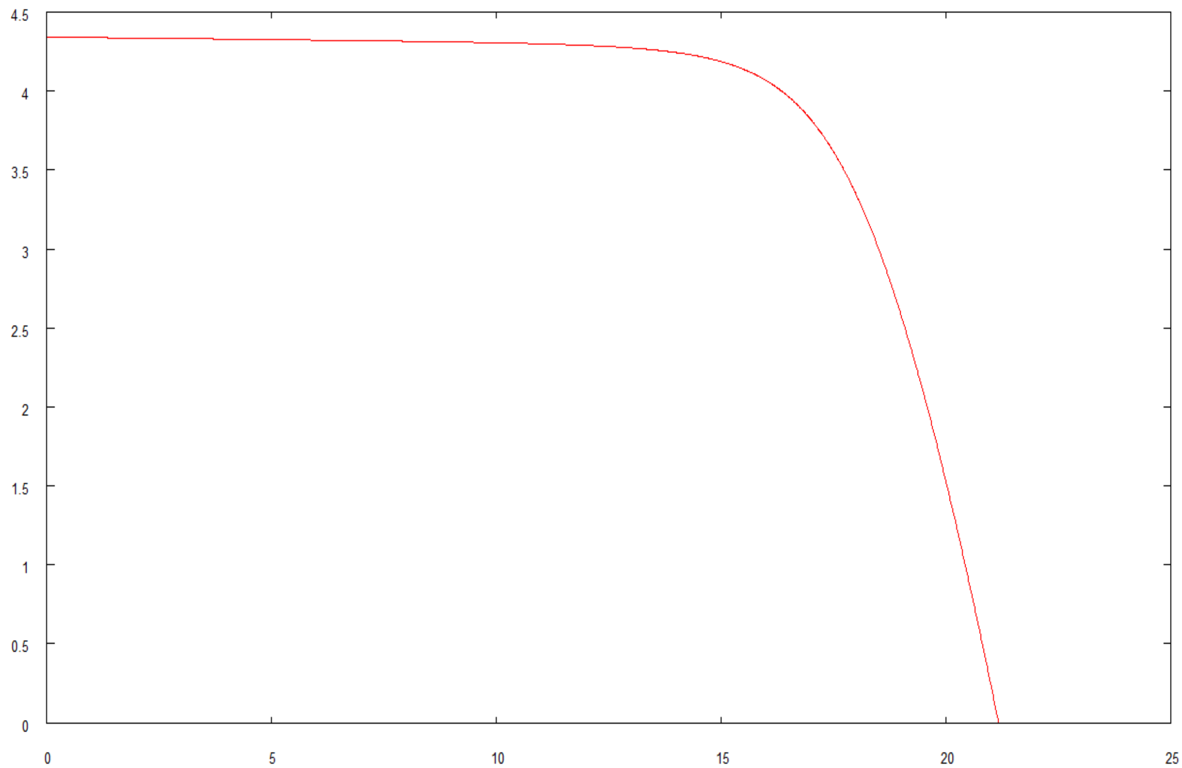


Figure4.30: simulink plot of I-V characterstics for may-2015 at 34^{0}C temperature and solar radiation of 1300(W/m^2) {At X axis Voltage (V), At Y axis Current (A)}

