A Project Report on

ACTIVE AND REACTIVE POWER CONTROL IN THREE PHASE SOLAR PV INVERTER USING MODIFIED IC METHOD.

Submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRICAL AND ELECTONICS ENGINEERING

SUBMITTED BY

T. SAI HARI HARA CHANDRA (19BJ1A0240)

Under the Esteemed Guidance of
Mr P.LAKSHMI NARAYANA M.Tech
Assistant Professor
DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

DEPARTEMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

ST.MARY'S GROUP OF INSTITUTIONS GUNTUR
Accredited by "NACC"
(Approved by AICTE New Delhi, Affiliated to JNTU, Kakinada)
CHEBROLU (V&M), GUNTUR dist - 522212 (A.P)

ST.MARY'S GROUP OF INSTITUTIONS GUNTUR

Accredited by "NACC"
(Approved by AICTE New Delhi, Affiliated to JNTU, Kakinada)
CHEBROLU (V&M), GUNTUR dist - 522212 (A.P)

CERTIFICATE

This is to certify that the thesis of Main project entitled **"ACTIVE AND REACTIVE POWER CONTROL IN THREE PHASE SOLAR PV INVERTER USING MODIFIED IC METHOD"** is a benefide work carried out by **TALAGADADEEVI SAI HARI HARA CHANDRA (19BJ1A0240)** under my supervision and guidance in partial fulfillment of the requirements for the award degree of BACHELOR OF TECHNOLOGY in the department of Electrical and Electronics engineering. The content of the thesis has not been submitted earlier for the award of any other degree or certificate.

PROJECT GUIDE

Mr. P. Lakshmi Narayana M.Tech.

Assistant Professor
Department of EEE.

HEAD OF THE DEPARTMENT

Mr. P. Lakshmi Narayana M.Tech.

Assistant Professor
Department of EEE.

EXTERNAL EXAMINER

ACKNOWLEDGEMENT

I thankful to our Founder and Chairman Sri. REV .**DR.K.V.K.Rao** Garu for his kind proceedings towards all aspects for completion of our project.

I profoundly thank to our Principle **Dr.B.Penchalaiah** for his kind permission and help proceed with our project

I wish to convey our sincere thanks to our Director **Dr. S Apparao** for his kind permission to proceed with our project.

I wish to convey our sincere thanks to our Vice- Principal **Mr.Ch.Ravi Babu** for his kind permission to proceed with our project.

I would like to express our gratitude to our Head of the Department of Electrical And Electronics Engineering **Mr. P.Lakshmi Narayana** for having encouraged do our projects work.

I would like to express our heart-left gratitude to our internal guide **Mr.P.Lakshmi Narayana** who was the main impetus behind the endeavor, we thank for Valuable guidance through our project.

I express our gratitude to all other Teaching and Non –Teaching staff members and colleagues concerned.

DECLARATION

I am the student of St. Mary's Group of Institutions Guntur, Chebrolu, Guntur District, Andhra Pradesh, hereby declare that this Project Work titled as **"ACTIVE AND REACTIVE POWER CONTROL IN THREE PHASE SOLAR PV INVERTER USING MODIFIED IC METHOD"** being submitted to the Department of Electrical and Electronics Engineering of this Institute, affiliated to Jawaharlal Nehru Technological University Kakinada, Kakinada, for the award of the Degree in Bachelor of Technology in Electrical and Electronics Engineering is a record of bonafide work done by us at "ST. MARY'S GROUP OF INSTITUTIONS GUNTUR" and it has not been submitted to any other institute or University for the award of any other Degree.

SUBMITTED BY

T.SAI HARI HARA CHANDRA **(19BJ1A0240)**

Place: Chebrolu
Date:

PROJECT TITLE

ACTIVE AND REACTIVE POWER CONTROL IN THREE PHASE SOLAR PV INVERTER USING MODIFIED IC METHOD

INDEX

CONTENTS	PAGE NO

CHAPTER -1

INTRODUCTION

CHAPTER-2

GENETIC ALGORITHM

CHAPTER -3

MATLAB

CHAPTER-4

SIMULATION AND RESULTS

CHAPTER-5

CONCLUSION AND FUTURE SCOPE

CHAPTER-6

REFERENCES

LIST OF FIGURES

FIGURE.NO **PAGE.NO**

CHAPTER-1

CHAPTER-2

CHAPTER-4

LIST OF TABLES

TABLE.NO **PAGE.NO**

CHAPTER-2

NOMENCLATURE

SYMBOL		UNITS
I_{ph}	Photocurrent	Amperes
I_d	Diode current	Amperes
I_p	Parallel branch current	Amperes
T	Module temperature	Kelvin
G	Solar irradiance	kW/m^2
T_{ref}	Module reference temperature	Kelvin
G_{ref}	Solar reference irradiance	kW/m^2
K	Boltzmann constant	J/K
Q	Electronic charge	Coulombs
V_{mp}	Voltage at peak power	volts
I_{mp}	Current at pea power	Amperes
A	P-N junction ideality factor	--
V_{mpp}	Voltage at maximum power point	volts
I_{mpp}	Current at maximum power point	Amperes
E_G	Band gap of the semi conductor	--

ABBREVIATIONS

MPPT	Maximum Power Point Tracking
PV	Photovoltaic
STC	Standard Test Condition
VSC	Voltage Source Converter
SPEGS	Solar Photovoltaic Energy Generation System
DVR	Dynamic Voltage Regulator
SPEGS	Solar Synchronous Series Compensator
PWM	Pulse Width Modulation
FV-IC	Fraction Voltage Based Incremental Conductance
DSTATCOM	Distribution Static Compensator
MLI	Multi Level Inverter
CSI	Current Source Inverter
THD	Total harmonics Distortion
IHD	Individual harmonic Distortion
DPW	Discountinous Pulse Width Modulation

ABSTRACT

Increment of solar photovoltaic installation in power grid, solar power penetration level, over loading of grid and power fluctuation are the issues. To fix the problems, active and reactive power fed to the grid from solar inverter are needed to be controlled. Regulation of active power from solar inverter is performed by modifying maximum power point tracking algorithm of photovoltaic generation and run in off maximum power mode. To operate the solar plant in off maximum power mode, incremental conductance method is introduced. This active power control is operated, is modeled in MATLAB/Simulink and this model is tested for real irradiance and temperature conditions. Simulation results illustrate the desired limited active power injection into the grid from solar photovoltaic system and reactive power necessary support as well.

CHAPTER-1

INTRODUCTION

1.1 Introduction

Moreover, from last few decades, solar photo voltaic energy generation system (SPEGS) is one of the focused areas of research community as it is pollution free, renewable, inexhaustible and has a lot of other advantages, which are discussed. The cost factor is one of the main aspects of any technology for its success or failure. Now a days, because of technology development, solar PV power is one of the feasible and alternative option among all non-traditional sources for power generation [12].

The grid participation of solar PV power generation systems (SPEGSs), is reported. SPEGSs may be majorly divided in two categories, in which one is off-grid and another one is interfaced to the distribution feeder. However, due to the certain pitfalls of standalone SPEGSs, grid interfaced solar PV systems are more preferred.

The non-linear relation between solar PV array voltage and its current, which depend on climatic condition, there is a need of MPPT (Maximum Power Point Tracking) scheme for harnessing the crest energy from the solar source. The initial expenditure of solar PV installation is also very high. Grid integrated SPEGSs are the systems, which harnesses the maximum power from the PV array and feeds that energy into the three phase grid.

Moreover, there are various control methodologies, which are proposed by many research communities in the literature with various topologies. These control techniques do not only serve for harnessing the maximum power from SPEGSs, however, they also work for grid synchronization and feed that harnessed power into three phase grid.

