A thesis
on

Grid Tie Solar System In Bangladesh

This thesis paper has been submitted to the Daffodil International University, of Bangladesh in partial fulfillment of the requirements of the degree of Bachelor of Science in Electrical and Electronics Engineering.

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ABSTRACT

An accurate PV module electrical model is presented based on the Shockley diode equation. The simple model has a photo-current current source, a single diode junction and a series resistance, and includes temperature dependences. The method of parameter extraction and model evaluation in MATLAB is demonstrated for a typical 60W solar panel. This model is used to investigate the variation of maximum power point with temperature and irradiation levels. A comparison of buck versus boost maximum power point tracker (MPPT) topologies is made, and compared with a direct connection to a constant voltage inverter. This paper presents the design and simulations of a photovoltaic system using perturb and observe method maximum power point tracking (MPPT) algorithm with boost converter. Also this paper deals with design and simulation of a three phase inverter in MATLAB SIMULINK environment which can be a part of photovoltaic grid connected systems.

Dedicated to

MY PARENTS

With Love & Respect

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List of principal Symbols Abbreviations

PV	Photovoltaic
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracker
I_L	Photo generated Current
STC	Standard Test Conditions
I_{sc}	Short Circuit Current
V_{oc}	Open Circuit Voltage
Q	Electron Charge
I_{pv}	Photodiode Current
Vpv	Photodiode Voltage
N	Diode Quality Factor
K	Boltzmann Constant
T	Temperature
C	Capacitor
V	Voltage
I	Current
L	Inductor
R	Resistor
I_D	Diode Current
R_s	Series Resistance
R_{SH}	Shunt Resistance

D	Diode
R_{Load}	Load Resistance
I_0	Saturation Current
G	Irradiant
DC	Direct Current
AC	Alternating Current
GIO	Gate Turn Off Thyristor
PWM	Pulse Width Modulated
K	Duty Cycle
V_s	Supply Voltage
V_L	Inductor Across Voltage
V_o	Output Voltage
PLL	Phase Locked Loop
CB	Circuit Breaker
V_g	Diode Band gap Voltage
N_s	Number of Cell

Chapter 1

Introduction

1.1 General Considerations

The most commonly installed solar system is a solar electric system interconnected with the national power grid, often called a grid-tied solar system.

Solar power is an alternative technology that will hopefully lead us away from our petroleum and gas dependents energy sources. The major problem with solar panel technology is that the efficiencies for solar power systems are still poor and the costs per kilo-watt-hour (kwh) are not competitive, in most cases, to compete with petroleum and gas energy sources. Solar panels themselves are quite inefficient (approximately 30%) in their ability to convert sunlight to energy. However, the charge controllers and other devices that make up the solar power system are also somewhat inefficient and costly. My goal is to design a Maximum Power Point Tracker (MPPT), a specific kind of charge controller, high efficiency Inverter, auto synchronization that will utilize the solar energy to efficient of tie grid system.

The MPPT is a charge controller that compensates for the changing Voltage vs. Current characteristic of a solar cell. The MPPT fools the panels into outputting a different voltage and current allowing more power to go into the battery or batteries by making the solar cell think the load is changing when you really are unable to change the load. The MPPT monitors the output Voltage and current from the solar panel and determines the operating point that will deliver that maximum amount of power available to the batteries. If our version of the MPPT can accurately track the always-changing operating point where the power is at its maximum, then the efficiency of the solar cell will be increased.

We are designed to pure sine wave inverter for tie grid solar system .The efficiency indicates the percentage of the available solar power that is actually converter and fed into the utility grid. Modern inverters currently consume between 4 and 8 % of the converted energy in the conversion process, which corresponds to an overall efficiency of 92 to 96 %.

In an alternating current electric power system, synchronization is the process of matching Phase Sequence, Voltage Magnitude, Frequency and Phase Angle. Phase Sequence controlled by phase sequence indicators and they are "Rotating type and Static type" and Voltage Magnitude controlled by Automatic Voltage Regulator (AVR).

1.2 Background and Motivation

The interest in renewable energy has been revived over last few years, especially after global awareness regarding the ill effects of fossil fuel burning. Energy is the source of growth and the mover for economic and social development of a nation and its people. No matter how we cry about development or poverty alleviation- it is not going to come until lights are provided to our people for seeing, reading and working. Natural resources or energy sources such as: fossil fuels, oil, natural gas etc. are completely used or economically depleted. Because we are rapidly exhausting, our non-renewable resources, degrading the potentially renewable resources and even threatening the perpetual resources. It demands immediate attention especially in the third world countries, where only scarcer sources are available for an enormous size of population. The civilization is dependent on electric power. There is a relationship between GDP growth rate and electricity growth rate in a country. The electricity sector in Bangladesh is handled by three state agencies under the Ministry of Energy and Mineral resources (MEMR). These are:

- √ Bangladesh Power Development Board (BPDB).
- √ Dhaka Electric Supply authority (DESA).
- √ Rural Electrification Board (REB).

Bangladeshis a largely rural agrarian country of about 160 million people situated on the Bay of Bengal in south Central Asia. Fossil energy resources in Bangladesh consist primarily of natural gas. Domestic oil supply in considered negligible. Several small deposits of coal exist on the north eastern region of the country, but these consist of peat, with low caloric value and very deep bituminous coal that will be quite expensive to extract. Only 15% of the total population has got access to the electricity. In 1990 only 2.2% of total households (mostly in urban areas) have piped natural gas connections for cooking and only 3.9% of total households used kerosene for cooking. These are by no means a pleasant scenario.

Per capita consumption of commercial energy and electricity in Bangladesh is one of the lowest among the developing countries. In 1990, more than 73% of total final energy consumption was met by different type of biomass fuels (e.g. agricultural residues, wood fuels, animal dung etc.). The rural and remote sector of Bangladesh economy, where 85% of the population lives, is characterized by an abundance of open and disguised unemployment, high Man-land ratio, alarmingly large numbers of landless farmers, extremely inadequate economic and social facilities, low standard of living and a general environment of poverty and deprivation. Larger energy supplies and greater efficiency of energy to tap all sources of renewable energy and to use these in an efficient converted form for benefit of the people. Primarily this will be done in remote inaccessible un electrified area in a standalone system where grid expansion is expensive. This energy conversion will reduce pressure on the national power demand. This will not only save excessive grid expansion cost but will also keep environment friendly recently a number of experimental land pilot projects are being undertaking by different organizations in different sectors of alternative energy technologies in Bangladesh.

Chapter 2

Generation of Electric Energy

2.1 Introduction

Electricity is the set of physical phenomena associated with the presence and flow of electric charge. Electricity is energy that the process of producing electric energy by transforming other forms of energy; electricity gives a wide variety of well-known sources, such as chemical energy, thermal energy, kinetic energy, nuclear energy, rotational energy, solar energy, wind energy and geothermal energy. Here some sources are renewable and some are non-renewable energy. The major parameter decisions that must be made for any new electric power-generating plant or unit include the choices of energy source, type of generation system, unit and plant rating, and plant site. These decisions must be based upon a number of technical, economic and environmental factors.

2.2 Renewable energy

Renewable energy is generally defined as energy that comes from resources which are naturally replenished on a human timescale such as sunlight, wind, rain, tide waves and geothermal. About 16% of global final energy consumption presently comes from renewable resources, with 10% of all energy from traditional biomass, mainly used for heating, and 3.4% from hydroelectricity. New renewable (small hydro, modem biomass, wind, solar and geothermal) account for another 3% and are growing rapidly. At the national level, at least 30 nations around the world already have renewable energy contributing more than 20% of energy supply. National renewable energy markets are projected to continue to grow strongly in the coming decade and beyond. Renewable energy is available in various forms including Wind, Solar and Biomass power. We aim to introduce people to the need and benefits of using the natural sources of energy. This is necessary as the Earth's sources of oil and coal are on the verge of depletion with a massive increase in the demand. Therefore, it has become extremely essential that people understand the requirement of preserving these exhaustible sources of energy and learn how to manage energy efficiently.

2.3 Solar Energy

Solar energy, radiant light and heat from the sun, is harnessed using a range of ever evolving technologies such as solar heating, solar photovoltaic's, solar thermal electricity, solar architecture and artificial photosynthesis. Solar technologies are broadly characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of photovoltaic panels and solar thermal collectors to harness the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties, and designing spaces that naturally circulate air.

A solar cell, or photovoltaic cell (PV), is a device that converts light into electric current using the photoelectric effect. The first solar cell was constructed by Charles Fritts in the 1880s. The German industrialist Ernst Werner von Siemens was among those who recognized the importance of this discovery. In 1931, the German engineer Bruno Lange developed a photo cell using silver selenide in place of copper oxide, although the prototype selenium cells converted less than 1% of incident light into electricity. Following the work of Russell Ohl in the 1940s, researchers Gerald Pearson, Calvin Fuller and Daryl Chapin created the silicon solar cell in 1954. These early solar cells cost 286 USD/watt and reached efficiencies of 4.5-6%.

2.4 Hydroelectric Power

In nature, energy cannot be created or destroyed, but its form can change. In generating electricity no new energy is created. Actually one form of energy is converted to another form. To generate electricity, water must be in motion. This is kinetic (moving) energy. When flowing water turns blades in a turbine, the form is changed to mechanical (machine) energy. The turbine turns the generator rotor which then converts this mechanical energy into another energy form- electricity. Since water is the initial source of energy, we call this hydroelectric power or hydropower for short.

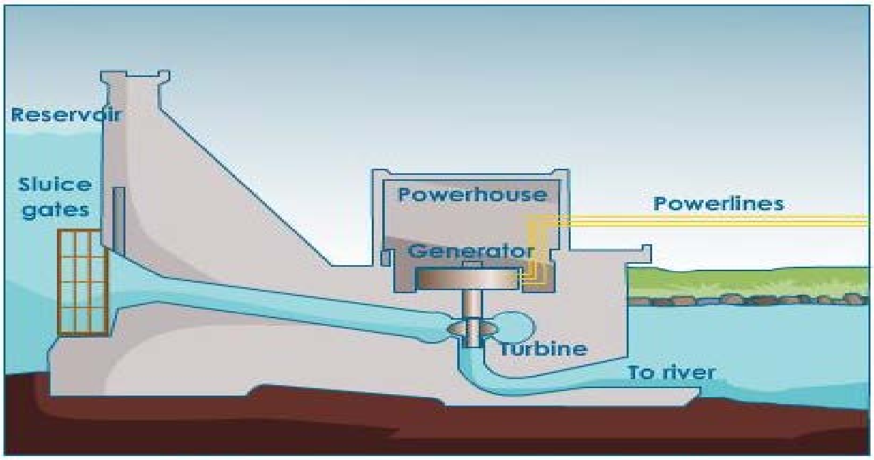


Figure 2.1:- Hydroelectric Power Plant

2.5 Wind Power

This method can be used at where wind flows for a considerable length of time. The wind energy is used to run the wind mill which drives a small generator. In order to obtain the electrical energy from a wind mill continuously, the generator is arranged to charge the batteries. These batteries supply the energy when the wind stops. This method has the advantages that maintenance and generation costs are negligible .

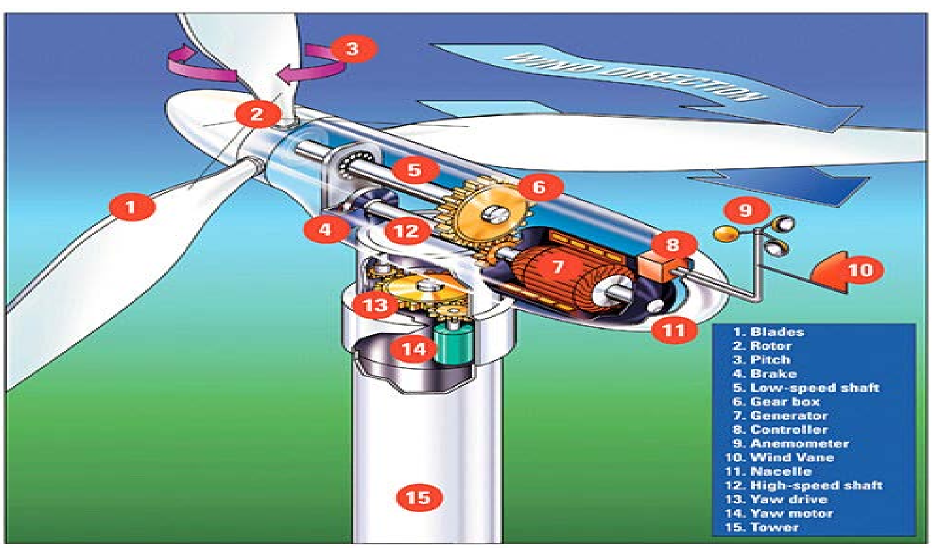


Figure 2.2 :- Wind Turbine Power Plant

2.6 Geothermal Power

Geothermal power plants can be divided into two main groups, steam cycles and binary cycles. Typically the steam cycles are used at higher well enthalpies, and binary cycles for lower enthalpies. The steam cycles allow the fluid to boil, and then the steam is separated from the brine and expanded in a turbine. Usually the brine is rejected to the environment (re-injected), or it is flashed again at a lower pressure. Here the Single Flash (SF) and Double Flash (DF) cycles will be presented. A binary cycle uses a secondary working fluid in a closed power generation cycle. A heat exchanger is used to transfer heat from the geothermal fluid to the working fluid, and the cooled brine is then rejected to the environment or re-injected. The Organic Rankine Cycle (ORC) and Kalina cycle will be presented.

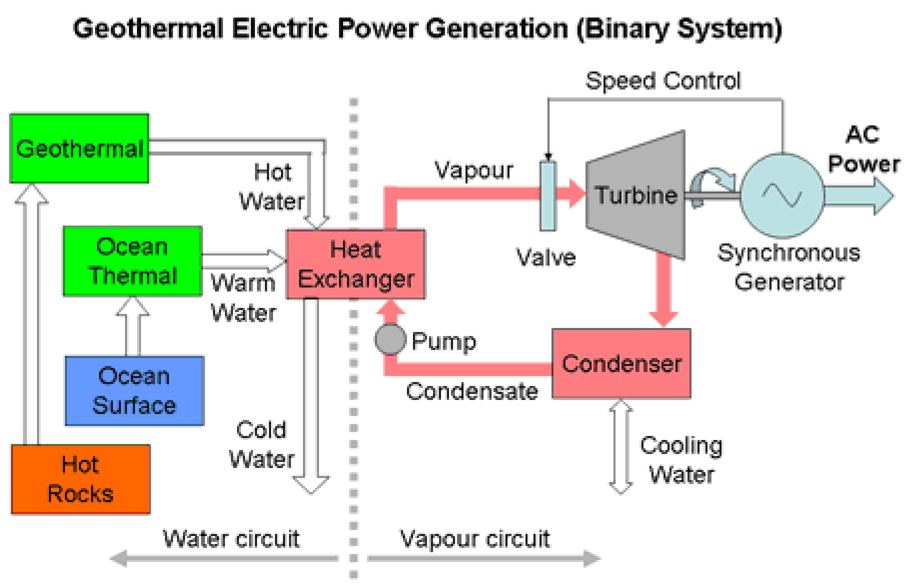


Figure 2.3 :- Geothermal Power Plant

2.7 Biomass Power

Biomass can be used in its solid form or gasified for heating applications or electricity generation, or it can be converted into liquid or gaseous fuels. Biomass conversion refers to the process of converting biomass feed stocks into energy that will then be used to generate electricity and/or heat. Multiple commercial, proven and cost effective technologies for converting biomass feed stocks to electricity and heat are currently available in the United States. Some of these boiler technologies are extremely clean and can result in electricity production of up to 50 megawatts (MW)-enough electricity to power 50,000 homes Additionally, an emerging class of biomass conversion technologies is becoming available that converts woody biomass feed stocks to useable fuel through gasification processes. Modular versions-smaller than 5 MW-of both direct-fired boiler and gasification technologies are also being developed, though they are at earlier stages of commercialization.