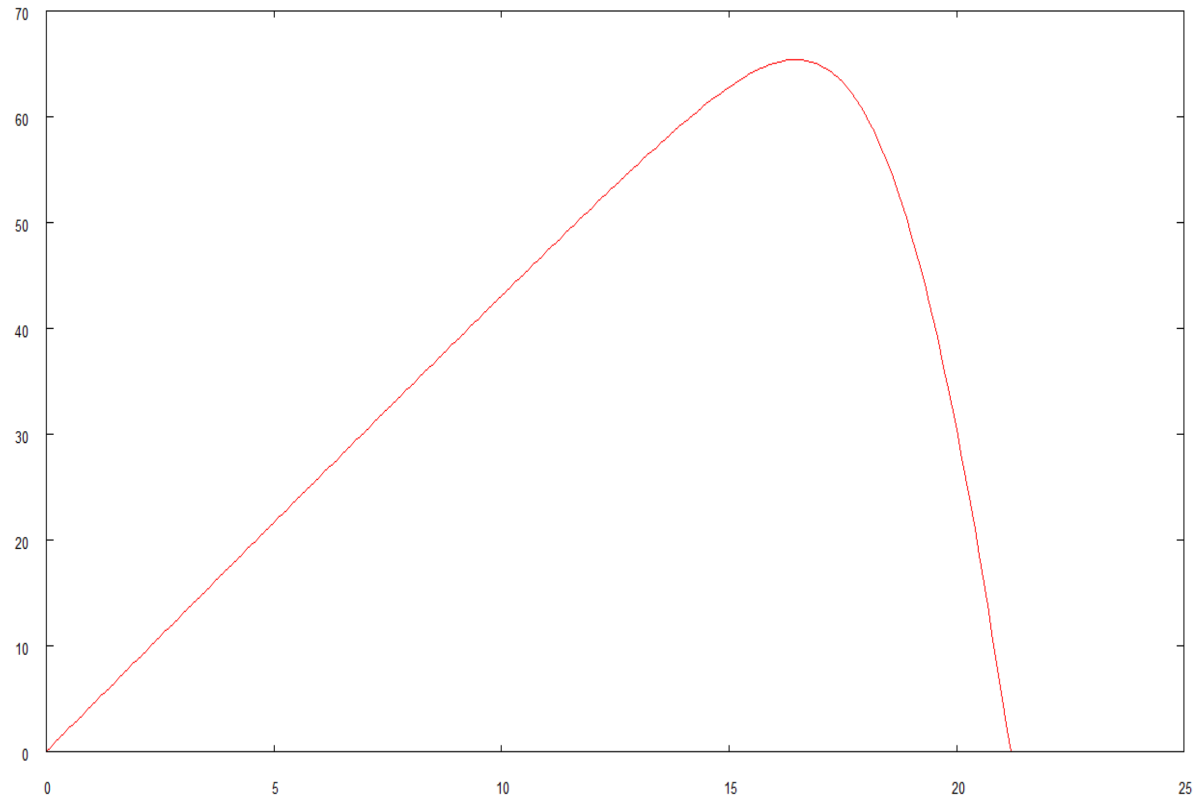


Figure4.31: simulink plot of DC power output for may-2015 at 34^{0}C temperature and solar radiation of 1300(W/m^2) {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

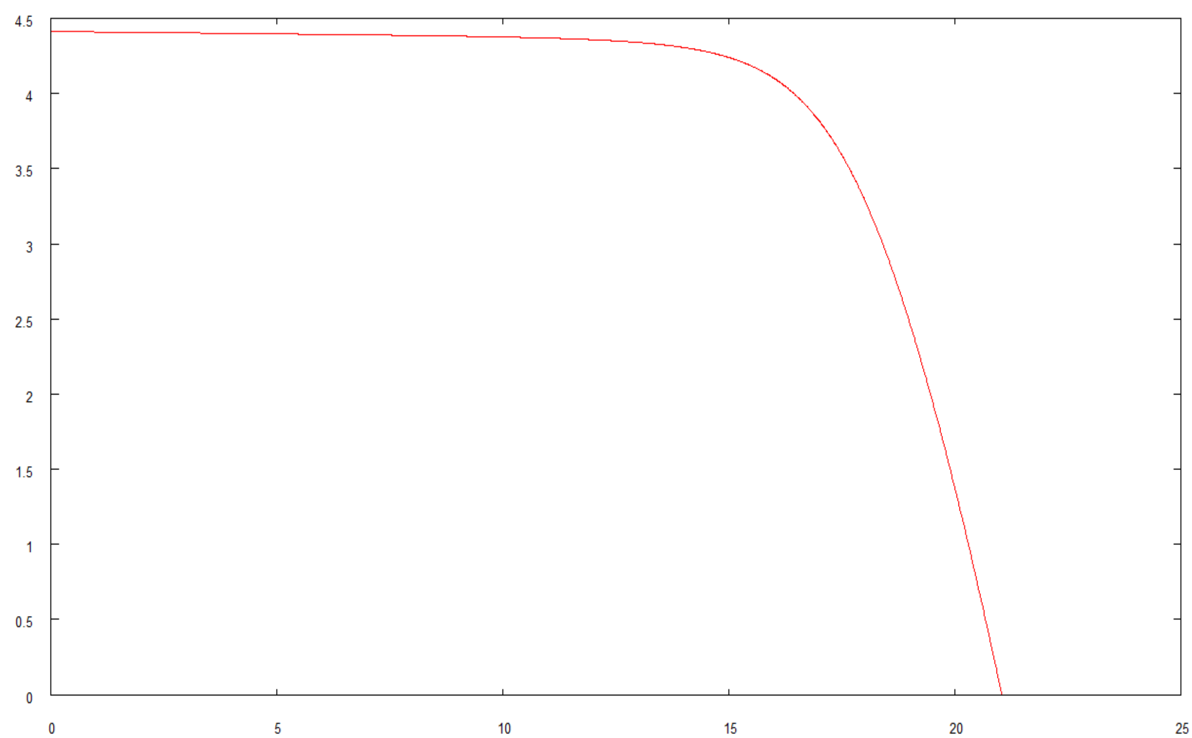


Figure4.32: simulink plot of I-V characterstics for june-2015 at 36^{0}C temperature and solar radiation of 1320(W/m^2) {At X axis Voltage (V), At Y axis Current (A)}