Hence, an improvement of control algorithm, is the popular research area in this field. In a current scenario, the power electronics-based loads are increasing every day because of their certain advantages like efficiency and compactness. The major demerits of these loads, are that they draw harmonics and reactive power from the distribution network, which deteriorate the power quality of the grid and increase the distribution losses.

To tackle such issues, many industries have utilized distribution static compensator (DSTATCOM), which serves for many purposes such as compensation of reactive power, harmonics minimization, load balancing, power factor correction etc. In practical application, its efficiency and performance mainly depend on its control algorithm However, the major pitfalls of such kind of devices, are their high cost.

In this work, all these functions are performed by grid interfaced voltage source converter (VSC) in a very cost effective manner. Various control approaches such adaptive controls, neural network based algorithms are also proposed in the literature.

1.2 Literature Survey

1.2.1 Solar Energy Renewable Energy and the Environment.

Solar energy systems/power plants do not produce air pollution or greenhouse gases. Using solar energy can have a positive, indirect effect on the environment when solar energy replaces or reduces the use of other energy sources that have larger effects on the environment However, some toxic materials and chemicals are used to make the photovoltaic (PV) cells that convert sunlight into electricity. Some solar thermal systems use potentially hazardous fluids to transfer heat. Leaks of these materials could be harmful to the environment. U.S. environmental laws regulate the use and disposal of these types of materials. As with any type of power plant, large solar power plants can affect the environment near their locations. Clearing land for construction and the placement of the power plant may have long-term effects on the habitats of native plants and animals. Some solar power plants may require water for cleaning solar collectors and concentrators or for cooling turbine generators. Using large volumes of ground water or surface water for cleaning collectors in some arid locations may affect the ecosystems that depend on these water resources. In addition, the beam of concentrated sunlight a solar power tower creates can kill birds and insects that fly into the beam.

1.2.2 Integration of Alternative Sources of Energy.

Renewable Energy Sources (RESs) particularly photovoltaic (PV) and wind are becoming important sources for power generation. Frequently varying output of PV and wind caused by clouds movement, weather condition and wind speed make them an intermittent and unreliable source when connected to grid. Connecting intermittent sources to grid introduces challenges in various technical aspects such as power quality, protection, generation dispatch control and reliability. In this context, leveling intermittent source output is necessary in order to maintain grid stability. This paper is aimed at bringing out the latest comprehensive literature review on problems associated when the intermittent PV is connected to grid and the methods of smoothing the output power fluctuation from PV[13].

1.2.3 DC Load and Batteries Control Limitations for Photovoltaic Systems.

An experimental control strategy of photovoltaic (PV) system composed of: PV array, dc–dc power converters, electrolytic storage, and programmable dc electronic load. This control aims to extract maximum power from PV array and manages the power transfer through the dc load, respecting the available storage level. The designed system allows simultaneously the supply of a dc load and the charge or the discharge of the storage during the PV power production.

The experimental results obtained with a dSPACE 1103 controller board show that the PV stand-alone system responds within certain limits that appear as soon as one of the storage thresholds is reached: either loss of energy produced, or insufficient energy toward the load. In urban area, it is proposed to overcome these limitations by connecting the utility grid with the PV system while maintaining the priority for self-feeding. The experimental results of this PV semi-isolated system are shown and discussed. For this first approach, the goal was to verify the technical feasibility of the suggested system controls. The final results are energetically relevant.

1.2.4 Power Management of a Stand-Alone Wind/Photovoltaic/Fuel Cell Energy System

This project proposes an AC-linked hybrid wind/photovoltaic (PV)/fuel cell (FC) alternative energy system for stand-alone applications. Wind and PV are the primary power sources of the system, and an FC- electrolizer combination is used as a backup and a long-term storage system. An overall power management strategy is designed for the proposed system to manage power flows among the different energy sources and the storage unit in the system. A simulation model for the hybrid energy system has been developed using MATLAB/Simulink. The system performance under different scenarios has been verified by carrying out simulation studies using a practical load demand profile and real weather data.

1.3 SOLAR PANEL

The term solar panel is best applied to a flat solar thermal collector, such as a solar hot water or air panel used to heat water, air, or otherwise collect solar thermal energy. But 'solar panel' may also refer to a photovoltaic module which is an assembly of solar cells used to generate electricity. In all cases, the panels are typically flat, and are available in various heights and widths.

An array is an assembly of solar-thermal panels or photovoltaic (PV) modules; the panels can be connected either in parallel or series depending upon the design objective. Solar panels typically find use in residential, commercial, institutional, and light industrial applications.

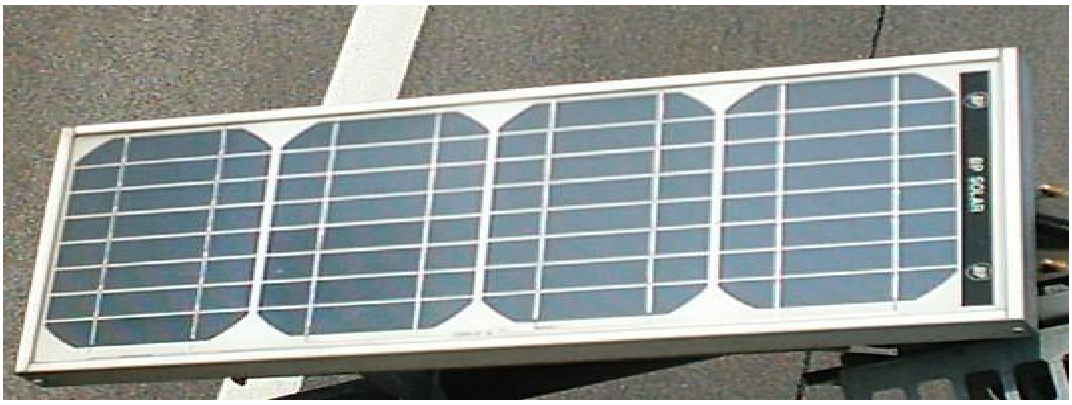


Fig.1.3(a)Solar panel

Solar-thermal panels saw widespread use in Florida and California until

The 1920's when tank-type water heaters replaced them. A thriving manufacturing business died seemingly overnight. However, solar-thermal panels are still in production, and are common in portions of the world where energy costs, and solar energy availability, are high.

Recently there has been a surge toward large scale production of PV modules. In parts of the world with significantly high insolation levels, PV output and their economics are enhanced. PV modules are the primary component of most small-scale solar-electric power generating facilities. Larger facilities, such as solar power plants typically contain an array of reflectors (concentrators), a receiver, and a thermodynamic power cycle, and thus use solar-thermal rather than PV.

1.3.1 Definition

A photovoltaic system is a system which uses one or more solar panels to convert solar energy into electricity. It consists of multiple components, including the photovoltaic modules, mechanical and electrical connections and mountings and means of regulating and or modifying the electrical output.

1.3.2 Photovoltaic cell

PV cells are made of semiconductor materials, such as silicon. For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side and negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current - that is, electricity. This electricity can then be used to power a load[16].

A PV cell can either be circular or square in construction. The PV cell with in the shape of the square is more useful than the circular shape, because there is more difficulty in construction and to place in a particular place. So, mostly the square shape PV cell is used to install in the real time application.