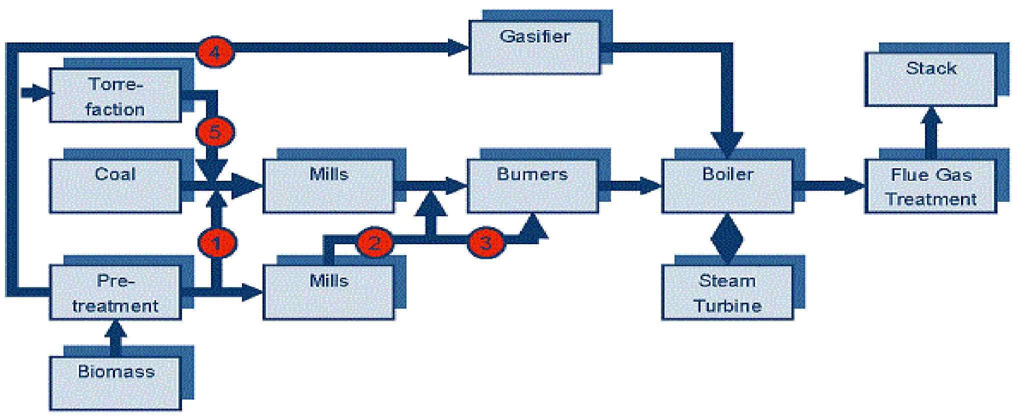


Figure 2.4:- Biomass Confiring in Coal Power Plant

2.8 Grid Tied Solar Electric Systems

Grid Tied Solar Electric systems generate electricity silently and without any moving parts. Sunlight falls on the solar array (blue, on the roof), generating DC electricity. That DC electricity is converted into household 120V AC electricity by the inverter (blue & grey, on the wall). The AC electricity is fed into your electric meter and circuit breaker panel (grey, on the wall). The electricity either goes to your appliances and lights, or to the grid, or some to each. This all happens silently and automatically every day. Grid intertied power systems are for folks who are (or will be) connected to utility company power lines (the "Grid"). They plan to use the Grid to supplement what they are able to make with renewable energy sources like the sun or wind.

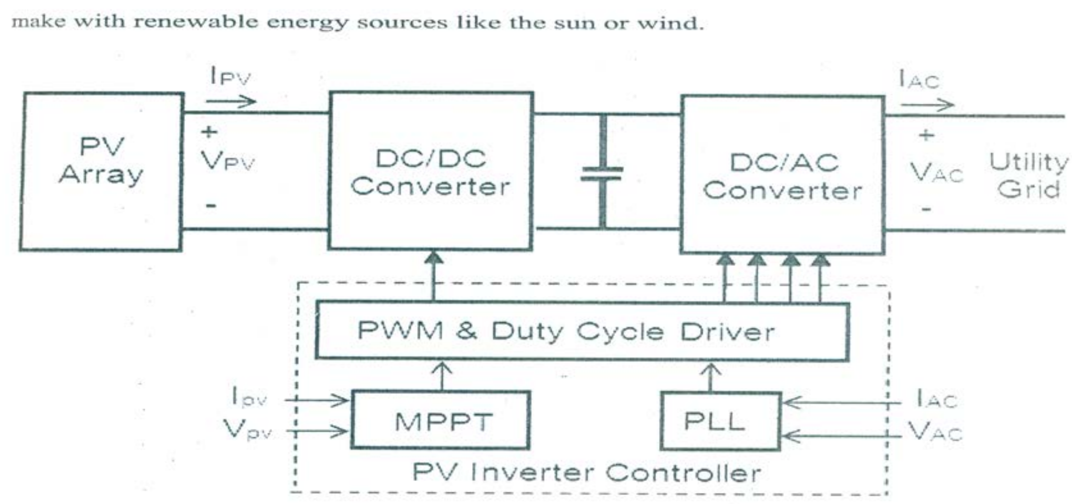


Figure 2.5:- Grid Tie Solar System

2.8.1 Parts of Grid Tie Solar System

* Solar Panel.
* Maximum Power Point Tracking (MPPT) .
* DC To DC Converter .
* DC To AC Converter (Inverter) .
* Utility Grid.

2.9 Solar Panel

The type of solar panel you have probably seen on people's roofs are called Photovoltaic Solar Panels photo meaning light, and voltaic meaning to do with electricity. As the name suggests, Photovoltaic (or PV) panels convert light directly into electrical energy.

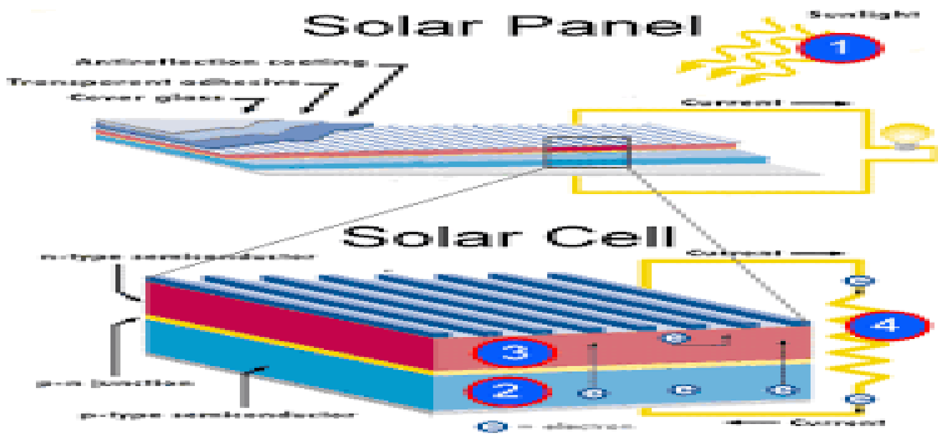


Figure 2.6:- Solar Panel

2.10 Basic Principal of Solar Panel

A solar cell or photovoltaic cell is a device that converts sunlight directly into electricity by the photovoltaic effect. Photovoltaic is a method of generating electrical power by converting solar radiation into direct current electricity using specially designed p-n junctions that exhibit the photovoltaic effect. When electromagnetic irradiation falls on such a junction, it transfers energy to an electron in the valence band and promotes it to the conduction band hence creating an electron-hole pair. The electrons and holes created can now act as mobile charge carriers and thus a current is produced. This process across a p-n junction is shown in figure

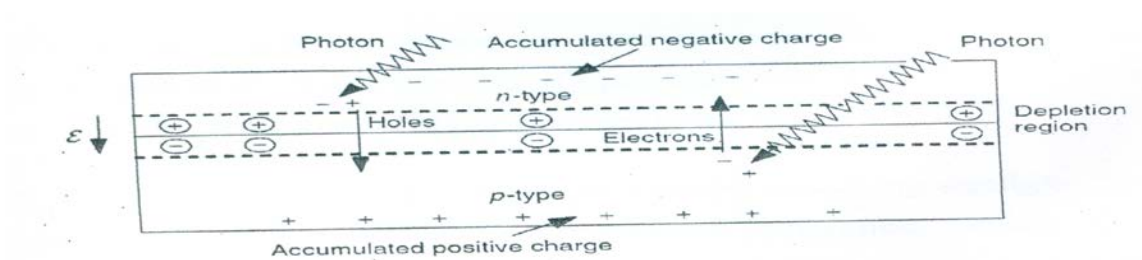


Figure2.7:- Creation of Electron-Hole Pairs by incident electromagnetic irradiation

2.11 Solar Cell

A solar cell (also called a photovoltaic cell) is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect. It is a form of photoelectric cell (in that its electrical characteristics such as current, voltage, or resistance vary when light is incident upon it) which, when exposed to light, can generate and support an electric current without being attached to any external voltage source, but do require an external load for power consumption.

The term "photovoltaic" comes from the Greek φ□ς (phos) meaning "light", and from "volt", the unit of electro-motive force, the volt, which in turn comes from the last name of the Italian physicist Alessandro Volta, inventor of the battery electrochemical cell). The term "photo-voltaic" has been in use in English since 1849.

Photovoltaic is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight. Cells an be described as photovoltaic even when the light source is not necessarily sunlight (lamplight, artificial light, etc.). In such cases the cell is sometimes used as photo detector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity.

2.11.1 Operation of a Photovoltaic (PV) Cell

The operation of a photovoltaic (PV) cell required

* The absorption of light, generating either electron-hole pairs or exactions .
* The separation of charge carriers of opposite types .
* The separate extraction of those carriers to an external circuit.

In contrast, a solar thermal collector supplies heat by absorbing sunlight, for the purpose of either direct heating or indirect electrical power generation. "Photo electrolytic cell" (photo electro chemical), on the other hand, refers either to a type of photovoltaic cell (like that developed by Edmond Becquerel and modem dye-sensitized solar cells), or to a device that splits water directly into hydrogen and oxygen using only solar illumination.

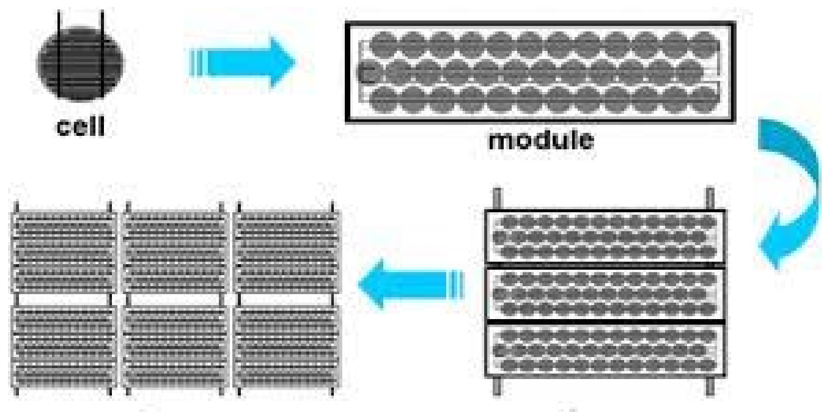


Figure 2.8:- Construction of Photovoltaic Solar Panel

2.12 Modules

PV modules consist of PV cell circuits sealed in an environmentally protective laminate and are the fundamental building block of PV systems.

2.13 Array

A PV array is the complete power-generating unit, consisting of any number of PV Modules and panels.

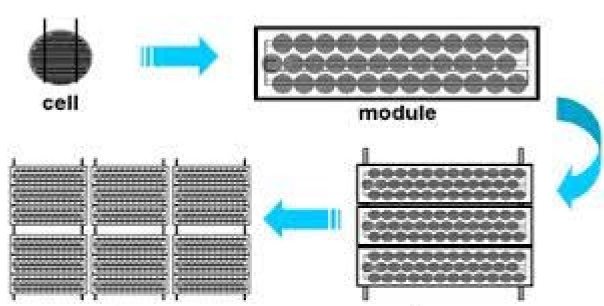


Figure 2.9:- Photovoltaic Array

Chapter 3

Evaluating MPP Using MATLAB PV Model

3.1 Introduction

A "grid-tie" solar system is one that ties into the power grid, pulling electricity from the An accurate PV module electrical model is presented based on the Shockley diode equation. The simple model has a photo-current, current source, a single diode junction and a series resistance, and includes temperature dependences. The method of parameter extraction and model evaluation in MATLAB is demonstrated for a typical 60W solar panel. This model is used to investigate the variation of maximum power point with temperature and irradiation levels.

3.2 Photovoltaic Modules

Solar cells consist of a p-n junction fabricated in a thin wafer or layer of semiconductor. In the dark, the I-V output characteristic of a solar cell has an exponential characteristic similar to that of a diode. When exposed to light, photons with energy greater than the band gap energy of the semiconductor are absorbed and create an electron-hole pair. These carriers are swept apart under the influence of the internal electric fields of the p-n junction and create a current proportional to the incident radiation. When the cell is short circuited, this current flows in the external circuit; when open circuited, this current is shunted internally by the intrinsic p-n junction diode. The characteristics of this diode therefore set the open circuit voltage characteristics of the cell.

3.3 Standard Test Conditions (STC) includes of PV Module

The industry standard against which all PV modules are rated and can be compared is called Standard Test Conditions (STC).

* Irradiance (sunlight intensity or power), in Watts per square meter falling on a flat surface. The measurement standard is 1kW per sq. m. (1,000 Watts/m2)
* Air Mass refers to "thickness" and clarity of the air through which the sunlight passes to reach the modules (sun angle affects this value). The standard is 1.5.
* Cell temperature, which will differ from ambient air temperature. STC defines cell testing temperature as 25 degrees C.

Each solar array panel includes a total of 36, 72, or even 96 individual standard solar cells. In the recent past, cell sizes have attained nearly 5" square (125mm) dimensions. The most commonly used type of solar cells are made of thick-film silicon, whose efficiency ratings go up to relatively high values of 20 percent for polycrystalline cells, and up to 25 percent for mono crystalline cells. In actual use, cells are connected in series, to accumulate sufficient voltage from the 0.6V that a standard cell delivers to deliver usable voltage levels. Industrial grade solar modules are built from individual cells, inter connected with wiring and sandwiched between glass plates and polymer for protection. Thin-film cells are also available in large interconnected arrays, sometimes even in auto-positioning carriers.

3.4 Modeling the Solar Cell

Thus the simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the light falling on the cell. The diode determines the I-V characteristics of the cell.

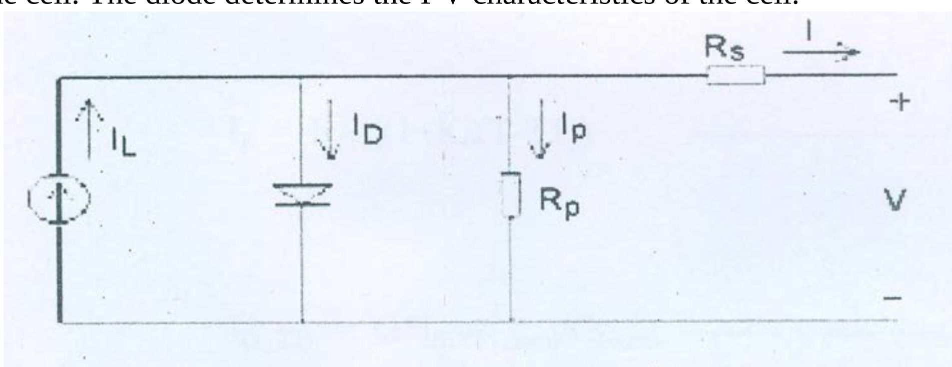


Figure 3.1: - The Circuit Diagram of the PV Model

Increasing sophistication, accuracy and complexity can be introduced to the model by adding in turn.

* Temperature dependence of the diode saturation current I_0.
* Temperature dependence of the photo current I_L.
* Series resistance R_s which gives a more accurate shape between the maximum power point and the open circuit voltage.
* Shunt resistance R_p, in parallel with the diode.
* Either allowing the diode quality factor n to become a variable parameter (instead of being fixed at either 1 or 2) or introducing two parallel diodes (one with A = 1, one with A = 2) with independently set saturation currents.