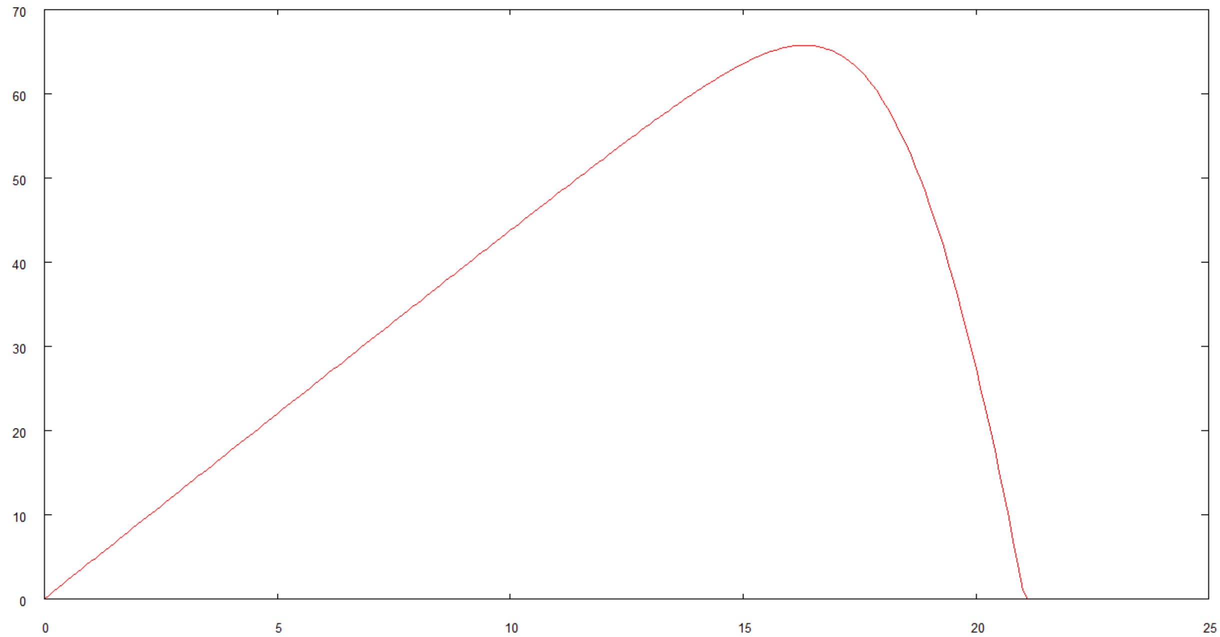


Figure4.33: simulink plot of DC power output for june-2015 at 36^{0}C temperature and solar radiation of 1320(W/m^2), {At X axis Voltage (volt), At Y axis DC power o/p (watt)}

Final simulation results are presented in table 4.5, here column three gives months wise solar radiations, then column four presents monthly average temperature, similarly column five gives current of the PV module, column six provides the voltage at which maximum power is attained and the last column give peak watts value. With the increase in solar radiations, current will also increase and voltage will decrease while maximum power will increase. But after 30^{0}C, with the increase in solar radiation current will increase but maximum power will decrease.

Table 4.5: Result of Simulation

S.No	Months	solar radiation (W/m^2)	Average Temperature (^{0}C)	Current of PV module (ampere)	MPPT voltage (Volt)	Maximum power W_p (watt peak)
1	July-14	1310	30	4.35	16.75	67.10
2	Aug-14	1280	31	4.25	16.83	65.48
3	Sep-14	1210	29	4.02	16.92	62.55
4	Oct-14	1100	27	3.65	17.18	57.24
5	Nov-14	970	23	3.20	17.85	51.54
6	Dec-14	940	15	3.09	18.28	51.52

7	Jan-15	910	14	3.00	18.41	50.13
8	Feb-15	1080	18	3.57	18.00	58.36
9	Mar-15	1165	24	3.86	17.58	61.57
10	April-15	1250	31	4.15	16.92	63.85
11	May-15	1300	34	4.32	16.72	65.33
12	June-15	1320	36	4.39	16.46	65.65