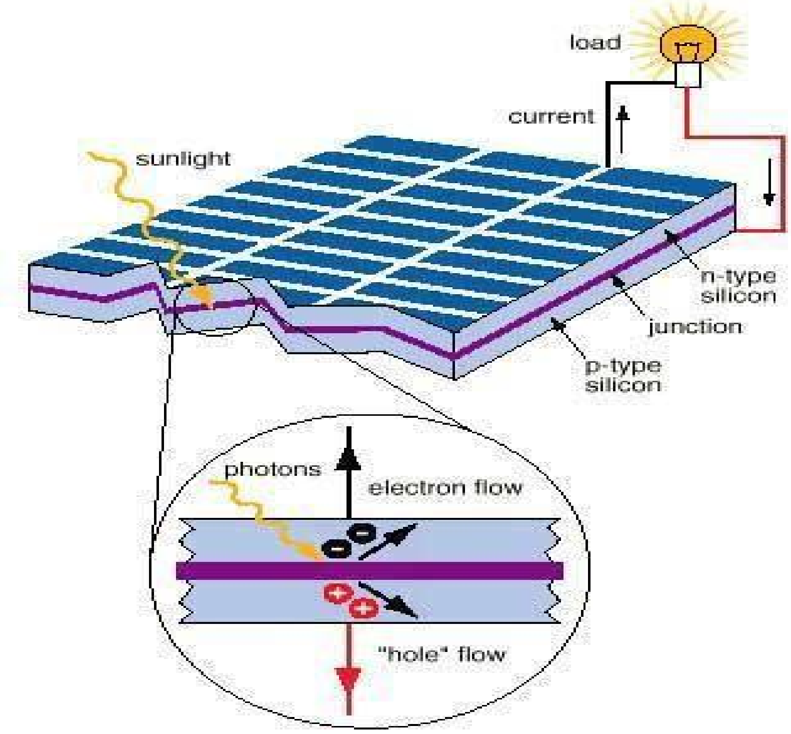


Fig.1.3(b)Photovoltaic arrangement

1.3.3 Photovoltaic Module

Due to the low voltage generated in a PV cell (around 0.5V), several PV cells are connected in series (for high voltage) and in parallel(for high current) to form a PV module for desired output. Separate diodes may be needed to avoid reverse currents, in case of partial or total shading, and at night. The p-n junctions of mono-crystalline silicon cells may have adequate reverse current characteristics and these are not necessary. Reverse currents waste power and can also lead to overheating of shaded cells. Solar cells become less efficient at higher temperatures and installers try to provide good ventilation behind solar panels.

1.3.4 Photovoltaic array

The power that one module can produce is not sufficient to meet the requirements of home or business. Most PV arrays use an inverter to convert the DC power into alternating current that can power the motors, loads, lights etc. The modules in a PV array are usually first connected in series to obtain the desired voltages; the individual modules are then connected in parallel to allow the system to produce more current.

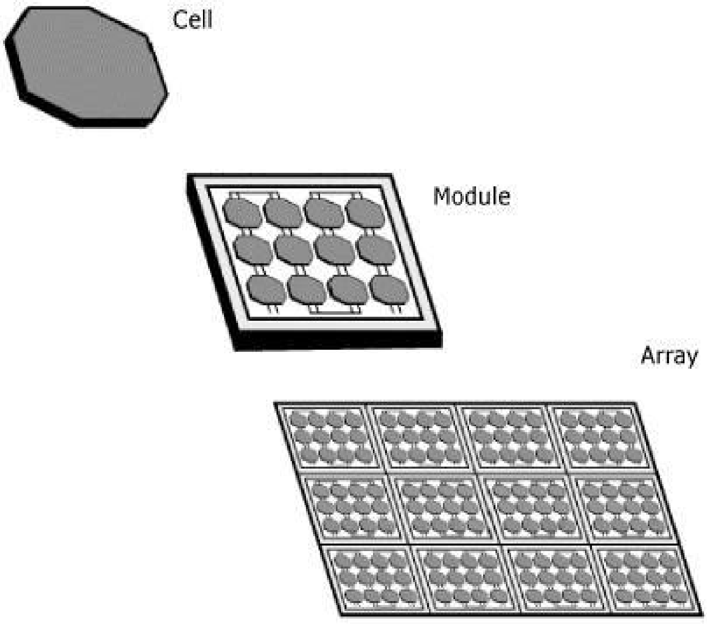


Fig 1.3(c)PV cell, PV array, PV module

1.4 Materials used in PV cell

The materials used in PV cells are as follows:

Single-crystal silicon

Single-crystal silicon cells are the most common in the PV industry. The main technique for producing single-crystal silicon is the Kochanski (CZ) method. High-purity polycrystalline is melted in a quartz crucible. A single-crystal silicon seed is dipped into this molten mass of polycrystalline. As the seed is pulled slowly from the melt, a single-crystal ingot is formed. The ingots are then sawed into thin wafers about 200-400 micrometeors thick (1 micrometre = 1/1,000,000 meter). The thin wafers are then polished, doped, coated, interconnected and assembled into modules and arrays.

Polycrystalline silicon

Consisting of small grains of single-crystal silicon, polycrystalline PV cells are less energy efficient than single-crystalline silicon PV cells. The grain boundaries in polycrystalline silicon hinder the flow of electrons and reduce the power output of the cell. A common approach to produce polycrystalline silicon PV cells is to slice thin wafers from blocks of cast polycrystalline silicon.

Another more advanced approach is the “ribbon growth” method in which silicon is grown directly as thin ribbons or sheets with the approach thickness for making PV cells.

Gallium Arsenide (GaAs)

A compound semiconductor made of two elements: Gallium (Ga) and Arsenic (As). GaAs has a crystal structure similar to that of silicon. An advantage of GaAs is that it has high level of light absorptivity. To absorb the same amount of sunlight, GaAs requires only a layer of few micrometres thick while crystalline silicon requires a wafer of about 200-300 micrometres thick. Also, GaAs has much higher energy conversion efficiency than crystal silicon, reaching about 25 to 30%. The only drawback of GaAs PV cells is the high cost of single crystal substrate that GaAs is grown on.

1.4.1 Cadmium Telluride (CdTe)

It is a polycrystalline compound made of cadmium and telluride with a high light absorbability capacity (i.e. a small thin layer of the compound can absorb 90% of solar irradiation). The main disadvantage of this compound is that the instability of PV cell or module performance. As it a toxic substance, the manufacturing process should be done by extra precaution.

1.4.2 Copper Indium Diselenide (CuInSe2)

It is a polycrystalline compound semiconductor made of copper, indium and selenium. It delivers high energy conversion efficiency without suffering from outdoor degradation problem. It is one of the most light-absorbent semiconductors. As it is a complex material and toxic in nature so the manufacturing process face some problem.

1.5 Characteristics of PV Cell

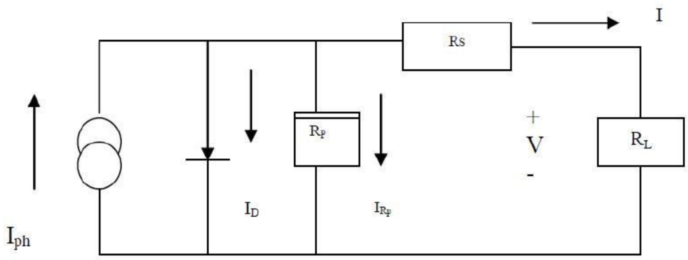


Fig.1.3(d) Ideal circuit of PV cell

An ideal is modelled by a current source in parallel with a diode. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the PV cell diagram above. R_S is the intrinsic series resistance whose value is very small. R_P is the equivalent shunt resistance which has a very high value [14].

Applying Kirchhoff's law to the node where I_{ph}, diode, R_p and R_s meet, we get

$I_{ph} = I_D + I\ R_p + I$...................(3.1)

We get the following equation for the photovoltaic current:

$I = I_{ph} - I\ R_p - I_D$ (3.2)

$$I = I_{ph} - I_o.\left[exp\left(\frac{V+I.R_S}{V_T}\right) - 1\right] - \left[\frac{V+I.R_S}{R_p}\right]$$

Where, I_{ph} is the Insolation current, I is the Cell current, I0 is the Reverse saturation current, V is the Cell voltage, Rs is the Series resistance, Rp is the Parallel resistance, VT is the Thermal voltage, K is the Boltzmann constant, T is the Temperature in Kelvin, q is the Charge of an electron.