For this research work, a model of moderate complexity was used. The model included temperature dependence of the photo-current k and the saturation current of the diode I_O . A series resistance R_s was included, but not a shunt resistance. A single shunt diode was used with the diode quality factor set to achieve the best curve match. This model is a simplified version of the two diode model presented by Gow and Manning. The circuit diagram for the solar ceil is shown in above figure.

The equations which describe the I-V characteristics of the cell are

$$I= I_L-I_o(e^{q(V+IRs)/nkT}-1) \text{ -----------(I)}$$

$$I_L= I_{L(T1)}(1+K_0(T-T1))\text{--------------------(11)}$$

$$I_{L(Tl)} = G*I_{SC(Tl,nom}/G(nom) \text{ --------------------(III)}$$

$$K_o = (I_{sc(T2)}-I_{sc(Tl)}))/(T2-T1) \text{ --------------------(IV)}$$

$$I_0= I_{0(T1)} *(T/T1)_{3/n} * e^{-qVg/nk*(1/T-l/Tl)} \text{ ------------(V)}$$

$$I_{0(T1)} = I_{sc(T1)}/(e^{qVoc(T1)/nKT1}-1)$$------------------(VI)

$$Rs = -dV/dI_{voc}-1/Xv$$-------------------------(VII)

$$Xv = I_{0(T1)}*q/nkT1*e^{qVoc(T1)/nkT1}$$-------------(VIII)

Where,

I_L = Photo Current

1_0=Diode Saturation Current

R_s =Series Resistance

R_p = Shunt Resistance

n = Diode Quality Factor

K= Boltzmann's Constant

I_{sc} =Short Circuit Current

v_g = Bandgap Voltage

V_{oc} = Open Circuit Voltage

q = Charge of Electron

T = Temperature

G= Irradiation

All of the constants in the above equations can be determined by examining the manufacturer's ratings of the PV array, and then the published or measured I-V curves of the array. As a typical example, the Solar "reusa" 60W array will be used to illustrate and verify the model. The photo-current I_L (A) is directly proportional to irradiance G (Wm^{-2}). When the cell is short circuited, negligible current flows in the diode. Hence the proportionality constant in equation (III) is set so the rated short circuit current Isc at is delivered under rated irradiation (usually 1 Sun = 1000Wm·2). For the "reusa", Isc = 3.8A at 1 Sun at Tl = 25 °c (298K), So, $IL_{(T1)}$ =3.8 A/sun.

The relationship between the photo-current and temperature is linear (eqn, II) and is deduced by noting the change of to 3.92A (3%) as T changes photo-current with the change of temperature (eqn. IV). Forthe "reusa", IL changes from 3.80 from 25 to 75°C. When the cell is not illuminated, the relationship between the cell's terminal voltage and. current is given by the Shockley equation. When the cell is open circuited and illuminated, the photo-current flows entirely in the diode. The I-V urve is offset from the origin by the photo generated current IL(eqn I).

When the cell is not illuminated, the relationship between the cell's terminal voltage and current is given by the Shockley equation. When the cell is open circuited and illuminated, the photo-current flows entirely in the diode. The I-V curve is offset from the origin by the photo generated current IL (eqn I). The value of the saturation current 10 at 25°C is calculated using the open circuit voltage and short circuit current at this temperature (eqn VI). An estimate must be made of the unknown "ideality factor" n. Green states that it takes a value between 1 and 2, being near one at high currents, rising towards two at low currents. A value of 1.3 is suggested as typical in normal operation, and may be used initially, until a more accurate value is estimated later through curve fitting. The effect of varying the ideality factor can be seen in the "reusa" model, figure higher values soften the knee of the curve. The relationship of 10 to temperature is complex, but fortunately contains no variables requiring evaluation (eqn V). The series resistance of the panel has a large impact on the slope of the I-V curve at V = Voc, as seen in figure (eqn VII) and (eqn VIII) are found by differentiating (eqn I), evaluating at V = Voc and. rearranging in terms of Its. Using the values obtained from the "reusa" manufactures' curves, a value of total panel series resistance Rs= 8mΩ was calculated.

3.5 MATLAB Model of the PV Module

The Solar "reusa", a typical60W PV module, was chosen for modeling. The module has 36 series connected polycrystalline cells. The key specifications are shown in table. The model was evaluated using MATLAB. The model parameters are evaluated during execution using the equations listed in the previous section using the above data points contained in the script. The current I is then evaluated using these parameters, and the variables voltage, Irradiation, and Temperature. If one of the input variables is a vector, the output variable (current) is also a vector. The inclusion of a series resistance in the model makes the solution for current a recurrent equation (refer to eqn. I). A simple iterative technique initially tried only converged for positive currents. The Newton Raphson method used converges much more rapidly, and for both positive and negative currents.

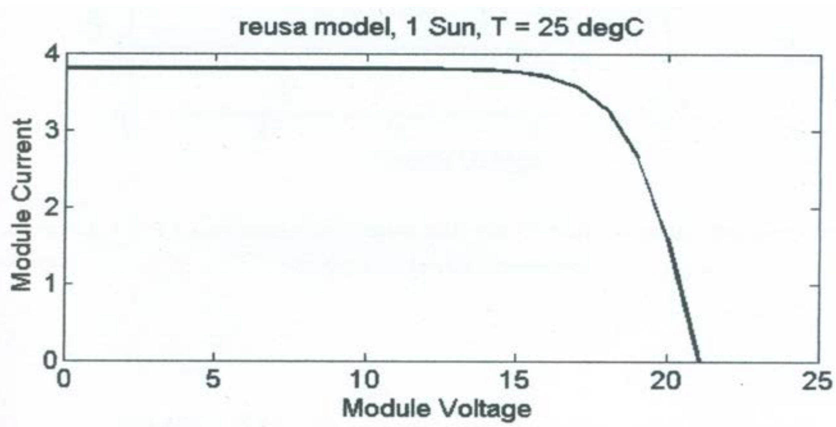


Figure 3.2: - V-I Characteristics Curve of Solar Cell at Constant Temperature and Irradiation

At Temperature	T	25^0	C
Open Circuit Voltage	V_{OC}	21.0	V
Short Circuit Current	I_{SC}	3.74	A
Voltage, Max Power	V_m	17	V
Current, Max Power	I_m	3.52	A
Maximum Power	P_m	59.84	W

Table 3.1:-The key specifications of the Solar "reusa" PV panel.

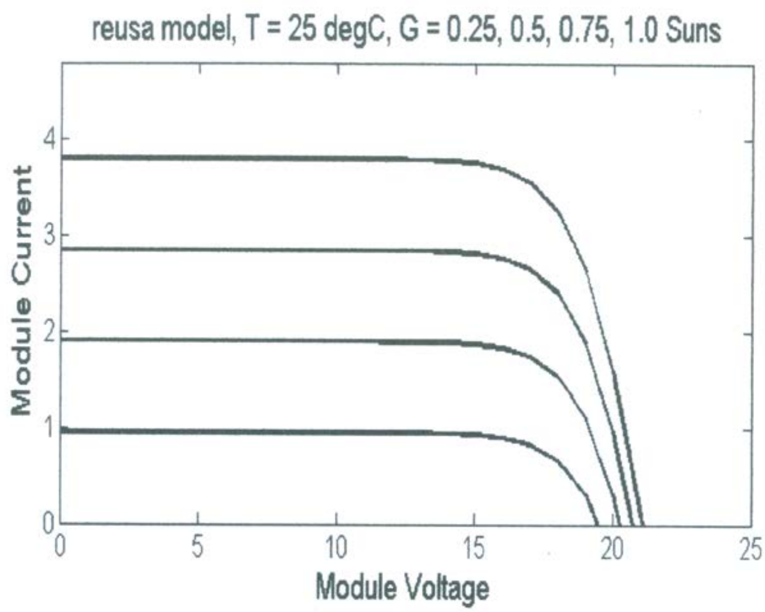
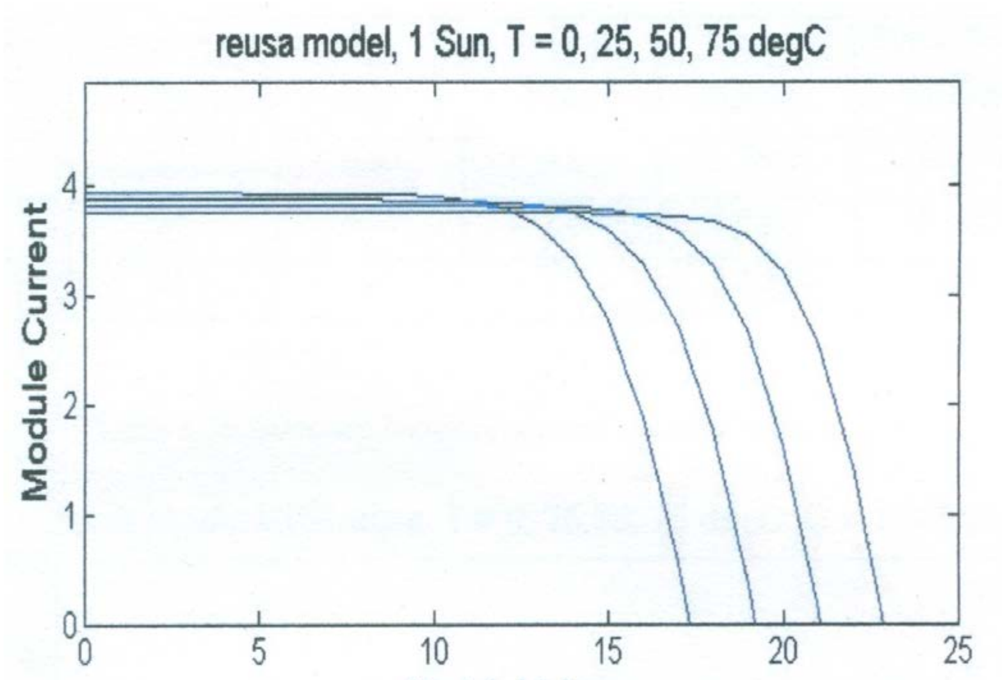
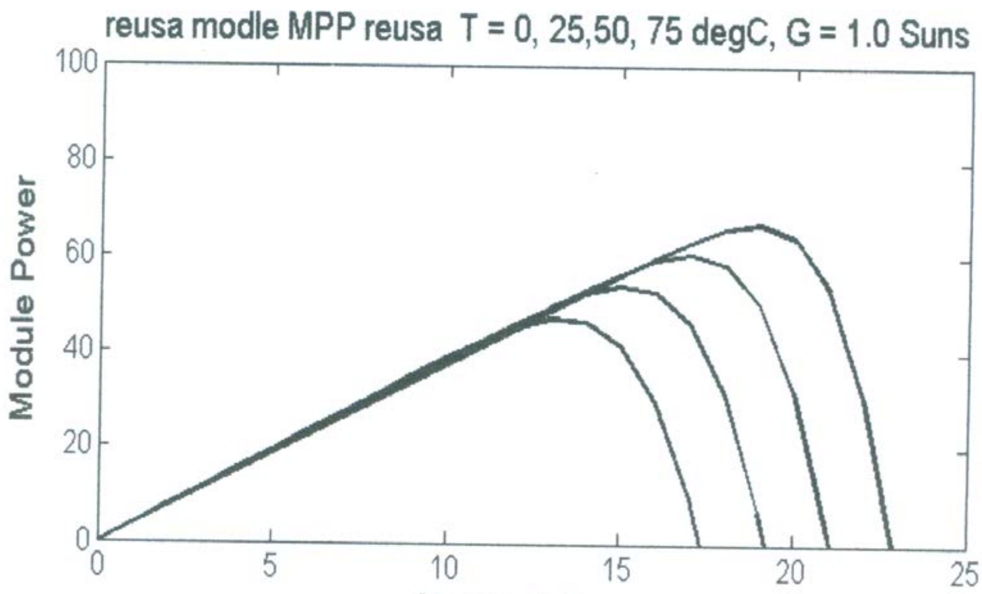


Figure 3.3: - V-I Characteristics Curve of Solar Cell at Constant Temperature and Various Value of Irradiation



Module Voltage

Figure 3.4: - V-I Characteristics Curve of Solar Cell at Constant Irradiation and Various Value of Temperature

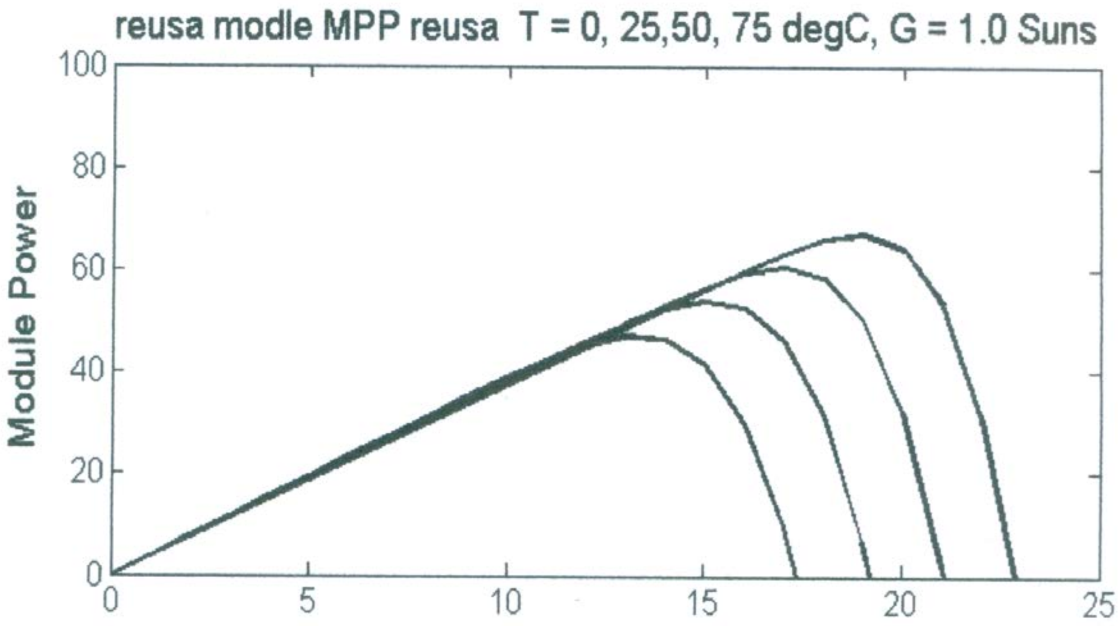


Module Voltage

Figure 3.5: - V-P Characteristics Curve of Solar Cell at Constant Temperature and Various Value of Irradiation

Serial No.	Temperature	Sun	Voltage	Current	Power Max.
01	25	0.25	16	0.8999	14.3978
02	25	0.50	17	1.7869	29.6971
03	25	0.75	17	2.6569	45.1681
04	25	1	17	3.5200	59.9000