The variation of current with different solar radiation (varies from 910 to 1320 W/m^2 with increment of 40) is shown if figure 4.34

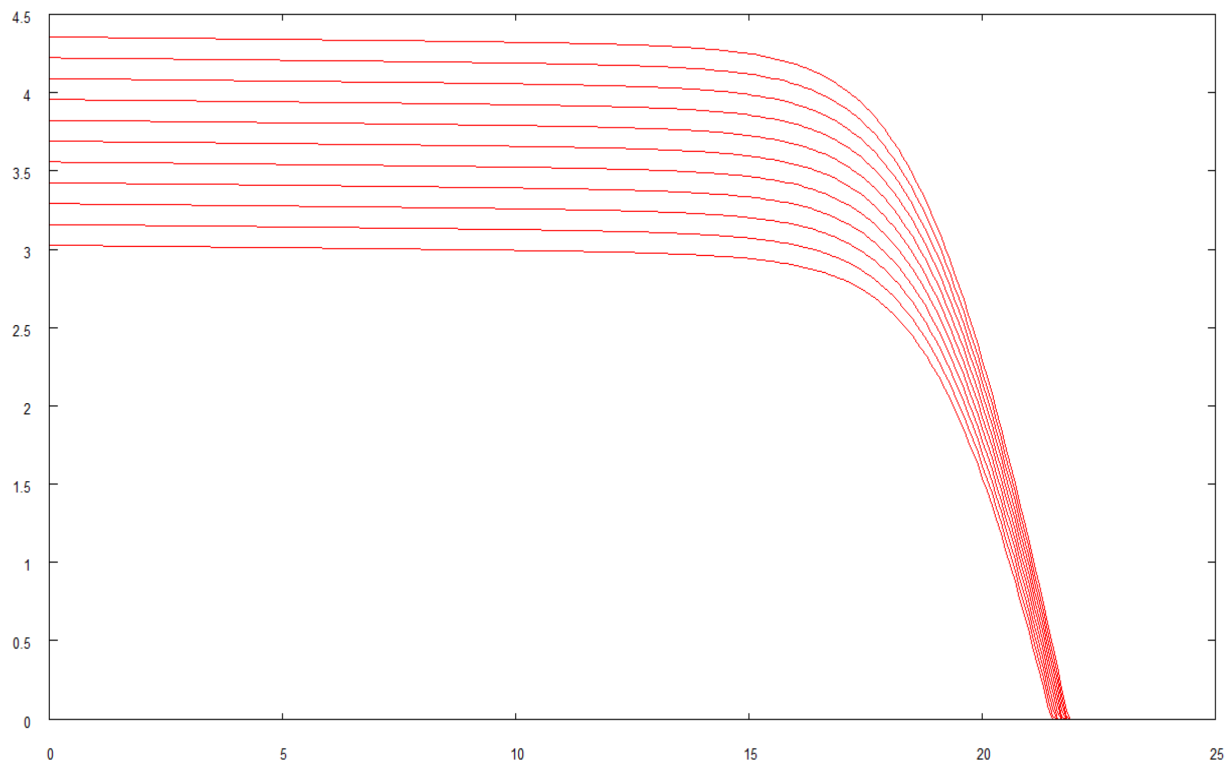


Figure 4.34: SIMULI NK plot of I-V characterstics at different values of solar radiation (varies from 910 to 1320 W/m^2 with increment of 40)

As we know that the ideal solar radiation for a power generation is 1000W/m^2 and in this study it comes to be 910-1320W/m^2. Hence it can be concluded that this location is suitable for power generation. But in the months November, December and January the solar radiation is below ideal. Results of Simulink also show that the maximum solar radiation is available in temperature range of 25^{0}C to 30^{0}C. In this range of temperature DC power output of PV module is also high. Finally it is concluded that the PV module gives best output in temperature range of 25^{0}C to 30^{0}C.

4.4 Design of solar power plant

As we know that the plant should be designed according to the peak load at the feeder. It is seen from the table 4.2 that the peak load of rural feeder is 37 ampere at 33KV side and multiplying factor for megawatt conversion is 0.05. Hence maximum load for the feeder is 1.85MW, so, we are designing a solar power plant with capacity of 2 MW.

The 2 MW Plant is divided into two independent segments of 1 MW each.