1.6 Efficiency of PV Cell

The efficiency of a PV cell is defined as the ratio of peak power to input solar power.

$$\eta = \frac{Vmp.Imp}{I\left(\frac{KW}{m^2}\right).A(m^2)}$$

where, V_{mp} is the voltage at peak power, Imp is the current at peak power, I is the solar intensity per square meters, A is the area on which solar radiation fall.

The efficiency will be maximum if we track the maximum power from the PV system at different environmental condition such as solar irradiance and temperature by using different methods for maximum power point tracking.

CHAPTER-2

GENETIC ALGORITHM

2.1 Modelling of PV Array:

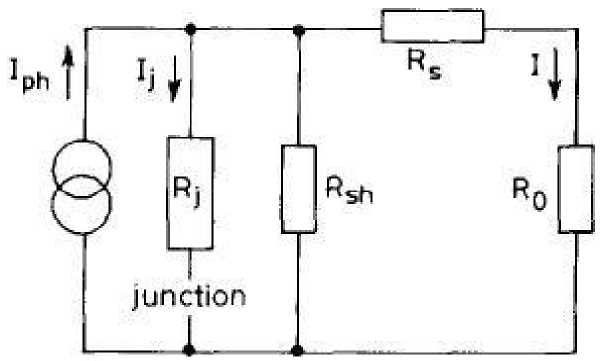


Fig.2.1(a)PV array Modelling

The current source I_{ph} represents the cell photo current; R_j is used to represent the non-linear impedance of the p-n junction; R_{sh} and R_s are used to represent the intrinsic series and shunt resistance of the cell respectively. Usually the value of R_{sh} is very large and that of Rs is very small. Hence they may be neglected to simplify the analysis. The PV mathematical model used to simplify our PV array is represented by the equation:

$$I=n_pI_{ph}-n_pI_{rs}[\exp(\frac{q}{KTA}*\frac{V}{n_s})-1]$$

where I is the PV array output current; V is the PV array output voltage; ns is the number of cells in series and np is the number of cells in parallel; q is the charge of an electron; k is the Boltzmann's constant; A is the p-n junction ideality factor; T is the cell temperature (K); I_{rs} is the cell reverse saturation current. The factor A in equation (3.5) determines the cell deviation from the ideal p-n junction characteristics; it ranges between 1-5 but for our case A=2.46.

The cell reverse saturation current I_{rs} varies with temperature according to the following equation:

$$I_{rs}=I_{rr}[\frac{T}{T_r}]^3\exp(\frac{qE_G}{KA}[\frac{1}{T_r}-\frac{1}{T}])$$

Where Tr is the cell reference temperature, I_{rr} is the cell reverse saturation temperature at Tr and EG is the band gap of the semiconductor used in the cell.

The temperature dependence of the energy gap of the semi-conductor is given by:

$$E_G = E_G(0) - \frac{\alpha T^2}{T+\beta}$$

The photo current I_{ph} depends on the solar radiation and cell temperature as follows:

$$I_{ph} = [\, I_{scr} + K_i(T - T_r)]\, \frac{S}{100}$$

where I_{scr} is the cell short-circuit current at reference temperature and radiation, Ki is the short circuit current temperature coefficient, and S is the solar radiation in mW/cm2. The PV power can be calculated as follows:

$$P = IV = n_p I_{ph} V[(\frac{q}{KTA} * \frac{V}{n_s}) - 1]$$

2.1.1 PV ARRAY CHARACTERISTIC CURVES

The current to voltage characteristic of a solar array is non-linear, which makes it difficult to determine the MPP. The Figure below gives the characteristic I-V and P-V curve for fixed level of solar irradiation and temperature[16].

Figure

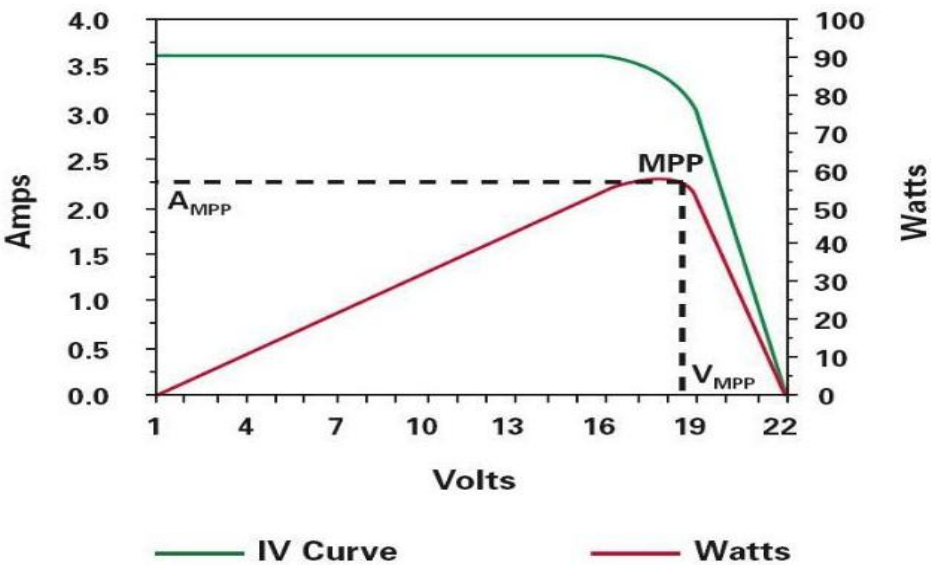
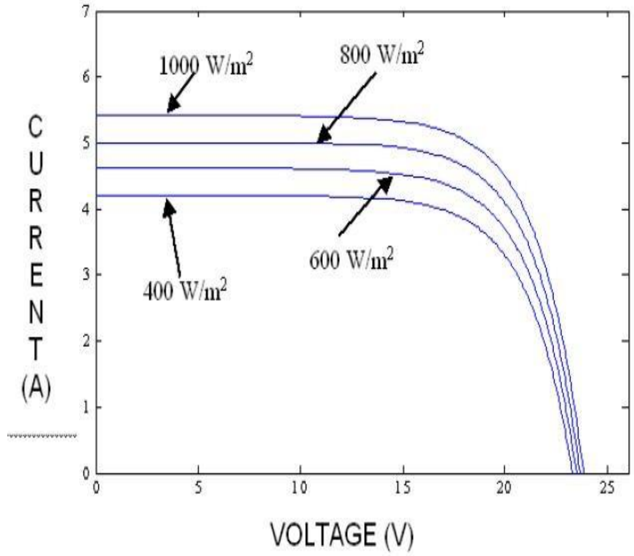
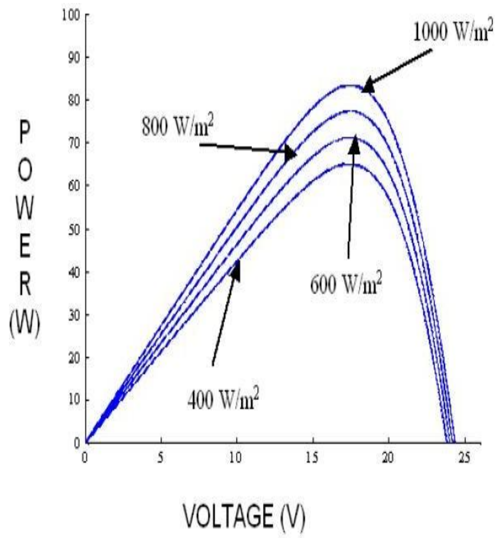


Fig.2.1(b): PV array characteristic curves

The IV and PV curves for various irradiance but a fixed temperature (250C) The characteristic I-V curve tells that there are two regions in the curve: one is the current source region and another is the voltage source region. In the voltage source region (in the right side of the curve), the internal impedance is low and in the current source region (in the left side of the curve),the impedance is high. Irradiance temperature plays an important role in predicting the I-V characteristic, and effects of both factors have to be considered while designing the PV system. Whereas the irradiance affects the output, temperature mainly affects the terminal voltage. The figures gives the simulated I-V and P-V characteristic for various temperatures at a fixed irradiance at 1000 W/m2.