Table 3.2:- Constant Temperature and Various Value of Sun

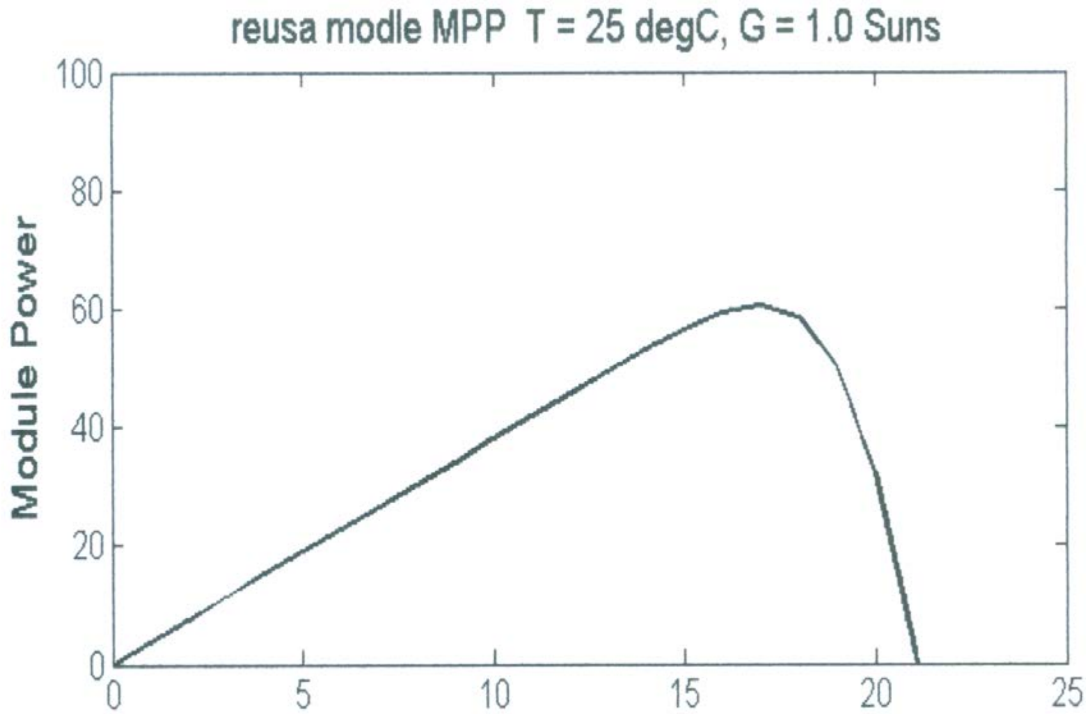


Module Voltage

Figure 3.6: - V-P Characteristics Curve of Solar Cell at Constant Irradiation and Various Value of Temperature

Serial No.	Temperature	Sun	Voltage	Current	Power Max.
01	0	1	19	3.5210	66.8993
02	25	1	17	3.5200	59.9000
03	50	1	15	3.5909	53.8631
04	75	1	13	3.6221	47.0875

Table 3.3:- Constant Sun and Various Value of Temperature



Module Voltage
Figure 3.7: - V-P Characteristics Curve of Solar Cell at Constant Irradiation and Temperature

Serial No.	Temperature	Sun	Voltage	Current	Power Max.
01	25	1	17	3.5200	59.9000

Table 3.4:- Constant Sun and Temperature

Chapter 4

Evaluating MPPT Converter Topologies
Using MATLAB Simulink

4.1 Introduction

A comparison of buck versus boost maximum power point tracker (MPPT) topologies is made and compared with a direct connection to a constant voltage load. Boost converter is the most suitable and the most used for photovoltaic systems because of its high efficiency and high output voltage.

4.2 Maximum Power Point Tracker (MPPT)

In order to optimize the electrical operating conditions of the generator, it is necessary to use an MPPT which consists of: a power section and a control section. The power section is generally a DC/DC converter where as the control section can be constructed either by logic or analog electronics. Several techniques have been proposed in order to drive an AC or DC loads at the MPPT. These techniques are based on the regulation of the PV module output voltage or current according to a reference voltage or current signal, which either constant or derived from the PV generator characteristics. A distinction of these techniques is to directly use the DC/DC converter duty cycle as a control parameter and force the derivative dP/dα to zero, where P is the PV output power and α is the duty cycle, therefore only one control loop is required as illustrated in figure

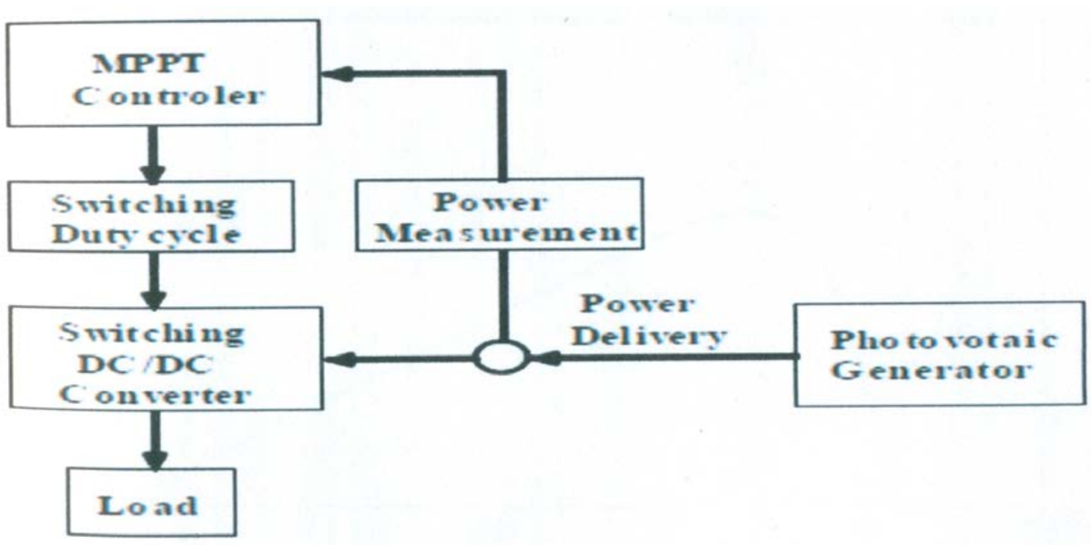


Figure 4.1:- Block Diagram of the MPPT Control

Depending on the result of the comparison the duty cycle is changed accordingly and the process is repeated until the maximum power point has been reached.

4.3 Methods of Maximum Power Point Tracking

The maximum power is reached with the help of a dc/dc converter by adjusting its duty cycle. Now question arises how to vary the duty cycle and in which direction so that maximum power is reached. Whether manual tracking or automatic tracking? Manual tracking is not possible so automatic tracking is preferred to manual tracking. An automatic tracking can be performed by utilizing various algorithms .

- √ Perturb and observe
- √ Incremental Conductance
- √ Parasitic Capacitance
- √ Voltage Based Maximum Power Tracking
- √ Current Based Maximum power Tracking

4.3.1 Perturb and Observe Method

In this algorithm a slight perturbation is introduced in the system. Due to this perturbation the power of the module changes. If the power increases due to the perturbation then the perturbation is continued in that direction. After the peak power is reached the power at the next instant decreases and hence after that the perturbation reverses

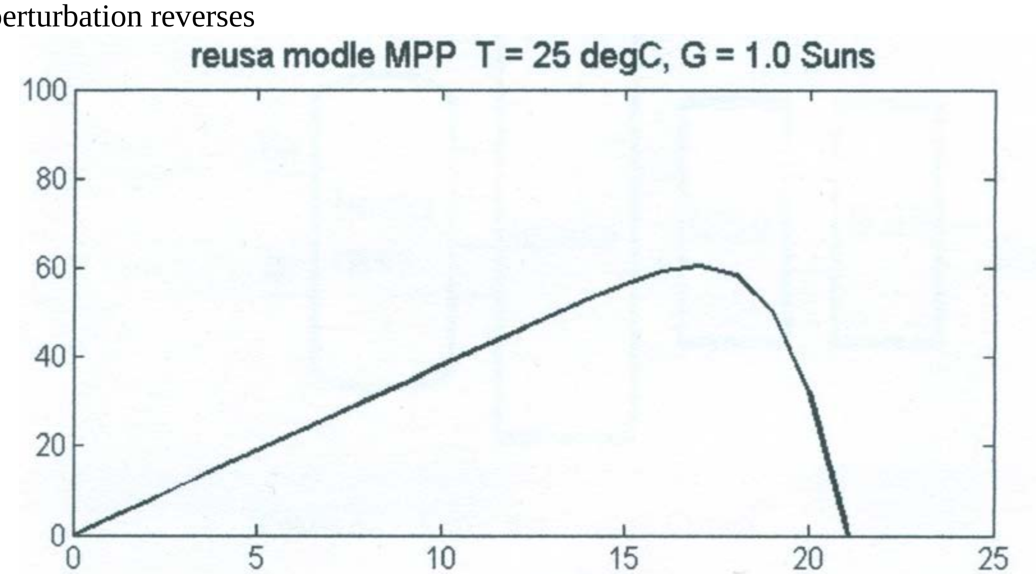


Figure 4.2: - Perturb and observe Method

When the steady state is reached the algorithm oscillates around the maximum point. In order to keep the power variation small the perturbation size is kept very small. The algorithm is developed in such a manner that it sets a reference voltage of the module corresponding to the maximum voltage of the module. A Microcontroller then acts moving the operating point of the module to that particular voltage level. It is observed that there some power loss due to this perturbation also the fails to track the power under fast varying atmospheric conditions. But still this algorithm is very popular and simple.

4.4 Converter control circuit

The system control circuit shown in figure -14 is based on the PIC Microcontroller. The control circuit consists of:

- √ Interface circuits which contain sensors and signal Conditioners connected to the microcontroller A/D converter
- √ PIC 16F877 microcontroller
- √ Quadruple differential line driver
- √ IC driver for the power GTOs.

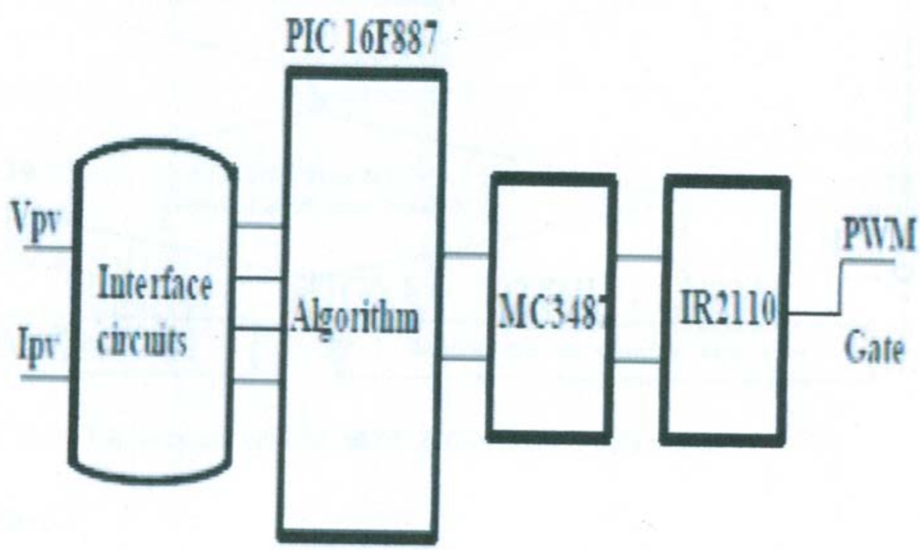


Figure 4.3:- Converter Control Circuit

4.5 MPPT Control Technique & Software Designs

In order to produce a constant output voltage, voltage feedback control system is used. In this control system, output voltage will be measured and compared with a reference voltage and the differential value is used to produce a PWM signal. Any changes in the output voltage will lead to the changes of duty cycle in PWM signal. To produce a set of PWM signal, a microcontroller is used. PIC16F877 microcontroller is selected as it is having a successive approximation analog-to-digital converter, comparator and PWM generator. PWM signal with frequency 20 kHz can be generated when PIC16F877 is driven by a 20 MHz clock cycle. Control strategy for voltage feedback control flow chart as shown in Figure is written and load into PIC 16F877 microcontroller.

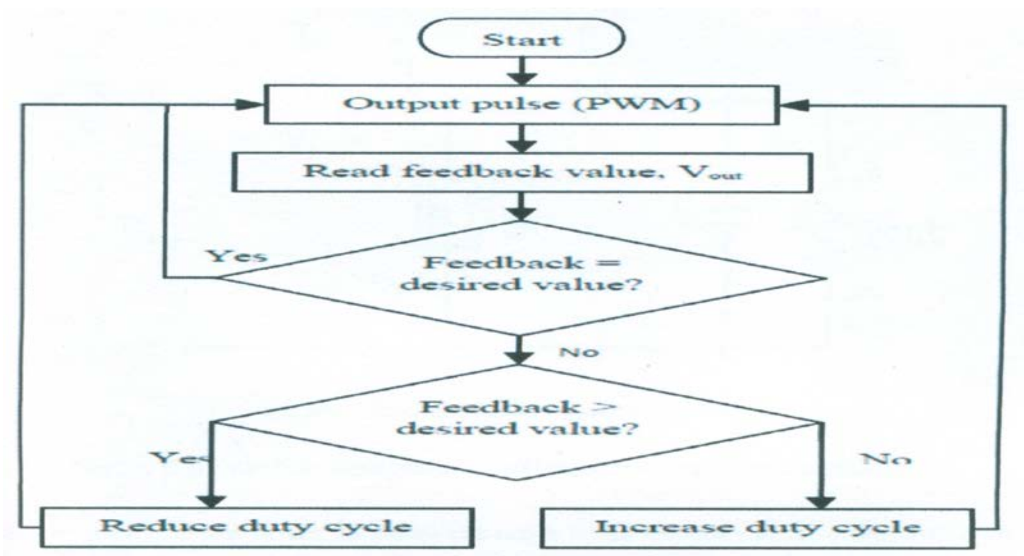


Figure 4.4:-Flowchart of the MPPT Control Technique

4.6 Boost Converter

The boost converter is a medium of power transmission to perform energy absorption and injection from solar panel to grid-tied inverter. The process of energy absorption and injection in boost converter is performed by a combination of four components which are inductor, electronic switch, and diode and output capacitor. The connection of a boost converter is shown in Figure-10. The process of energy absorption and injection will constitute a switching cycle. In other word, the average output voltage is controlled by the switching on and off time duration. At constant switching frequency, adjusting the on and off duration of the switch is called pulse-width-modulation (PWM) switching. The switching duty cycle, k is defined as the ratio of the on duration to the switching time period. The energy absorption and injection with the relative length of switching period will operate the converter in two different modes known as continuous conduction mode (CCM) and discontinuous conduction mode (DCM).