I. Calculation for 1 MW segment

- Total number of PV arrays, required to connect in parallel to one inverter = 45
- Requirement of total PV arrays = 45×4=180 (240W_p modules)
- Total numbers of PV modules required to form one array = 24 modules
- So total numbers of PV modules required for 1MW segment = 24×45×4 =4320
- Output voltage of each array =240Volt
- So line voltage = 240×√3 =415Volt
- Rating of required inverter = 250 kW
- Total number of inverters required for 1 MW segment = 4
- Output voltage of each inverter = 240Volt
- Requirement of step up transformer for 1 MW segment =1(415V/11KV)

II. Calculations for complete power plant(2MW)

- Total number of 1 MW segment required=2
- Requirement of total PV arrays = 180×2=360
- So total number of PV modules required =2×4320= 8640
- Total number of inverters required = 4×2 =8
- Total number of step up transformer required = 2(415V/11KV)

III. Requirement of batteries

- Total number of batteries required for 1MW = 500 (200amp/hr)
- 200A/h= 50×4 (a string of four batteries)
- Total number of batteries required for 2MW plant = 1000

We will use single wire DC link for transmission of power instead of four wire three phase AC transmission. In single wire earth return (SWRE) DC link, earth is used to provide return path to the circuit. In this system, single wire is used whereas in AC transmission four wires are needed therefore lesser space is required and a narrow pole can be acceptable. Another benefits are lesser protection equipment are required, there are no power factor problem.

We will provide 1000 battery sets of 200 A/h at the receiving end of transmission line instead of sending end. A 200A/h Battery set is further divided into four 50A/h battery set. Its benefit is when power is supplying through battery; the transmission distance will be reduced. Therefore, the transmission losses will also reduce. To increase the reliability of the system, we will provide a string of 4 batteries set of 50 A/h instead of using one battery set of 200 A/h.

In each battery set, there are 12-14 cells, with nominal voltage 2.154 (for each cell). For charging each battery set 24-28 volt and 4-5 current is required. For this we have to design a separate DC to DC converter.

IV. Designing of DC to DC convertor

(A) Inductor selection

The value of inductors is calculated using equation (6)

- $L_1 = (34.6)(0.466) / (.022)(50 \times 1000) = 1.48mH$
- $L_2 = (34.6)(0.466) / (.25)(50 \times 1000) = 1.28mH$

A commercially available 1.5mH inductor is selected. For example, 1.5mH power coke (5.0A DC max, 0.07Ω DCR) is available.

(B) Capacitor selection

The value of input and output capacitor is calculated using eq (7) and eq (9)

- $C_1 = \{(30)(0.466)\} \div \{ (6))(50 \times 1000)(3.225)\} = 14.40\mu F$

The next commercially available size is 22µF. An aluminium electrolytic capacitor with low ESR type is selected.

- $C_2 = \{ (1- 0.465)\} \div \{(8)(0.05)(1.5\times 10^{-3})(50 \times 1000)\} = 0.357\mu F$

The next available size is 0.47µF. An aluminium electrolytic capacitor with low ESR type is selected.

(C) Diode selection

Schottky diode should be selected because it has a low forward voltage and very good reverse recovery time (typically 5 to 10ns). The peak reverse voltage (*VRRM*) of the diode is the same as the average voltage of capacitor (C_1) , thus VRRM = 64.5*V*. Adding the 30% of safety factor gives the voltage rating of 83.9V. The average forward current (I_F) of diode is the combination of input and output currents at the Switch off, thus it is $I_d = I_{L1} + I_{L2}$ = 9.35A. Adding the 30% of safety factor gives the current rating of 12.2A. MBR15100 (I_F=15Amax, VRRM=100Vmax) meets the above-mentioned voltage and current ratings.

(D) Switch Selection

The maximum voltage of Switch is up to 48V by the specification. Adding the 30% of safety factor gives the voltage rating of 62.4V. The peak switch current is the same as the diode. Thus, adding the 30% of safety factor gives the current rating of 12.2A. There are a wide variety of Power-MOSFETs available commercially. IRF530 (I_D=14Amax,V_{DS}=100Vmax) meets the above-mentioned requirements

V. Cost Analysis

Table 4.5: Cost Analysis[33]

Components	Cost(Rs.)		Total cost (Rs.)

Solar panel	35/W	For 2MW	70000000
Mounting structure	4/W	For 2MW	8000000
Inverters and LT transformer	8/W	For 2MW	16000000
Cables	1/W	For 2MW	2000000
Battery	0.60/W	For 2MW	1200000
Main junction boxes	0.80/W	For 2MW	16000000
Fuses	3000/set	Total sets=2	6000
Protection switches	0.85/W	For 2MW	1700000
Energy meter	4000/set	Total sets=2	8000
Remote control and monitoring system	200000/unit	One unit	200000
Total			1151,14,000
Total area requirement			6.87 acres (approx.)