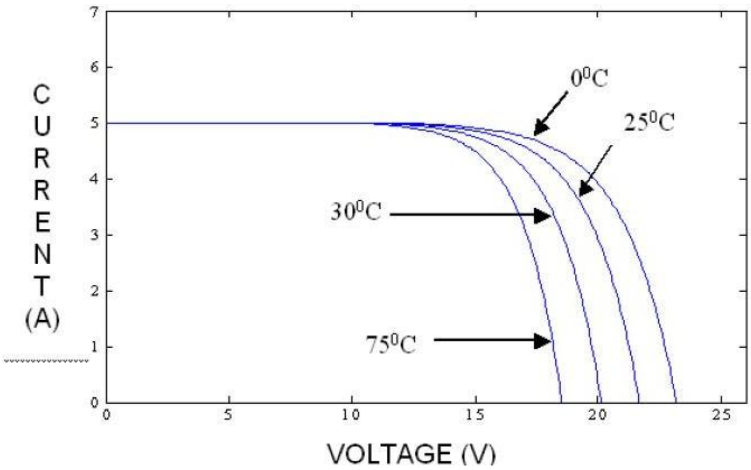


Fig.2.1(c) PV array characteristic curves

The largest solar panel in the world is under construction in the south of Portugal. A 52,000 photovoltaic module, 11-megawatt facility covering a 60-hectare south-facing hillside in the southern Alentejan region and it will produce electricity for 21,000 households.

2.2 MODELLING OF BOOST CONVERTER

A boost converter is used as DC-DC converter inside the three phase inverter. Boost converter's inductor L^* and input capacitor C_{in} are calculated considering 1% current ripple and 10 % voltage ripple respectively. DC link capacitor of boost converter C_{dclink} is calculated considering 1% voltage ripple. The boost converter parameters are listed in Table 2.2.

Boost converter parameters

Table 2.2 boost converter parameters

Boost Converter Parameters	Values
Cin, Input capacitor	125 µF
L*, Inductor	30 mH
C_{dclink}, DC link capacitor	1000 µF
MOSFET switch's switching frequency	20 kHz

2.3 MODELLING OF INVERTER

Traditional Single Phase Inverter

Conventional two-level inverters, are mostly used today to generate an AC voltage from an DC voltage. The two-level inverter can only create two different output voltages for the load, +Vdc2 or –Vdc2 (when the inverter is fed with Vdc).

To build up an AC output voltage these two voltages are usually switched with PWM.

Though this method is effective it creates harmonic distortions in the output voltage, EMI and high dv/ dt (compared to multilevel inverters) . This may not always be a problem but for some applications there may be a need for low distortion in the output voltage.

The concept of Multilevel Inverters (MLI) does not depend on just two levels of voltage to create an AC signal. Instead several voltage levels are added to each other to create a smoother stepped waveform, with lower dv/dt and lower harmonic distortions.

With more voltage levels in the inverter the waveform it creates becomes smoother, but with many levels the design becomes more complicated, with more components and a more complicated controller for the inverter is needed.

To better understand multilevel inverters the more conventional three-level inverter, can be investigated. It is called a three-level inverter since every phase-leg can create the three voltages +Vdc / 2 , 0, -Vdc / 2 , as can be seen in the first part of Figure .

A three-level inverter design is similar to that of an conventional two-level inverter but there are twice as many valves in each phase-leg. In between the upper and lower two valves there are diodes, called clamping diodes , connected to the a neutral midpoint in between two capacitors, These capacitor build up the DC-bus, each capacitor is charged with the voltage Vdc / 2 .

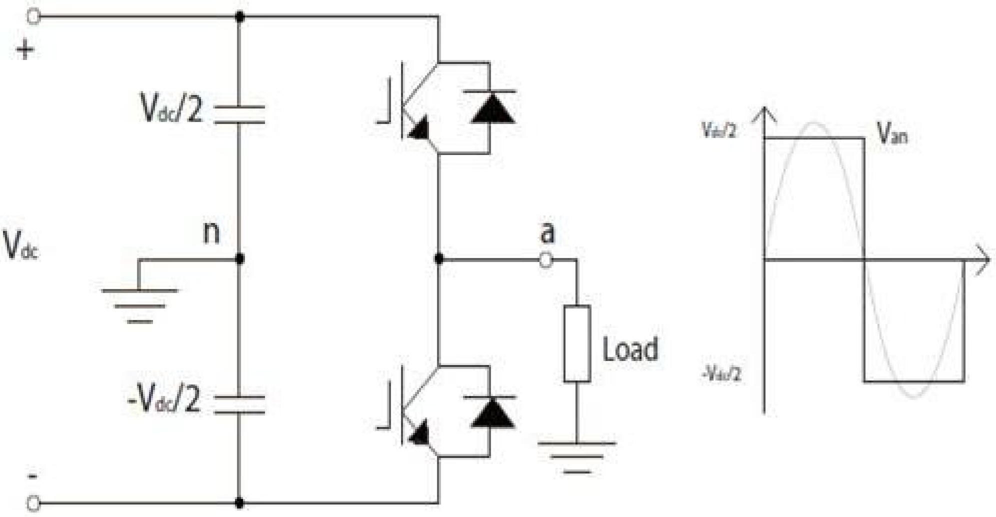


Fig.2.3(a) single phase inverter

2.3.1 Traditional Single Phase Inverter

Together with another phase-leg an output line-to-line voltage with even more levels can be obtained. To create the zero voltage the two switches closest to the midpoint are switched on and the clamping diodes hold the voltage to zero with the neutral point. Now, if more valve pairs, clamping diodes and capacitors are added the inverter can generate even more voltage levels, see the result is a multilevel inverter with clamping diode topology [15].

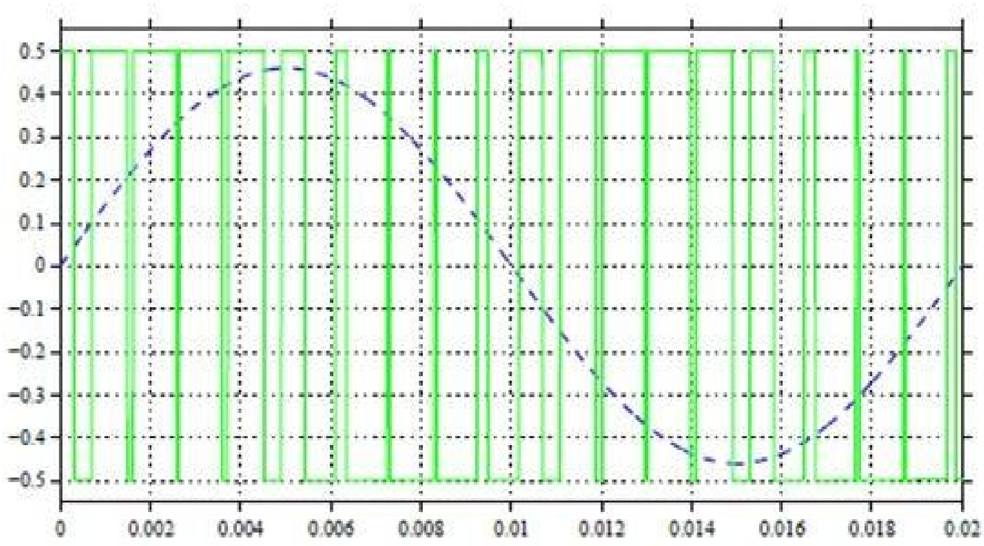


Fig 2.3 (b): Results of multilevel inverter with clapping diode

2.3.2 Pulse Width Modulation Technique

A single-phase square wave type voltage source inverter produces square shaped output voltage for a single-phase load. Such inverters have very simple control logic and the power switches need to operate at much lower frequencies compared to switches in some other types of inverters, discussed in later lessons.