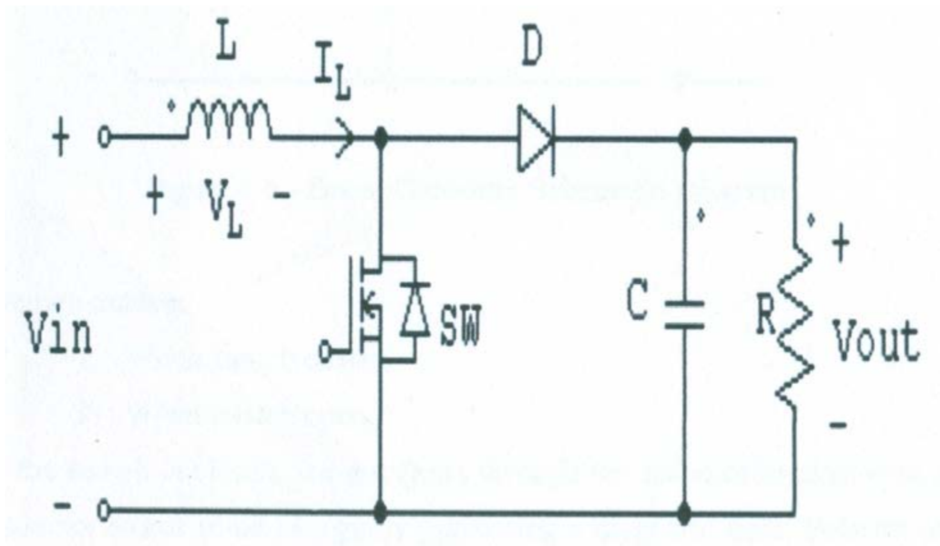


Figure 4.5:- Schematic of Boost Converter

4.7 Boost Converter Analysis Continuous Conduction Mode

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost power stage is shown in Figure (4.6)

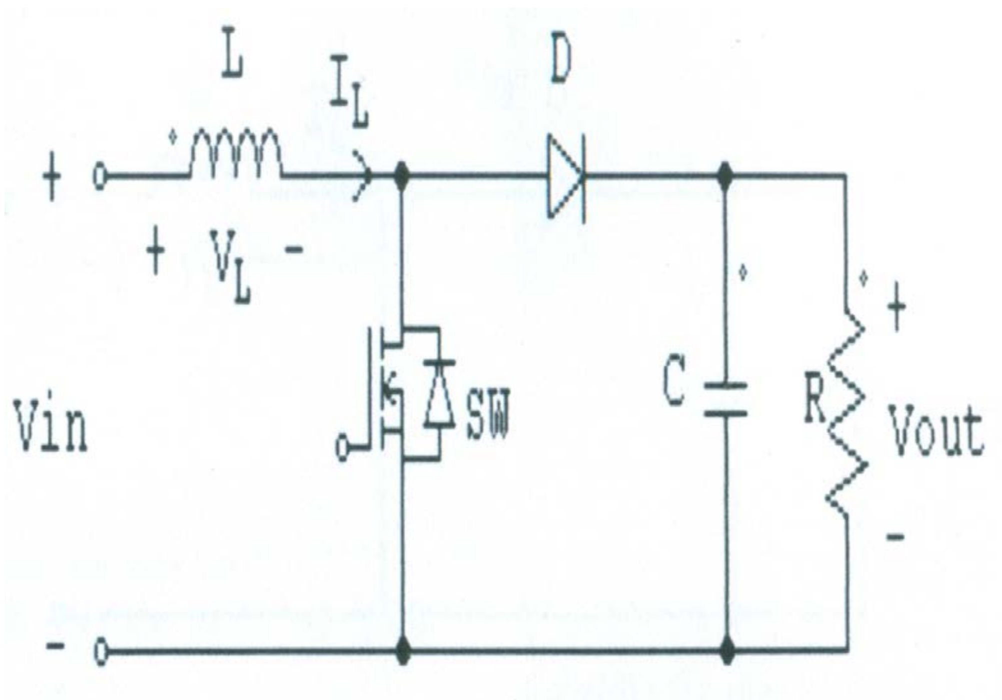


Figure 4.6:- Boost Converter Schematic Diagram

There have two modes:

1. When switch closed.
2. When switch open.

(1) When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive. Shown in figure-

(2) When the switch is opened, current will be reduced as the impedance is higher. The magnetic field previously created will be destroyed to maintain the current flow towards the load. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result two sources will be in series causing a higher voltage to charge the capacitor through the diode D. Shown in figure 4.6 (a)

When Mode 1

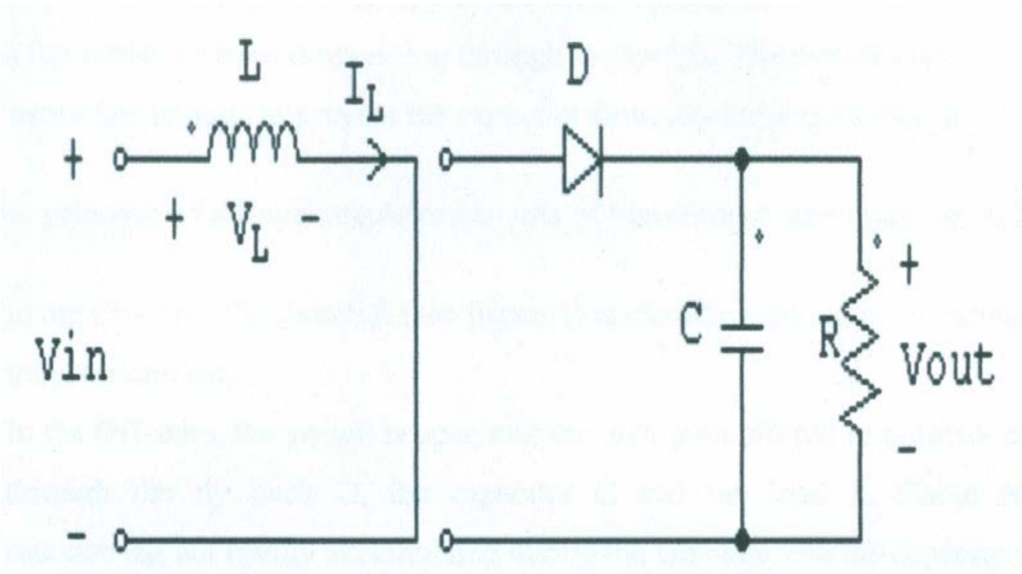


Figure 4.6(a):- Circuit Diagram of Boost Converter During Mode 1

When Mode 2

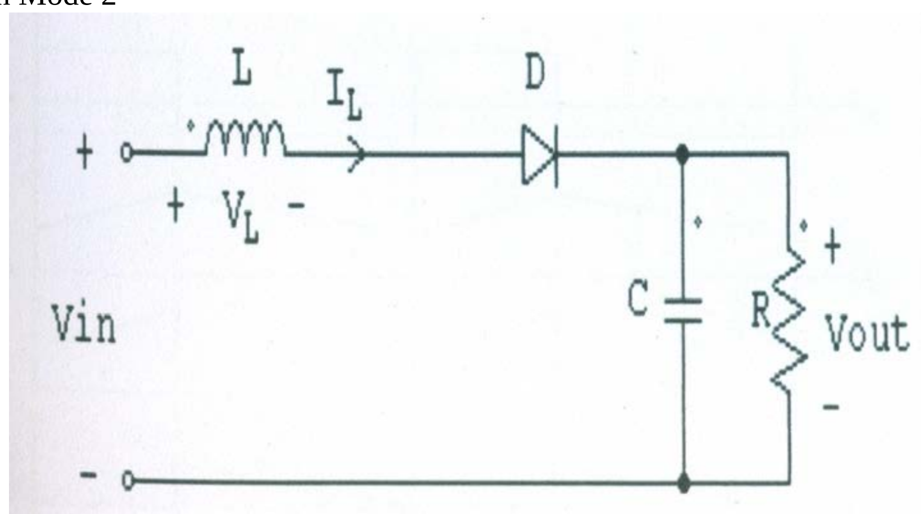


Figure 4.6(b):- Circuit Diagram of Boost Converter During Mode 2

If the switch is cycled fast enough, the inductor will not discharge fully in between charging stages, and the load will always see a voltage greater than that of the input source alone when the switch is opened. Also while the switch is opened, the capacitor in parallel with the load is charged to this combined voltage. When the switch is then closed and the right hand side is shorted out from the left hand side, the capacitor is therefore able to provide the voltage and energy to the load. During this time, the blocking diode prevents the capacitor from discharging through the switch. The switch must of course be opened again fast enough to prevent the capacitor from discharging too much.

The basic principle of a Boost regulator consists of two distinct states (see figure b):

• in the On-state, the switch 8 (see figure 1) is closed, resulting in an increase in the inductor current;

• In the Off-state, the switch is open and the only path offered to inductor current is through the fly back D, the capacitor C and the load R. These results in transferring the energy accumulated during the On-state into the capacitor.

• The input current is the same as the inductor current as can be seen in figure 2.80 it is not discontinuous as in the buck converter and the requirements on the input filter are relaxed compared to a buck converter.

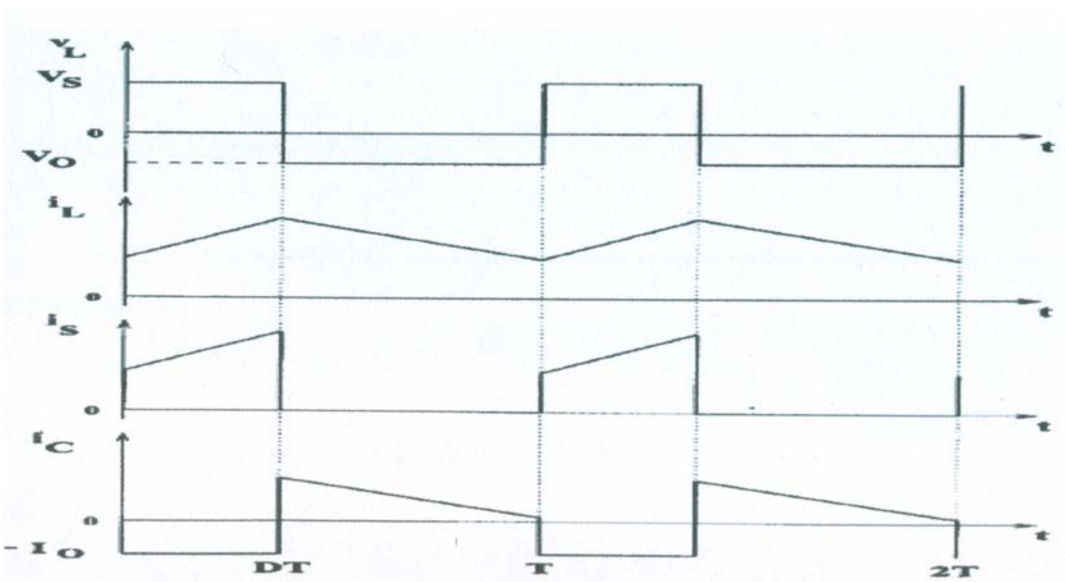


Figure 4.7:- Boost Converter Output Waveform

Here,

$V_S = L\, di/dt$

$= L\Delta I/t1$

$\Delta I = (V_s/L)\,t1$ --(I)

When inductor current falls linearly from I_2 to I_1 time t2

The average output voltage is

$$V_s - V_a = V_L$$

$$= L\,(I1 - I2/t2)$$

$$= -\,L(I2 - I1/t2)$$

$$= -\,L\,\Delta I/t2$$

$$\Delta I = -\,(V_s - V_a)t2/L$$

$= (V_a - V_s)t2/L$ ---(II)

(I) &(II) we get,

$$V_s t1/L = (V_a - V_s)t2/L$$

$$V_a = V_s(\,1/1-k)$$

4.8 Boost Converter Circuit Simulation By MATLAB Simulink

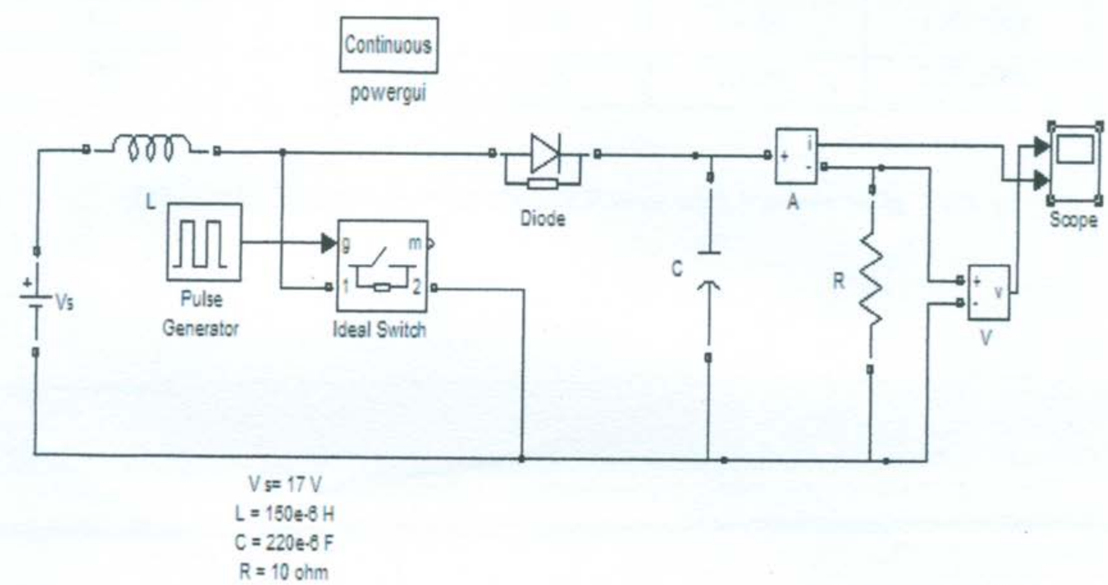


Figure 4.8:- Boost Converter Circuit Simulation By MATLAB Simulink

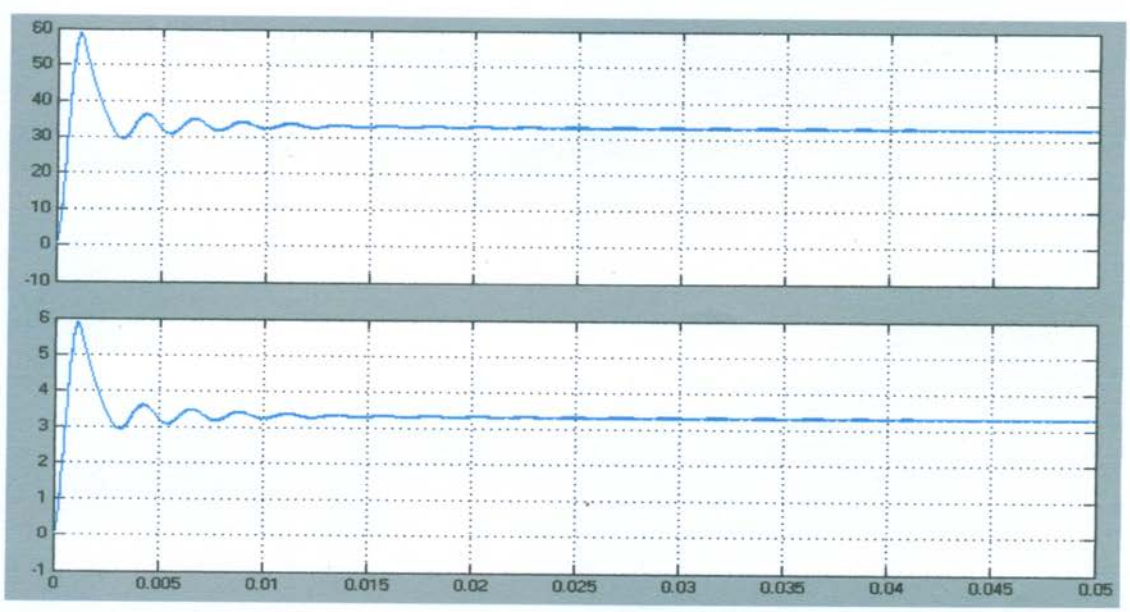


Figure 4.9:- Boost Converter Output Volage and Current Label

Serial No.	Vs	Vout	Iout	Pout
01	16	32.20	3.02	97.2440
02	17	33.00	3.30	108.9000
03	18	37.50	3.56	133.5000

Table 4.1:- Boost Converter Output Power with Various Solar Voltage

Chapter 5

Grid Tie Inverter Design

5.1 Introduction

Dc to Ac converter is known as inverter. Electrical power is usually transmitted and used in the form of alternating current. However, some kinds of electrical generation and storage devices produce direct current, examples being PV modules and batteries. An inverter is a power electronic apparatus which converts DC to AC, allowing the DC power from these generators to be used with ordinary AC appliances, and/or mixed with the existing electrical grid. Photovoltaic generation is usually interfaced at a grid bus through a PWM inverter in which a switch signal is generated by comparing the desired sinusoidal output (i.e the modulated signal or control signal) with high frequency triangle wave (carrier signal). The points of intersection of the modulating signal and the carrier signal are the points in which the GTOs or thyristors of the inverter are switched on by turn.