4.5 PSpice Simulations of DC to DC converter

According to the above design component the PSpice Simulink circuit diagram is shown in figure 4.35. The DC to DC converter is used to step down the DC voltage for charging of battery set. Figure 4.36 shows the equivalent resistive load circuit diagram.

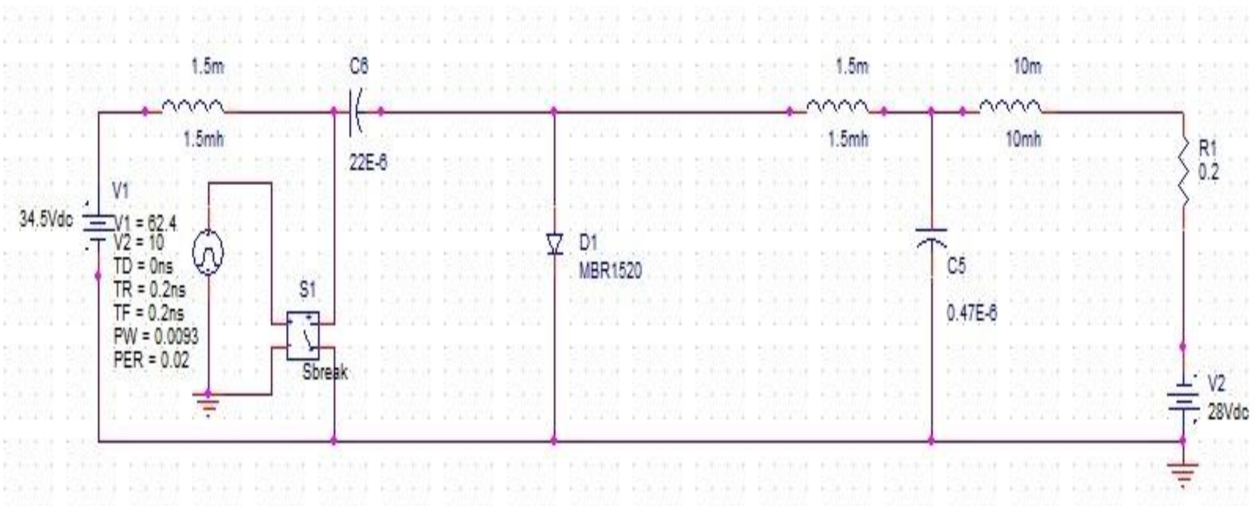


Figure 4.35: Schematic of the converter with DC battery load

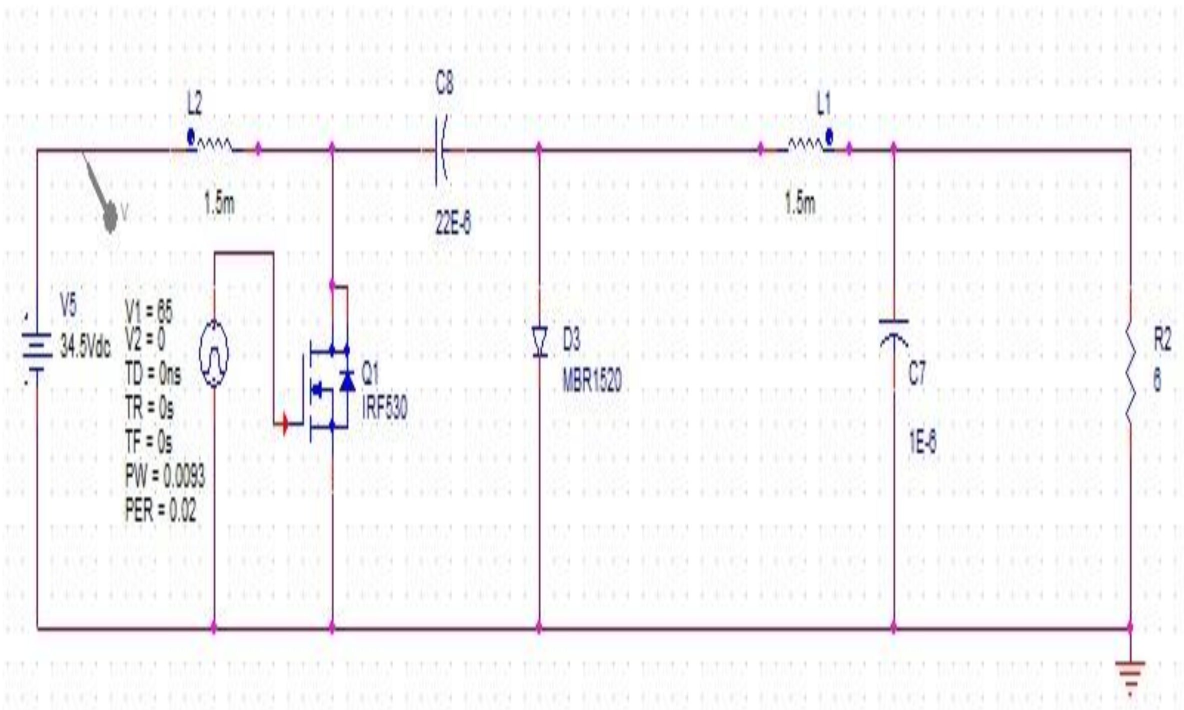
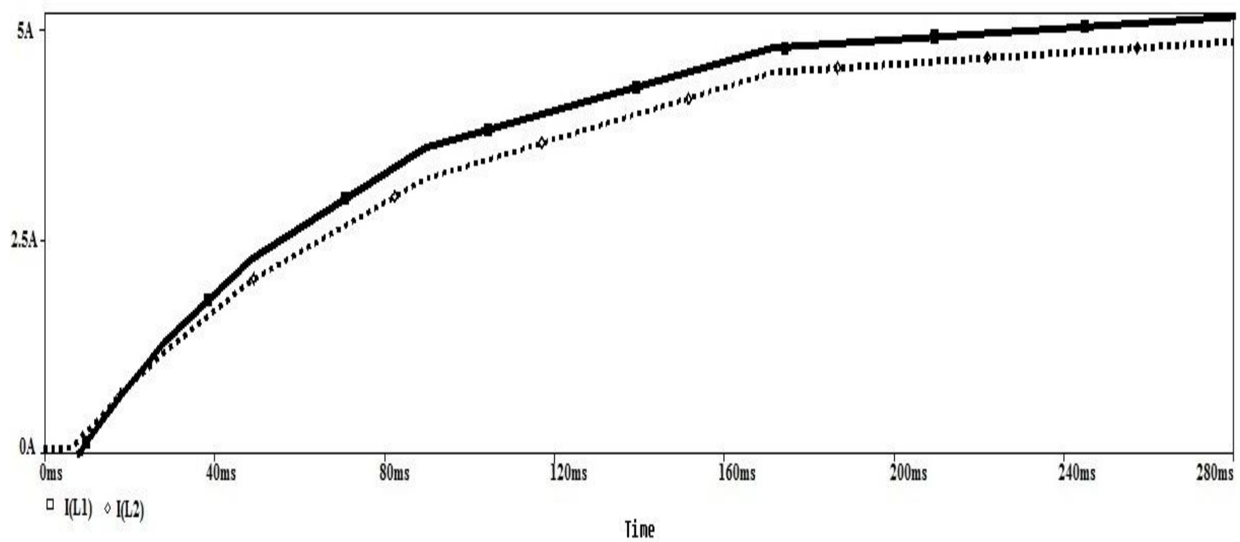
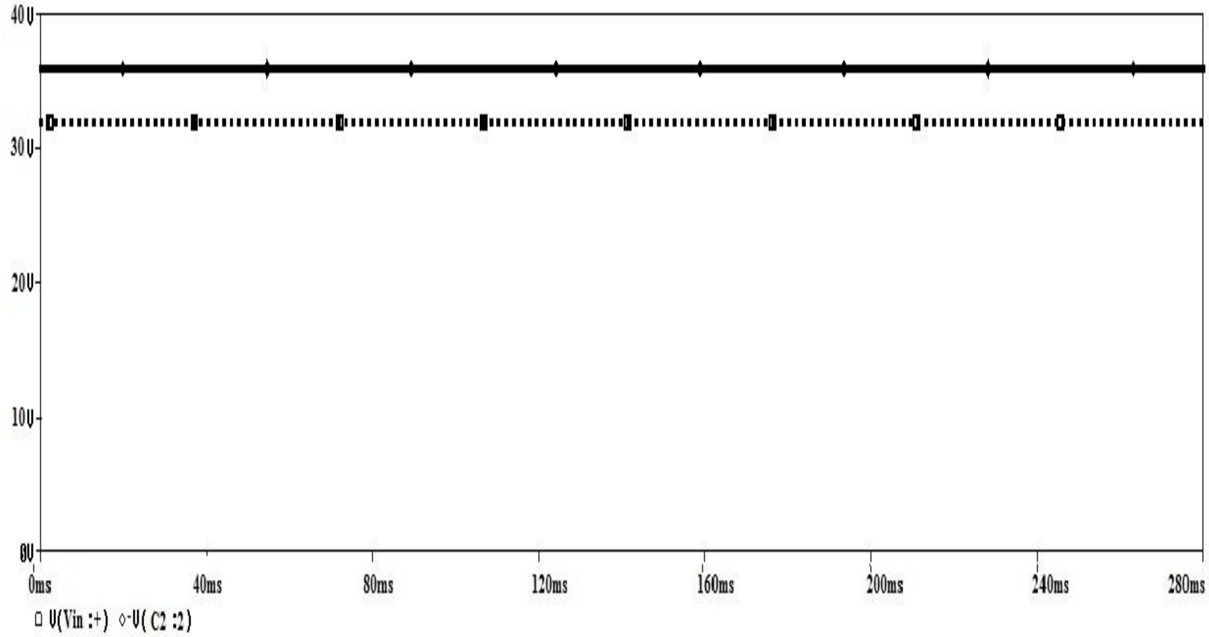