The first generation inverters, using thyristor switches, were almost invariably square wave inverters because thyristor switches could be switched on and off only a few hundred times in a second. In contrast, the present day switches like IGBTs are much faster and used at switching frequencies of several kilohertz. As pointed out single-phase inverters mostly use half bridge or full bridge topologies. Power circuits of these topologies are redrawn for further discussions.

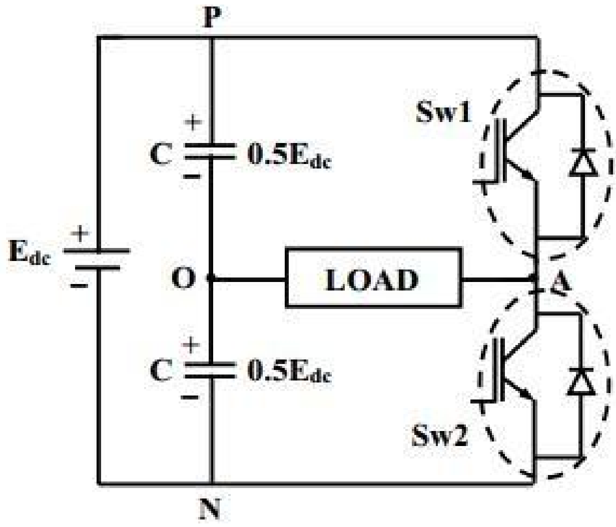


Fig. 2.3.1(a): A 1-phase half bridge VSI

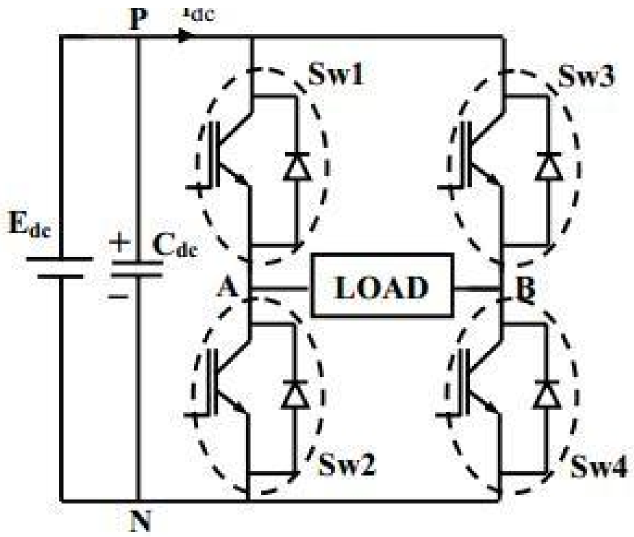


Fig. 2.3.1 (b): A 1-phase full-bridge VSI

In this lesson, both the above topologies are analysed under the assumption of ideal circuit conditions. Accordingly, it is assumed that the input dc voltage (E_{dc}) is constant and the switches are lossless. In half bridge topology the input dc voltage is split in two equal parts through an ideal and loss-less capacitive potential divider. The half bridge topology consists of one leg (one pole) of switches whereas the full bridge topology has two such legs. Each leg of the inverter consists of two series connected electronic switches shown within dotted lines in the figures. Each of these switches consists of an IGBT type controlled switch across which an uncontrolled diode is put in anti-parallel manner. These switches are capable of conducting bi-directional current but they need to block only one polarity of voltage.

The junction point of the switches in each leg of the inverter serves as one output point for the load. In half bridge topology the single-phase load is connected between the mid-point of the input dc supply and the junction point of the two switches these points are marked as ‘O’ and ‘A’ respectively). For ease of understanding, the switches Sw1 and Sw2 may be assumed to be controlled mechanical switches that open and close in response to the switch control signal. In fact it has been shown that the actual electronic switches mimic the function of the mechanical switches. Now, if the switches Sw1 and Sw2 are turned on alternately with duty ratio of each switch kept equal to 0.5, the load voltage (V_{AO}) will be square wave with a peak-to-peak magnitude equal to input dc voltage (E_{dc}). shows a typical load voltage waveform output by the half bridge inverter. V_{AO} acquires a magnitude of +0.5 E_{dc} when Sw1 is on and the magnitude reverses to -0.5 E_{dc} when Sw2 is turned on. also shows the fundamental frequency component of the square wave voltage, its peak-to-peak magnitude being equal to $4/\pi\ E_{dc}$. The two switches of the inverter leg are turned on in a complementary manner. For a general load, the switches should neither be simultaneously on nor be simultaneously off. Simultaneous turn-on of both the switches will amount to short circuit across the dc bus and will cause the switch currents to rise rapidly. For an inductive load, containing an inductance in series, one of the switches must always conduct to maintain continuity of load current. In a case of inductive load has been considered and it has been shown that the load current may not change abruptly even though the switching frequency is very high. Such a situation, as demands that the switches must have bi-directional current carrying capability.

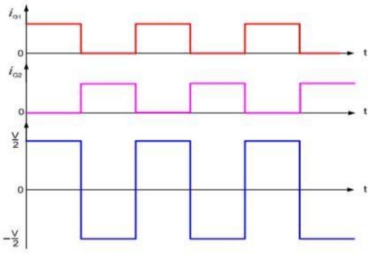


Fig 2.3.1(c): Gating signals and output voltage of a single-phase half-bridge inverter

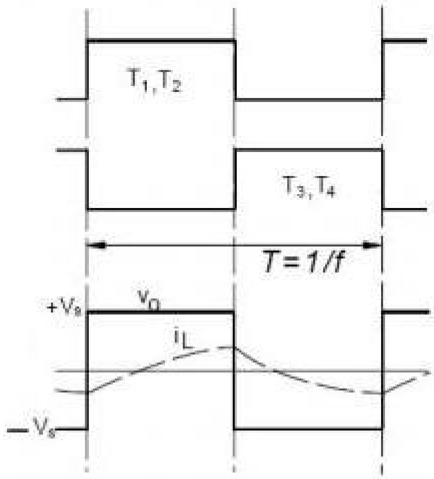
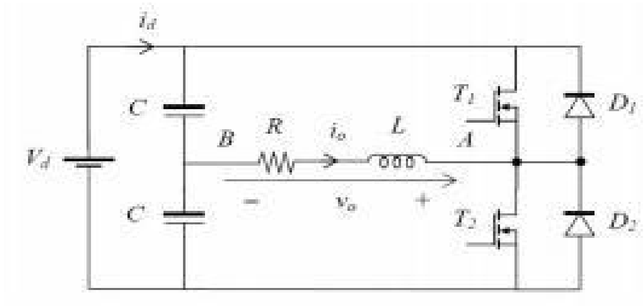


Fig 2.3.1 (d) :Gating signals and output voltage of a single-phase full-bridge inverter



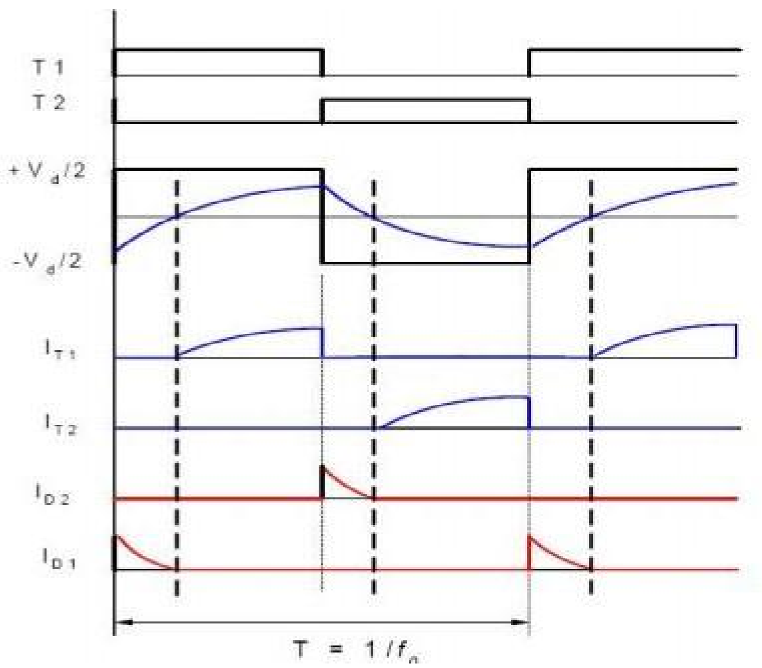


Fig 2.3.1(e):The voltage and current waveforms of single phase half bridge inverter