5.2 Phase-Locked Loop

A phase-locked loop or phase lock loop (PLL) is a control system that generates an output signal whose phase is related to the phase of an input signal. While there are several differing types, it is easy to initially visualize as an electronic circuit consisting of a variable frequency oscillator and a phase detector. The oscillator generates a periodic signal. The phase detector compares the phase of that signal with the phase of the input periodic signal and adjusts the oscillator to keep the phases matched. Bringing the output signal back toward the input signal for comparison is called a feedback loop since the output is 'feedback' toward the input forming a loop.

Keeping the input and output phase in lock step also implies keeping the input and output frequencies the same. Consequently, in addition to synchronizing signals, a phase-locked loop can track an input frequency, or it can generate a frequency that is a multiple of the input frequency. These properties are used for computer clock synchronization, demodulation and frequency synthesis, respectively.

They can be used to demodulate a signal, recover a signal from a noisy communication channel, generate a stable frequency at multiples of an input frequency (frequency synthesis), or distribute precisely timed clock pulses in digital logic circuits such as microprocessors. Since a single integrated circuit can provide a complete phase-locked loop building block, the technique is widely used in modem electronic devices, with output frequencies from a fraction of a hertz up to many gigahertz's.

5.3 Three-Phase PWM Inverter

A three phase output can be obtained from a configuration of six transistors and six diodes. Two types of control signal can be applied to the transistors: 180° conduction or 120° conduction. The 180° conduction has better utilization of the switches and is the preferred method. We consider 180° conduction inverter for grid tie solar system. Describe the function of grid tie inverter in bellow. The frequency of the output voltage wave form depends on the switching rate of the switches and hence can be varied over a wide range. In this mode of operation each switch conducts for 180°. Hence, at any instant of time three switches remain on. When S1 is on, the terminal a gets connected to the positive terminal of input DC source. Similarly, when S4 is on, terminal a gets connected to the negative terminal of input DC source. There are six possible modes of operation in a cycle and each mode is of 60° duration and the explanation of each mode is as follows: result of this the terminals a and c are connected to the positive terminal of the input DC source and the terminal *b* is connected to the negative terminal of the DC source.

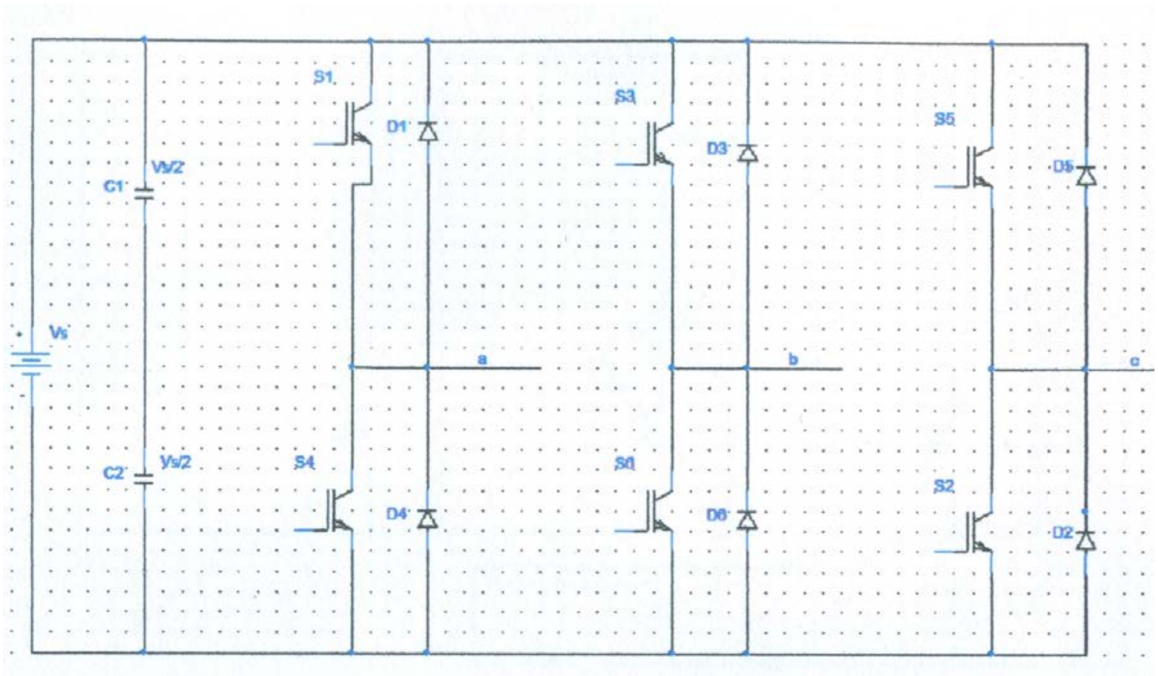


Figure 5.1 :-Configuration of a Three-Phase DC-AC Inverter

5.4 180-Degree Conduction with Star Connected Resistive Load

The configuration of the three phase inverter with star connected resistive load is shown in Figure 2. The following convention is followed:

√ A current leaving a node point a, b or c and entering the neutral point n is assumed to be positive .
√ All the three resistances are equal, Ra=Rb,=Rc=R.

In this mode of operation each switch conducts for 180°. Hence, at any instant of time three switches remain on. When S1 is on, the terminal a gets connected to the positive terminal of input DC source. Similarly, when S4 is on, terminal a gets connected to the negative terminal of input DC source. There are six possible modes of operation in a cycle and each mode is of 60° duration and the explanation of each mode is as follows:

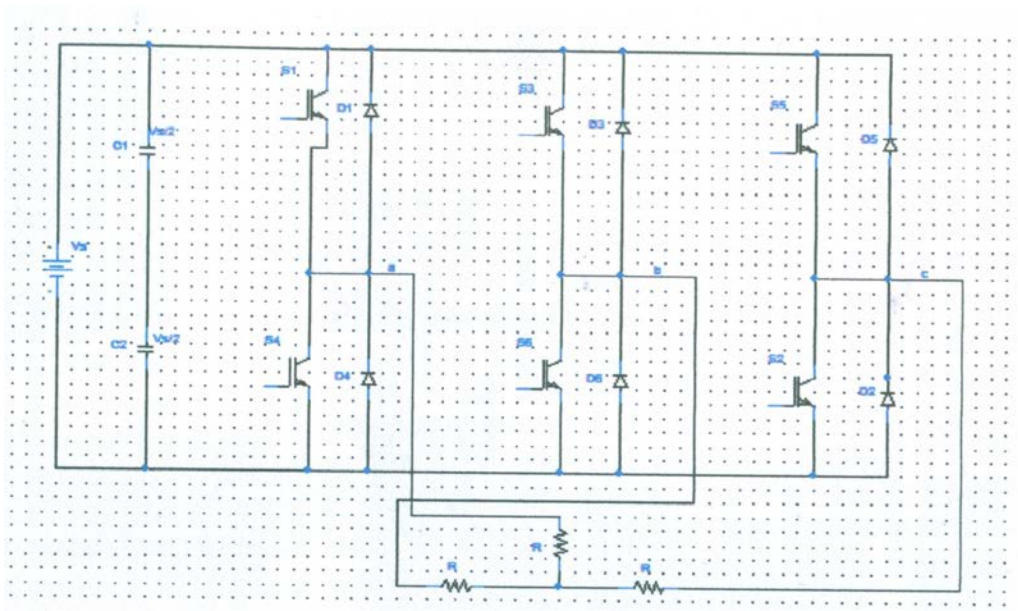


Figure 5. 2: Three-Phase DC-AC Inverter with Star Connect Resistive Load

Mode 1: In this mode the switches S**5**, S**6** and S**1** are turned on for time interval O$\le$***wt$\le\pi$/3.*** As a

Result of this the terminals a and c are connected to the positive terminal of the input DC source and the terminal b is connected to the negative terminal of the DC source. The current flow through Ra, R, and R, is shown in Figure 5.2a and the equivalent circuit is shown in Figure 5.2b. The equivalent resistance of the circuit shown in Figure 5.2b is

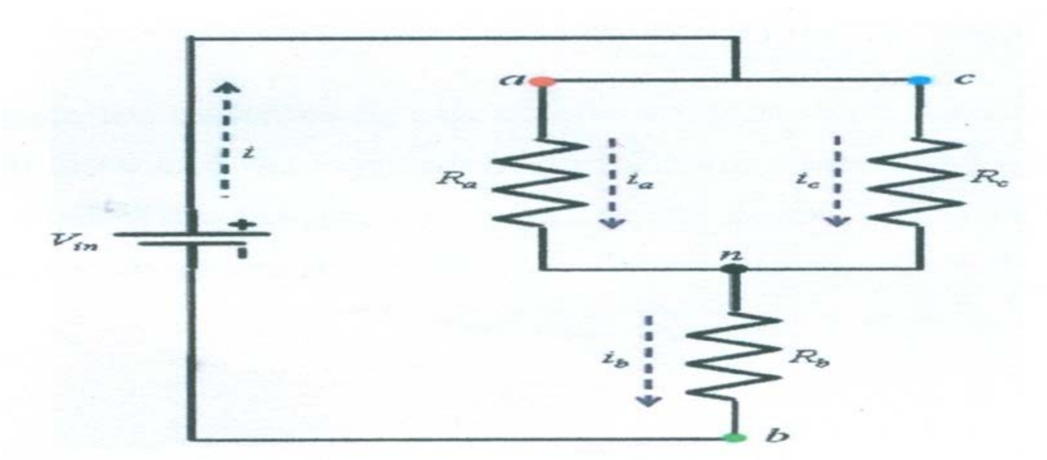


Figure 5.2 (a):- Equivalent Circuit in Mode 1

$$R_{eq} = R + \frac{R}{2} = \frac{3R}{2}$$

$$i_a = i_c = \frac{1}{3}\frac{V_{in}}{R}$$

The current i delivered by the DC input source is

$$i = \frac{V_{in}}{R_{eq}} = \frac{2}{3}\frac{V_{in}}{R}$$

The currents i_a and i_b are

$$i_a = i_c = \frac{1}{3}\frac{V_{in}}{R}$$

Keeping the current convention in mind, the current i_b is

$$i_b = -i = -\frac{2}{3}\frac{V_{in}}{R}$$

Having determined the currents through each branch, the voltage across each branch is

$$v_{an} = v_{cn} = i_a R = \frac{V_{in}}{3};\ v_{bn} = i_b R = -\frac{2V_{in}}{3}$$

Mode 2: In this mode the switches S_6 , S_1 and S_2 are turned *on* for time interval $\pi/3 \le \omega t \le 2\pi/3$ .The current flow and the equivalent circuits are shown in Figure 5.2a and Figure 5.2c respectively. Following the reasoning given for mode 1, the currents through each branch and the voltage drops are given by

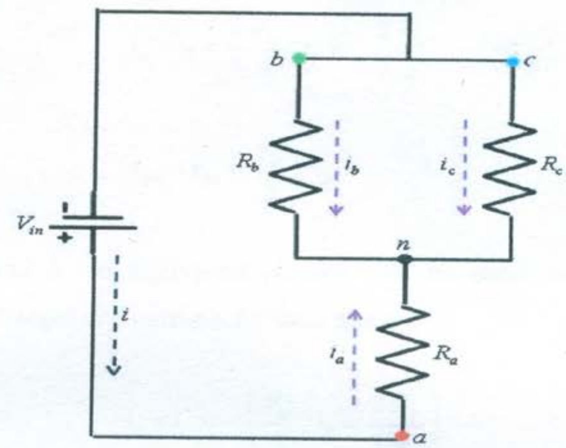


Figure 5.2(b):- Equivalent Circuit in Mode 2

$$i_b = i_c = \frac{1}{3}\frac{V_{in}}{R};\ i_a = -\frac{2}{3}\frac{V_{in}}{R}$$

$$v_{bn} = v_{cn} = \frac{V_{in}}{3};\ v_{an} = -\frac{2V_{in}}{3}$$

Mode 3: In this mode the switches S_1, S_2 and S_3 are on for $2\pi/3 \le \omega t \le \pi$. The current flow and the equivalent circuits are shown in Figure 5.2a and figure 5.2d respectively. The magnitudes of currents and voltages are:

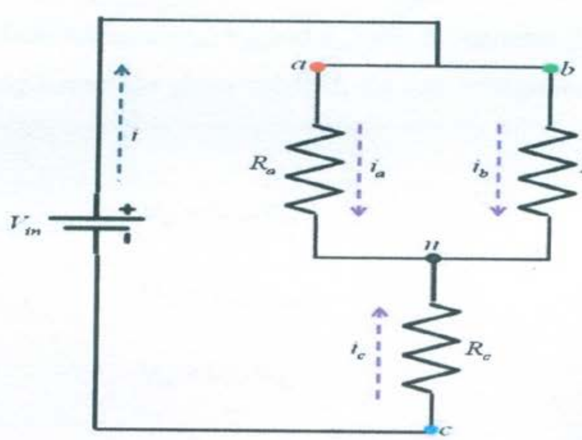


Figure 5.2(c):- Equivalent circuit in Mode 3

$$i_a = i_b = \frac{1}{3}\frac{V_{in}}{R};\ i_c = -\frac{2}{3}\frac{V_{in}}{R}$$

$$v_{an} = v_{bn} = \frac{V_{in}}{3};\ v_{cn} = -\frac{2V_{in}}{3}$$

For modes 4, 5 and 6 the equivalent circuits will be same as modes 1, 2 and 3 respectively. The voltages and currents for each mode are:

$$\left.\begin{aligned} i_a = i_c = -\frac{1}{3}\frac{V_{in}}{R};\ i_b = \frac{2}{3}\frac{V_{in}}{R} \\ v_{an} = v_{cn} = -\frac{V_{in}}{3}; V_{bn} = \frac{2V_{in}}{3} \end{aligned}\right\} \text{For mode 4}$$

$$\left.\begin{aligned} i_b = i_c = -\frac{1}{3}\frac{V_{in}}{R};\ i_a = \frac{2}{3}\frac{V_{in}}{R} \\ v_{bn} = v_{cn} = -\frac{V_{in}}{3}; V_{an} = \frac{2V_{in}}{3} \end{aligned}\right\} \text{For mode 5}$$

$$\left.\begin{aligned} i_a = i_b = -\frac{1}{3}\frac{V_{in}}{R};\ i_c = \frac{2}{3}\frac{V_{in}}{R} \\ v_{an} = v_{bn} = -\frac{V_{in}}{3}; V_{cn} = \frac{2V_{in}}{3} \end{aligned}\right\} \text{For mode 6}$$