Figure 4.36: Schematic of the converter with resistive load



(a)



(b)

Figure 4.37: PSpice transient plots of input/output (a) current waveforms and (b) voltage waveforms

For charging of battery set 24-28 volt and 4-5ampere current is required before this converter a rectifier is also connected between LT transformer and DC to DC converter. Rectifier is required to convert AC voltage output of LT transformer into DC voltage to give inputs to DC to DC converter. The output of the converter in this simulation is in the range of 24-30 volts and 4-5 ampere after saturation. Therefore, this converter is appropriate for the desired purpose.

Chapter 5
Conclusions

In the country like India, domestic and agricultural electrical load is rising day by day because of rapidly increasing population and the new technology in agriculture. The grid supply is not at swiftness with this increase due to numerous technical and economic factors. Because of the above reason, there is shortage of power in many areas of the country. Therefore an alternative unconventional power source is needed with present grid supply system.

Now we have numerous technologies of renewable energy sources and each of them has certain characteristics with pros and cons. Solar energy, fuel-cell technology, wind energy and biomass are more into practice. Meanwhile the most important and common source of renewable energy is the solar energy.

In this project an attempt is made to check the feasibility of a solar power plant for a small rural area of Rajasthan. Firstly the power consumptions of this area are measured. Therefore, the solar radiations of this area are computed with the help of software and then the behaviour of PV module is checked by the software output. The month wise I-V characteristics and DC voltage are computed. Lastly a 2MW solar power plant and DC to DC converter are designed theoretically.

Salient features of the project

- As compare to AC transmission only one conductor wire is required instead of four wires.
- Lesser space is needed for transmission as compare to AC transmission which will ultimately reduce the cost.
- Less protection equipment are involved as compare ton AC transmission which will increase the simplicity and ultimately reduce the maintenance cost.
- Only LT transformer, DC battery set, converter and rectifier are required at receiving end.
- As compare to AC transmission there is no need to construct a 33KV sub station at the receiving end.
- The feeder selected for this study is a rural feeder which has 70-75% load of agriculture; therefore it can be supplied in day hours and the rest domestic load can be supplied at night hours also through the battery installed at receiving end.
- We are using 1000 battery set with capacity of 200 A/h which is capable to supply 200×1000A/h.

Future Scope and Limitations of the project:-

- High static inverter losses for small distance transmission.
- The conversion cost of DC to AC or AC to DC conversion is very high.
- No transformer is available to stepup or stepdown the DC voltage hence we have to design a converter for every application.
- The power of the PV plant cannot be fed to the grid if the power supply from the grid stops. Due to this, the power from the PV Plant is not available when it is needed most and the capacity of the Plant to work effectively has been retarded.
- There is no tracking mechanism to locate the modules if they fail. If a module fails, it is very difficult to identify it because no sensors have been installed for this purpose. The only solution presently available is to wait till the peak time to identify the Inverter (from which the output is lower). Then the Inverter has to be isolated and all the arrays

connected to this inverter should be checked. Once the faulty array is located, all the connected modules need to be checked to identify the faulty one.

- Presently the modules are cleaned by spraying water. But the dust accumulated on the modules turns into paste form once the modules are water sprayed, making it difficult to remove. Also, the height of the modules mounting structures makes it impossible to remove the dirt completely with wipers while standing on the ground. This has led inevitably, to the option of cleaning the modules by climbing on top of them (and then using wipers!). This will weaken the strength of solar modules as well as mounting structures in the long run and also affect structures in the long run and also affect that there is a need to address this issue by developing alternate method/technology for cleaning the PV modules.

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