2.3.3 Three Phase Inverter

An inverter is a power electronic device, used to change the power from one form to other like DC to AC at the necessary frequency & voltage o/p. The classification of this can be done based on the source of supply as well as related topology in the power circuit. So these are classified into two types (voltage source inverter) and CSI (current source inverter). The VSI type inverter has a DC voltage source with less impedance at the input terminals of an inverter. The CSI type inverter has a DC current source with high impedance

Definition: We know that inverter converts DC to AC. We have already discussed different types of inverters. A three-phase inverter is used to change the DC voltage to three-phase AC supply. Generally, these are used in high power and variable frequency drive applications like HVDC power transmission.

Fig 2.3 (c) : Phase Inverter

In a 3 phase, the power can be transmitted across the network with the help of three different currents which are out of phase with each other, whereas in single-phase inverter, the power can transmit through a single phase. For instance, if you have a three-phase connection in your home, then the inverter can be connected to one of the phases.

Working Principle of Three Phase Inverter

A three-phase inverter working principle is, it includes three inverter switches with single-phase where each switch can be connected to load terminal. For the basic control system, the three switches operation can be synchronized so that single switch works at every 60 degrees of basic o/p waveform to create a line-to-line o/p waveform including six steps. This waveform includes a zero voltage stage among the two sections like positive &negative of the square-wave. Once PWM techniques based on the carrier are applied to these waveforms, then the basic shape of the waveform can be taken so that the third harmonic including its multiples will be cancelled.

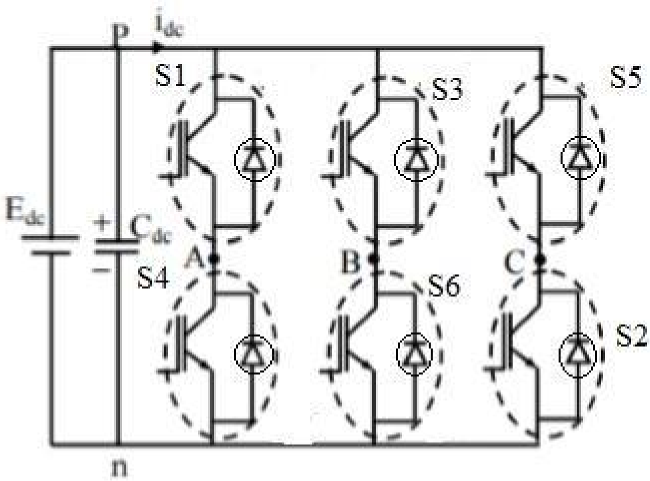
Single Phase Inverter

These inverters are available in two types like full-bridge type and half-bridge type. The full-bridge type inverter circuit mainly used to change DC to AC. This can be achieved through the opening and closing of the switches within the right sequence. This kind of inverter includes four dissimilar operating states where these switches work on closed switches.

The half-bridge type inverter circuit is the basic building block in a full-bridge type inverter. This inverter includes two switches where each type of switch includes capacitors that have output voltage. Additionally, these switches complement each other, because if the first switch is turned ON then the remaining switch will be turned OFF.

Three Phase Inverter Design/Circuit Diagram

The circuit diagram of a three-phase inverter is shown below. The main function of this kind of inverter is to change the input of DC to the output of three-phase AC. A basic 3 phase inverter includes 3 single phase inverter switches where each switch can be connected to one of the 3 load terminals.



2.3(d): Three Phase Inverter Circuit Design

180° Conduction Mode

In this conduction mode, each device will be in conduction with 180° where they are activated at intervals with 60°. The output terminals like A, B, and C are connected to the star or 3 phase delta connection of the load.

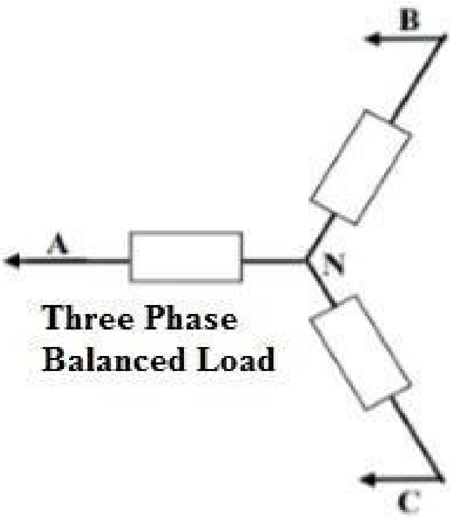


Fig 2.3(e): Three phase balanced load

The balanced load for three phases is explained in the following diagram. For 0 to 60 degrees, the switches like S1, S5 & S6 are in conduction mode. The load terminals like A & C are linked to the source on its positive point, whereas the B terminal is associated with the source on its negative point. Furthermore, The R/2 resistance is available among the two ends of neutral & the positive whereas R resistance is available among the neutral & the negative terminal.

In this mode, the voltages of load are given in the following.

VAN = V/3,
VBN = −2V/3,
VCN = V/3

The line voltages are given in the following.

VAB = VAN − VBN = V,
VBC = VBN − VCN = −V,
VCA = VCN − VAN = 0

120° Conduction Mode

In this type of conduction mode, every electronic device will be in a conduction state with 120°. It is apt for a delta connection within a load as it results within a six-step kind of waveform across one of its phases. So, at any instant, only these devices will conduct every device that will conduct at 120° only.

The connection of 'A' terminal on the load can be done through the positive end whereas the B terminal can be connected toward the negative terminal of the source. The 'C' terminal on the load will be in conduction is known as the floating state. Also, the phase voltages are equivalent to the voltages of load which is given below.

Phase voltages are equal to line voltages, so

VAB = V
VBC = −V/2
VCA = −V/2

Three Phase Inverter Applications

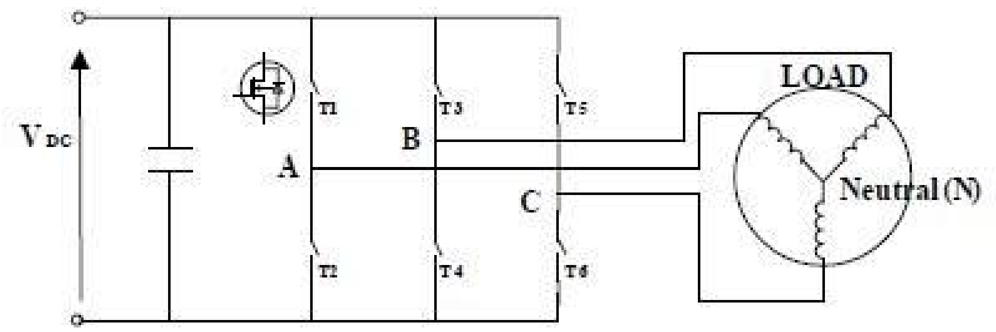
The applications of this type of inverter include the following.

- These inverters are utilized in variable frequency drive applications
- Used in high-power applications like HVDC power transmission.
- A three-phase square wave inverter is used in a UPS circuit and a low-cost solid-state frequency charger circuit.