The plots of the phase voltages (v_{an}, v_{bn} and v_{cn}) and the currents (i_a, i_b and i_c) are shown in Figure 6. Having known the phase voltages, the line voltages can also be determined as:

$$V_{ab} = V_{an} - V_{bn}$$

$$V_{bc} = V_{bn} - V_{cn}$$

$$V_{ca} = V_{cn} - V_{an}$$

The plots of line voltages are also shown in Figure 5.2 and the phase and line voltages can be expressed in terms of Fourier series as:

$$v_{an} = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_{in}}{3n\pi}\left[1+\sin\frac{n\pi}{2}\sin\frac{n\pi}{6}\right]\sin(n\omega t)$$

$$v_{bn} = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_{in}}{3n\pi}\left[1+\sin\frac{n\pi}{2}\sin\frac{n\pi}{6}\right]\sin\left(n\omega t-\frac{2n\pi}{3}\right)$$

$$v_{cn} = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_{in}}{3n\pi}\left[1+\sin\frac{n\pi}{2}\sin\frac{n\pi}{6}\right]\sin\left(n\omega t-\frac{4n\pi}{3}\right)$$

$$v_{ab} = v_{an} - v_{bn} = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_{in}}{n\pi}\sin\frac{n\pi}{2}\sin\frac{n\pi}{3}\sin\left(n\omega t+\frac{n\pi}{6}\right)$$

$$v_{bc} = v_{bn} - v_{cn} = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_{in}}{n\pi}\sin\frac{n\pi}{2}\sin\frac{n\pi}{3}\sin\left(n\omega t-\frac{n\pi}{2}\right)$$

$$v_{ca} = v_{cn} - v_{an} = \sum_{n=1,3,5,\dots}^{\infty} \frac{4V_{in}}{n\pi}\sin\frac{n\pi}{2}\sin\frac{n\pi}{3}\sin\left(n\omega t-\frac{7n\pi}{6}\right)$$

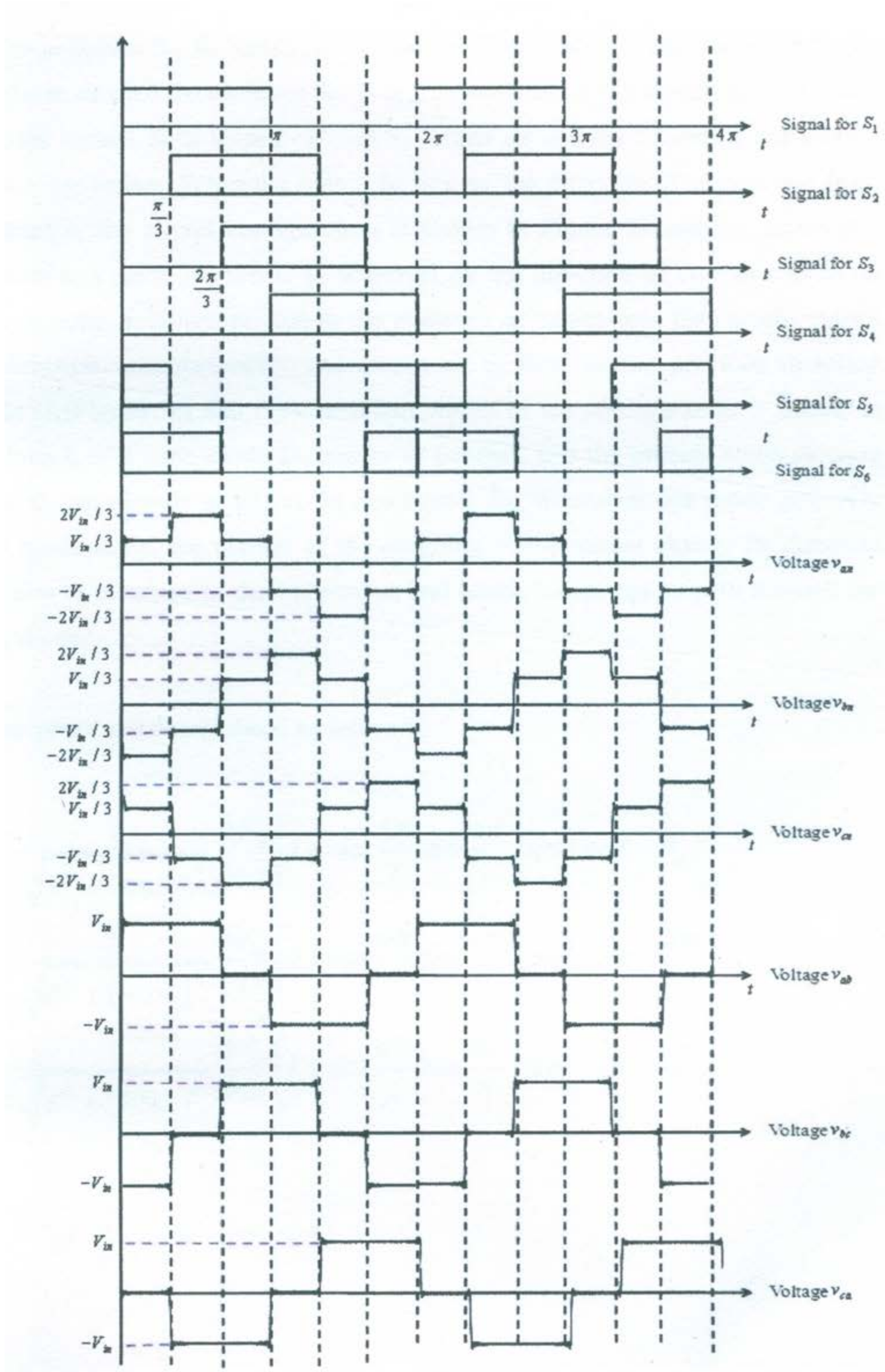


Figure 5.3:-Voltage Waveforms for Resistive Load for 180°

In mode 1 the switches S5, S4 and S1 are turned on. The mode previous to model 1 was mode 6 and the in mode 6 the switches S4, S5 and S6 were on. In the transition from mode 6 to mode I the switch 84 is turned off and 8) turned on and the current i, changes its direction (outgoing phase). When the switch 84 was on, the direction of current was from point n to point a, the circuit configuration is shown in Figure 7a and the equivalent circuit is shown in Figure 7b. When 8) is turned on the direction of current should be from point a to point n. However, due to the presence of inductance, the current cannot change its direction instantaneously and continues to flow in the previous direction through diode D) (Figure 7c) and the equivalent circuit of the configuration is shown in Figure 7d. Once $i_a = 0$, the diode D1 ceases to conduct and the current starts flowing through S1 as shown already in Figure 3a and Figure 3b. Whenever one mode gets over and the next mode starts, the current of the outgoing phase cannot change its direction immediately due to presence of the inductance and hence completes its path through the freewheeling diode.

The phase currents are determined as follows:

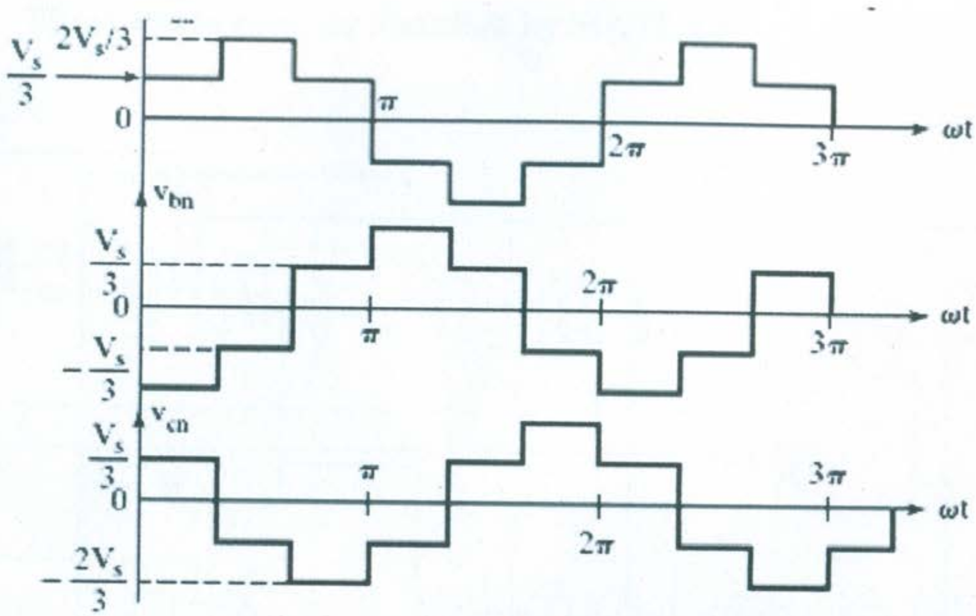
$$i_a = \sum_{n=1,3,5,\ldots}^{\infty} \frac{1}{\sqrt{R^2 + (n\omega L)^2}} \frac{4V_{in}}{3n\pi}\left[1 + \sin\frac{n\pi}{2}\sin\frac{n\pi}{6}\right]\sin(n\omega t - \theta_n)$$

$$i_b = \sum_{n=1,3,5,\ldots}^{\infty} \frac{1}{\sqrt{R^2 + (n\omega L)^2}} \frac{4V_{in}}{3n\pi}\left[1 + \sin\frac{n\pi}{2}\sin\frac{n\pi}{6}\right]\sin\left(n\omega t - \frac{2n\pi}{3} - \theta_n\right)$$

$$i_c = \sum_{n=1,3,5,\ldots}^{\infty} \frac{1}{\sqrt{R^2 + (n\omega L)^2}} \frac{4V_{in}}{3n\pi}\left[1 + \sin\frac{n\pi}{2}\sin\frac{n\pi}{6}\right]\sin\left(n\omega t - \frac{4n\pi}{3} - \theta_n\right)$$

where

$$\theta_n = \tan^{-1}\left(\frac{n\omega L}{R}\right)$$



(b) Phase voltages for 180° conduction

Figure 5.4:- Phase Voltage for 180^0 Conduction

Equivalent Circuits for Y-Load

$$v_{ab}(t) = \sum_{n=1,3,5,..}^{\infty} \frac{4V_S}{\sqrt{3}n\pi} \sin(\frac{n\pi}{3}) \sin n(\omega t)$$

$$v_{bc}(t) = \sum_{n=1,3,5,...}^{\infty} \frac{4V_S}{\sqrt{3}n\pi} \sin(\frac{n\pi}{3}) \sin n(\omega t - \frac{2\pi}{3})$$

$$v_{ca}(t) = \sum_{n=1,3,5,..}^{\infty} \frac{4V_S}{\sqrt{3}n\pi} \sin(\frac{n\pi}{3}) \sin n(\omega t - \frac{4\pi}{3})$$

5.5 Three Phase Inverter Simulink by MATLAB

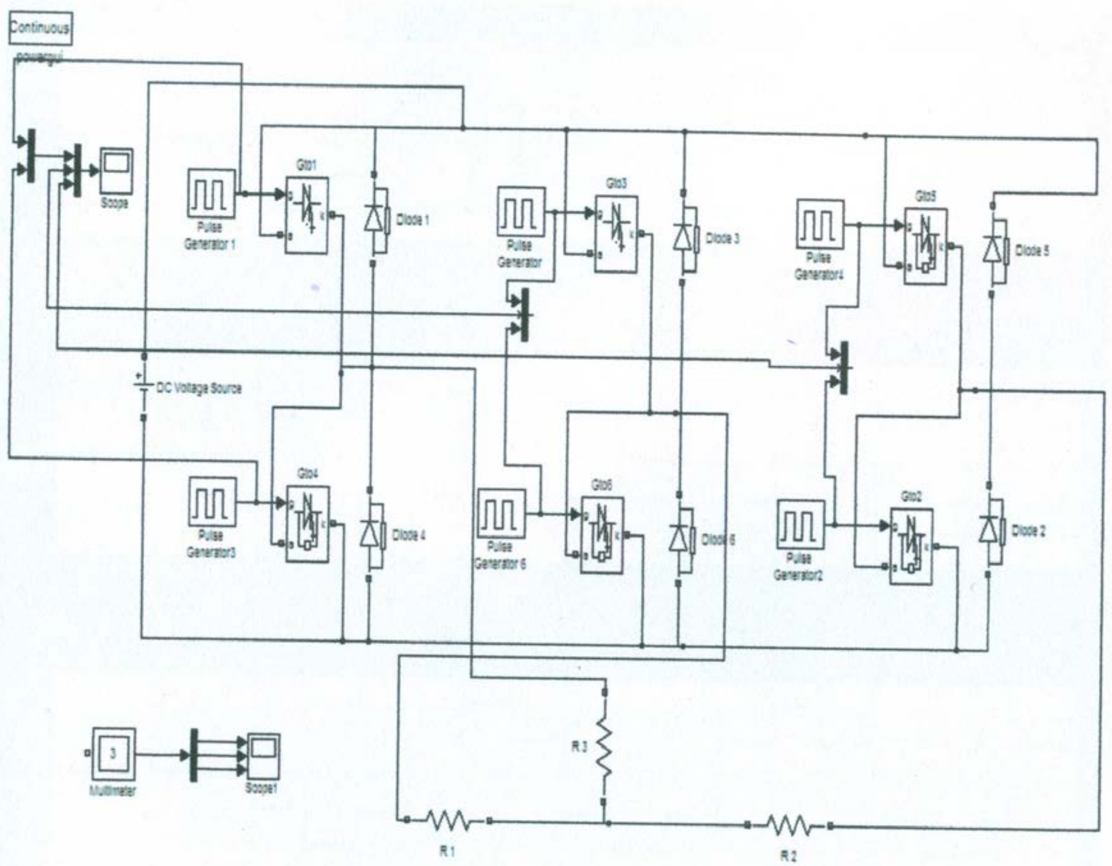


Figure 5.5: - Three Phase Inverter Simulink by MATLAB

5.6 Three Phase Inverter Simulink Output Waveform by MATLAB

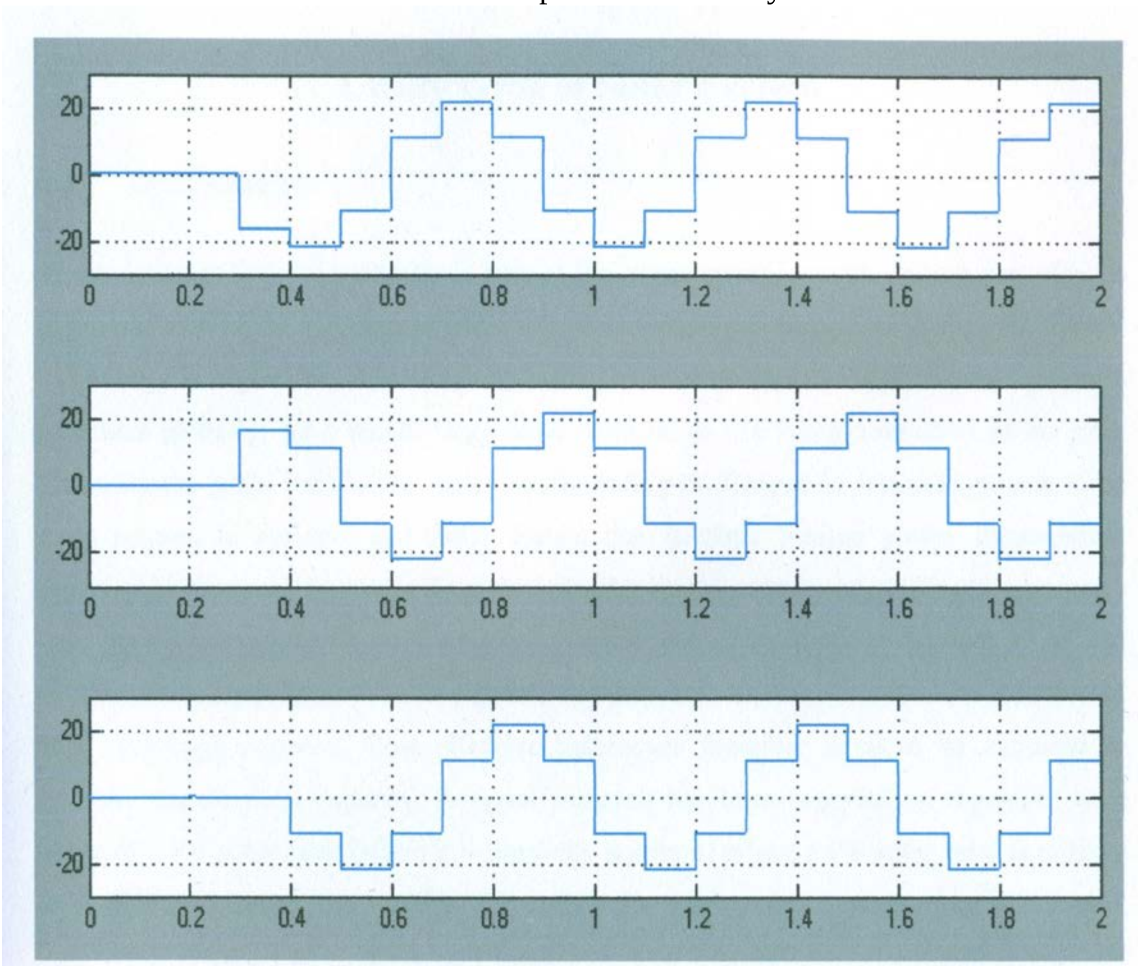


Figure 5.6:- Three Phase Inverter Simulink Output Waveform by MATLAB

Chapter 6

Utility Grid of Solar System

6.1 Introduction

Photo voltaic (PV) solar energy is one of the green energy sources which can play an important role in the program of reducing green house gas emissions. Although, the PV technology is expensive, it is receiving strong encouragement through various incentive programs globally. As a result, large scale solar farms are being connected to the grid. Transmission grids worldwide are presently facing challenges in integrating such large scale renewable systems and Solar Farms due to their limited power transmission capacity. To increase the available power transfer limits/capacity of existing transmission line, series compensation and various Flexible AC Transmission System (FACTS) devices are being proposed. In an extreme situation new lines may need to be constructed at a very high expense. Cost effective techniques therefore need to be explored to increase transmission capacity. A novel research has been reported on the night time usage of a PV solar farm (when it is normally dormant) where a PV solar farm is utilized as a Static Compensator a FACTS device for performing voltage control, thereby improving system performance and increasing grid connectivity of neighbouring solar farms. It is known that voltage control can assist in improving transient stability and power transmission limits, several shunt connected FACTS devices, such as, Static Var. Compensator and static compensator are utilized worldwide for improving transmission capacity. This project presents a novel night-time application of a PV solar farm by which the solar farm inverter is employed as a static compensator for voltage control in order to improve power transmission capacity during nights. During day time also, the solar farm while supplying real power output is still made to operate as a static compensator and provide voltage control using its remaining inverter MVA capacity (left after what is needed for real power generation). This day time voltage regulation is also shown to substantially enhance stability and power transfer limits.

6.2 Theory of Synchronizing

When closing a circuit breaker between two energized parts of the power system, it is crucial to match voltages on both sides of the circuit breaker before closing. If this matching or "synchronizing" process is not done correctly, a power system disturbance will result and equipment (including generators) can be damaged. In order to synchronize properly, three different aspects of the voltage across the circuit breaker must be closely monitored. The three aspects of the voltage are called the synchronizing variables and are:

√ The voltage magnitudes

√The frequency of the voltages

√ The phase Sequence

6.3 Synchronizing Method

Modem power plants typically utilize automatic synchronizers. The importance of synchronizing cannot be overstated. All system operators should understand the theory and practice of synchronizing. If two power systems are synchronized via an open circuit breaker, and the synchronizing process is not done correctly, solar system can be severely damaged.

6.3.1 Synchronizing Two Islands

The first scenario assumes that two islands are about to be connected together using the open circuit breaker as illustrated in Figure 1. The two islands, since they are independent electrical systems, will have different frequencies so all three of the synchronizing variables must be monitored to ensure they are within acceptable limits prior to closing the open circuit breaker.

The system operators for the two islands will likely have to adjust generator MW output levels (or adjust island load magnitudes) in one or both islands to achieve the desired adjustment in frequencies and phase angles. Voltage control equipment (reactors, capacitors, etc.) may also be used as necessary to change voltage magnitudes to within acceptable levels.

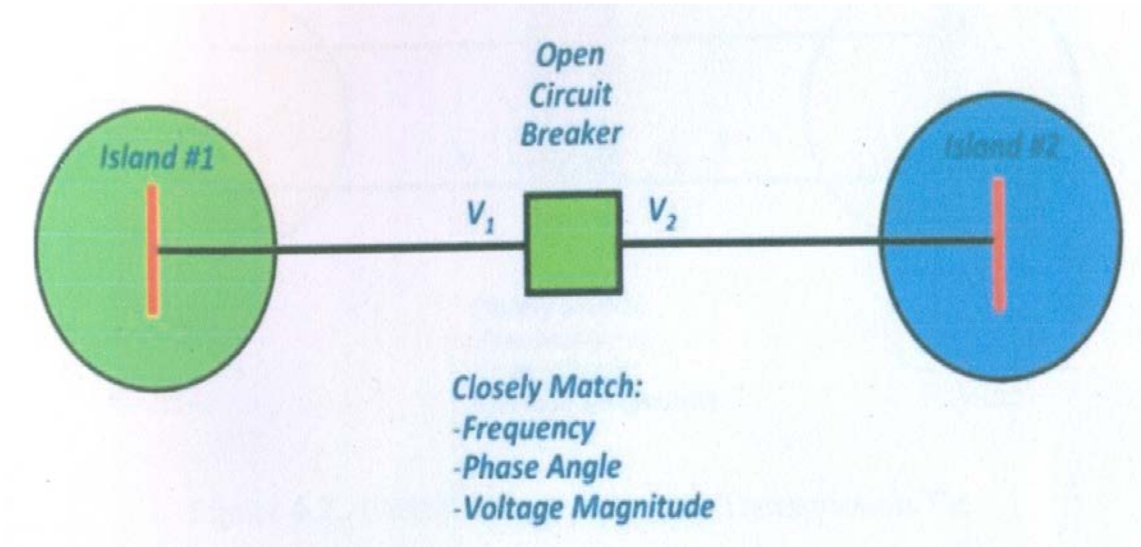


Figure 6.1:-Synchronizing Two Islands

6.3.2 Establishing the Second Tie

Once the first transmission line is closed interconnecting the two islands, the frequency will be the same in the two areas. Therefore, one of the three synchronizing variables (the frequency) is no longer a factor. However, as illustrated in Figure 2, the other two synchronizing variables must still be monitored. Generation and/or voltage control equipment may be to be utilized to ensure the phase angle and voltage magnitude differences are within acceptable limits prior to closing the second circuit breaker. This process should be easier than closing the first transmission line as frequency isnoongera factor.

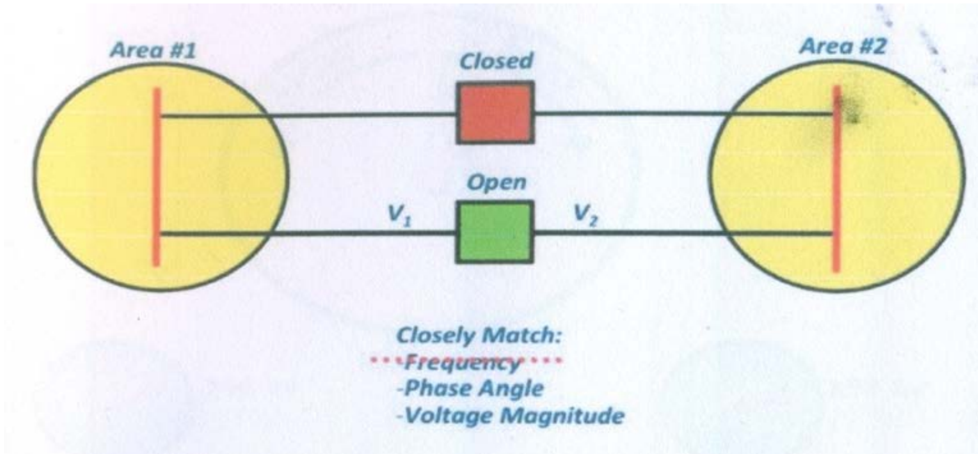


Figure 6.2:-Establishing the Second Transmission Tie

6.4 Synchronizing Measuring Equipment

6.4.1 Synchroscope

A synchroscope is a simple piece of equipment that is used to monitor the three synchronizing variables. A basic synchroscope (illustrated in Figure 3) inputs voltage waveforms from the two sides of the open circuit breaker. If the voltage waveforms are at the same frequency, the synchroscope does not rotate. If the voltage waveforms are at a different frequency, the synchroscope rotates in proportion to the frequency difference. The synchroscope needle always points to the voltage phase angle difference.

A synchroscope is a manual device in that an operator must be watching the "scope" to ensure they close the circuit breaker at the correct time. The synchroscope is normally mounted above eye level on a "synch panel". The synch panel also contains two voltmeters so that the voltage magnitudes can be imultaneously compared.

The synchroscope in Figure 3 reflects a slight voltage magnitude mismatch, and a stationary synchroscope with a phase angle of approximately 35°. The fact that the synchroscope needle is not rotating indicates frequency is the same on either side of the circuit breaker.

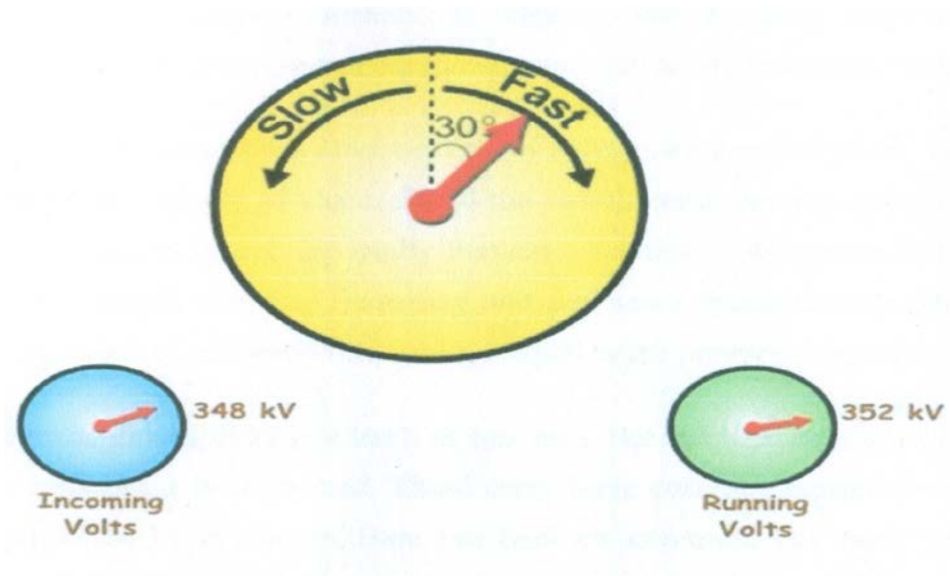


Figure 6.3:- Synchroscope in a Synch Panel

6.5 Photovoltaic Systems Monitoring

Monitoring and control of photovoltaic systems is essential for reliable functioning and maximum yield of any solar electric system. The simplest monitoring of an inverter can be performed by reading values on display - display (usually LCD) is part of almost each grid-connected inverter. Values like PV array power, AC grid power, PV array current are usually available.

6.6 Electric Switchboard

An electric switchboard is a device that directs electricity from one source to another. It is an assembly of panels, each of which contains switches that allow electricity to be redirected. The U.S. National Electrical Code (NEC) defines a switchboard as a large single panel, frame, or assembly of panels on which are mounted, on the face, back, or both, switches, over current and other protective devices, buses, and usually instruments. The role of a switchboard is to divide the main current provided to the switchboard into smaller currents for further distribution and to provide switching, current protection and metering for these various currents. In general, switchboards distribute power to transformers, panel boards, control equipment, and ultimately to system loads.

The operator is protected from electrocution by safety switches and fuses. There can also be controls for the supply of electricity to the switchboard, coming from a generator or bank of electrical generators, especially frequency control of AC power and load sharing controls, plus gauges showing frequency and perhaps a synchroscope. The amount of power going into a switchboard must always equal to the power going out to the loads.

Inside the switchboard there is a bank of bus bars, flat strips of copper or aluminum, to which the switchgear is connected. These carry large currents through the switchboard, and are supported by insulators. Bare bus bars are common, but many types are now manufactured with an insulating cover on the bars, leaving only connection points exposed.

Modern switchboards are metal enclosed and of "dead front" construction; no energized parts are accessible when the covers and panels are closed. Formerly, open switchboards were made with switches and other devices were mounted on panels made of slate, granite, or ebony asbestos board. The metal enclosure of the switchboard is bonded to earth ground for protection of personnel. Large switchboards may be free-standing floor mounted enclosures with provision for incoming connections at either the top or bottom of the enclosure. A switchboard may have incoming bus bars or bus duct for the source connection, and also for large circuits fed from the board. A switchboard may include a metering or control compartment separated from the power distribution conductors.

6.7 Distribution Board

A distribution board (or panel board) is a component of an electricity supply system which divides an electrical power feed into subsidiary circuits, while providing a protective fuse or circuit breaker for each circuit, in a common enclosure. Normally, a main switch, and in recent boards, one or more 'Residual-current devices (RCD) or Residual Current Breakers with Over current protection (RCBO), will also be incorporated.

6.8 Busbar

In electrical power distribution, a busbar (also spelled bus bar, or sometimes incorrectly as buss bar or busbar, with the term bus being a contraction of the Latin omnibus - meaning for all) is a strip or bar of copper, brass or aluminum that conducts electricity within a switchboard, distribution board, substation, battery bank or other electrical apparatus. Its main purpose is to conduct electricity, not to function as a structural member.

6.9 Electricity Meter

An electricity meter or energy meter is a device that measures the amount of electric energy consumed by a residence, business, or an electrically powered device.
Electricity meters are typically calibrated in billing units, the most common one being the kilowatt hour [kWh]. Periodic readings of electricity meters established billing cycles and energy used during a cycle.

In settings when energy savings during certain periods are desired, meters may measure demand, the maximum use of power in some interval. "Time of day" metering allows electric rates to be changed during a day, to record usage during peak high-cost periods and off-peak, lower-cost, periods. Also, in some areas meters have relays for demand response load shedding during peak load periods.

Chapter 7

Conclusion and Recommendations

7.1 Conclusion

Electricity is the basic necessity for the economics of a country. The industrial development and the increase of living standard of people are directly related to the more use of electricity. Solar power is connected to the National grid then increase total generation power. So, we study how to connect solar energy to the national grid. That system is very complex but solar source free from cost also, there has no environment effect and reliable.

The general trends in the past decade of increasing solar cell efficiency, decreasing PV system costs, increasing government incentive programs, and several other factors have all combined synergistically to reduce the barriers of entry for PV systems to enter the market and expand their contribution to the global energy portfolio. The increase in economic feasibility could not come at a better time to provide a clean solution for generating energy to meet the rapidly rising demand. However, the price paid for tapping into the free resource is its intermittent nature and the problems discovered when integrating the resource into electrical power systems. The problems continue to grow as a larger percent of generation is coming from renewable sources. In an attempt to help mitigate some of the problems produced by PV systems, rather than installing additional equipment along a feeder, this thesis presents a solution by modifying the controls of the inverter to eliminate the problems. The additional control features designed, modeled, and analyzed in the MATLAB simulation environment are voltage regulation, frequency response, and remote curtailment and ramping capabilities.

7.2 Recommendations for Further Research

The following points are worthy of further investigation:

- √ The proposed operating strategies can be implemented developing and experimental prototype .

- √ The results of simulation studies can be applied in the practical generation and security analysis of a grid system in which one or more Photovoltaic generation are embedded.

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