Thus, this is all about an overview of a three-phase inverter, working principle, design or circuit diagram, conduction modes, and its applications. A 3 phase inverter is used to convert a DC i/p into an AC output. It includes three arms which are usually delayed through 120° of an angle to produce a 3 phase AC supply. The switches in an inverter have a 50% of ratio & switching happens after each T/6 of the time with 60° of angle interval.

A review of three-phase VSI modelling with space vector PWM

The power circuit topology of a Three-phase VSI each switch (1, 2,3,4,5 & 6) in the inverter branch is composed of semiconductor devices connected with antiparallel diode.



2.3(f): Power circuit of a three-phase VSI

Space vector representation of the three-phase inverter output voltages is introduced next. Space vector is defined as:

The space vector is a simultaneous representation of all the three-phase quantities. It is a complex variable and is function of time in contrast to the phasor. Phase-to-neutral voltages of a star-connected load are most easily found by defining a voltage difference between the star point n of the load and the negative rail of the dc bus N. The following correlation then holds true:

$$v_A = v_a + v_{nN}$$
$$v_B = v_b + v_{nN}$$
$$v_C = v_c + v_{nN}$$

Indices with capital letters are inverter branch voltages and indices with small letters are phase to neutral voltages. v_{nN} are called common-mode voltage or zero sequence voltages.
Since the phase voltages in a star connected load sum to zero, summation of equation yields

$$v_{nN} = (1/3)(v_A + v_B + v_C)$$

Substitution of v_A, v_B &v_C yields phase-to-neutral voltages of the load in the following form:

$$v_a = (2/3)v_A - (1/3)(v_B + v_C)$$
$$v_b = (2/3)v_B - (1/3)(v_A + v_C)$$
$$v_c = (2/3)v_C - (1/3)(v_B + v_A)$$

The discrete phase voltage space vector positions thus obtained are shown in Figure 2.

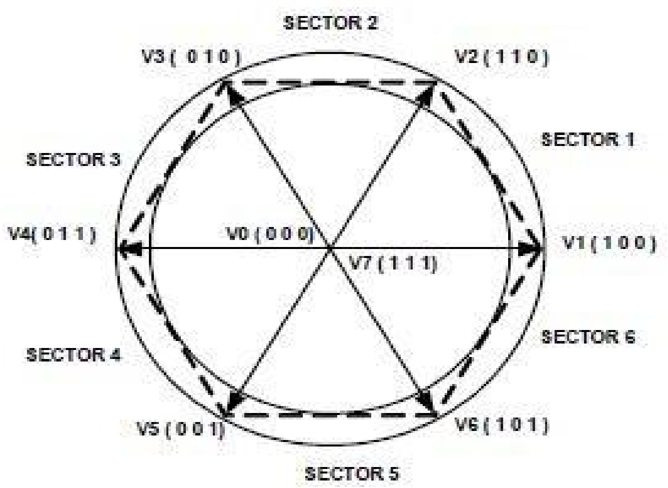


Fig 2.3(g): Phase voltage vector position

Phase-to-neutral voltage space vectors

The binary numbers on the Figure 2 indicate the switch state of inverter branch. Here, 1 implies upper switch being on and 0 refers to the lower switch of the branch being on. The most significant bit is for branch A, the least significant bit is related to branch C and the middle is for branch B.

Continuous space vector PWM

In mid 1980s Space vector pulse width modulation was proposed in Ogasawara et all and Holmes (1996), which offer significant advantages over the existing natural and regular sampled sinusoidal PWM. The major advantages include its high performance in terms of better harmonic spectra, ease of implementation and enhanced dc bus utilization . This section briefly discusses the space vector PWM principle. It is seen in the previous section that a three-phase VSI generates eight switching states which include six active and two zero states. These vectors form a hexagon which can be seen as consisting of six sectors spanning 60° each. The reference vector which represents three-phase sinusoidal voltage is synthesized using SVPWM by switching between two nearest active vectors and zero vector.

The time of application of active space voltage vectors is found as where (2 / 3) a b dc v = v = V .vs* is the reference vector magnitude, α is the angle or position of reference vector and ta, tb & t0 are time of applications of vector va, vector vb and zero vectors, respectively. In order to obtain fixed switching frequency and optimum harmonic performance from SVPWM, each branch should change its state only once in one switching period. This is achieved by applying zero state vector followed by two adjacent active state vectors in half switching period. The next half of the switching period is the mirror image of the first half. The total switching period is thus divided into 7 parts, the zero vector is applied for 1/4th of the total zero vector time first followed by the application of active vectors for half of their application times and then again zero vector is applied for 1/4th of the zero vector time. This is then repeated in the next half of the switching period. This is how symmetrical SVPWM is obtained. The branch voltages in one switching period are depicted in Figure 2.3(h) for sector I.

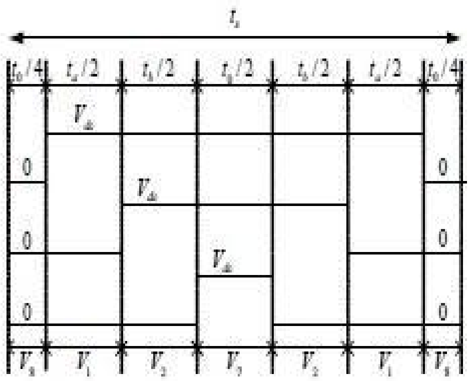


Fig 2.3(h): branch voltage in switching period

The sinusoidal reference space vector form a circular trajectory inside the hexagon. The largest output voltage magnitude that can be achieved using SVPWM is the radius of the largest circle that can be inscribed within the hexagon. This circle is tangential to the mid points of the lines joining the ends of the active space vector. Thus the maximum obtainable fundamental output voltage

Discontinuous space vector PWM

The distinct feature of space vector PWM is the freedom of explicit pulse placement in half of the carrier cycle. By using this degree of freedom alternative space vector PWM strategy can be formulated in which the active vectors in two successive half switching period are moved to join together, and zero space vector consequently vanishes resulting in Discontinuous Space vector PWM (Houdsworth and Grant, 1984).

Due to this manipulation one branch of the inverter remain unmodulated during one switching interval. Switching takes place in two branches and one branch is either tied to the positive dc bus or negative dc bus.

The number of switching is thus reduced to 2/3 compared to the continuous SVPWM, hence, the switching losses are reduced significantly. Six different schemes are available depending on the variation in the placement of the zero space vectors.

1. T0 = 0 (DPWMMAX)
2. T7 = 0 (DPWMMIN)
3. 00 Discontinuous modulation (DPWM 0)
4. 300 Discontinuous modulation (DPWM 1)
5. 600 Discontinuous modulation (DPWM 2)
6. 900 Discontinuous modulation (DPWM 3)

In this a 3-phase bridge type VSI with square wave pole voltages has been considered. The output from this inverter is to be fed to a 3-phase balanced load. shows the power circuit of the three-phase inverter. This circuit may be identified as three single-phase half-bridge inverter circuits put across the same dc bus. The individual pole voltages of the 3-phase bridge circuit are identical to the square pole voltages output by single-phase half bridge or full bridge circuits.

The three pole voltages of the 3-phase square wave inverter are shifted in time by one third of the output time period. These pole voltages along with some other relevant waveforms have been plotted. The horizontal axis of the waveforms has been represented in terms of ‘ωt’, where ‘ω’ is the angular frequency (in radians per second) of the fundamental component of square pole voltage and ‘t’ stands for time in second.

In Fig the phase sequence of the pole voltages is taken as V_{AO}, V_{BO} and V_{CO}. The numbering of the switches has some special significance vis-a-vis the output phase sequence.

Due to this manipulation one branch of the inverter remain unmodulated during one switching interval. Switching takes place in two branches and one branch is either tied to the positive dc bus or negative dc bus.

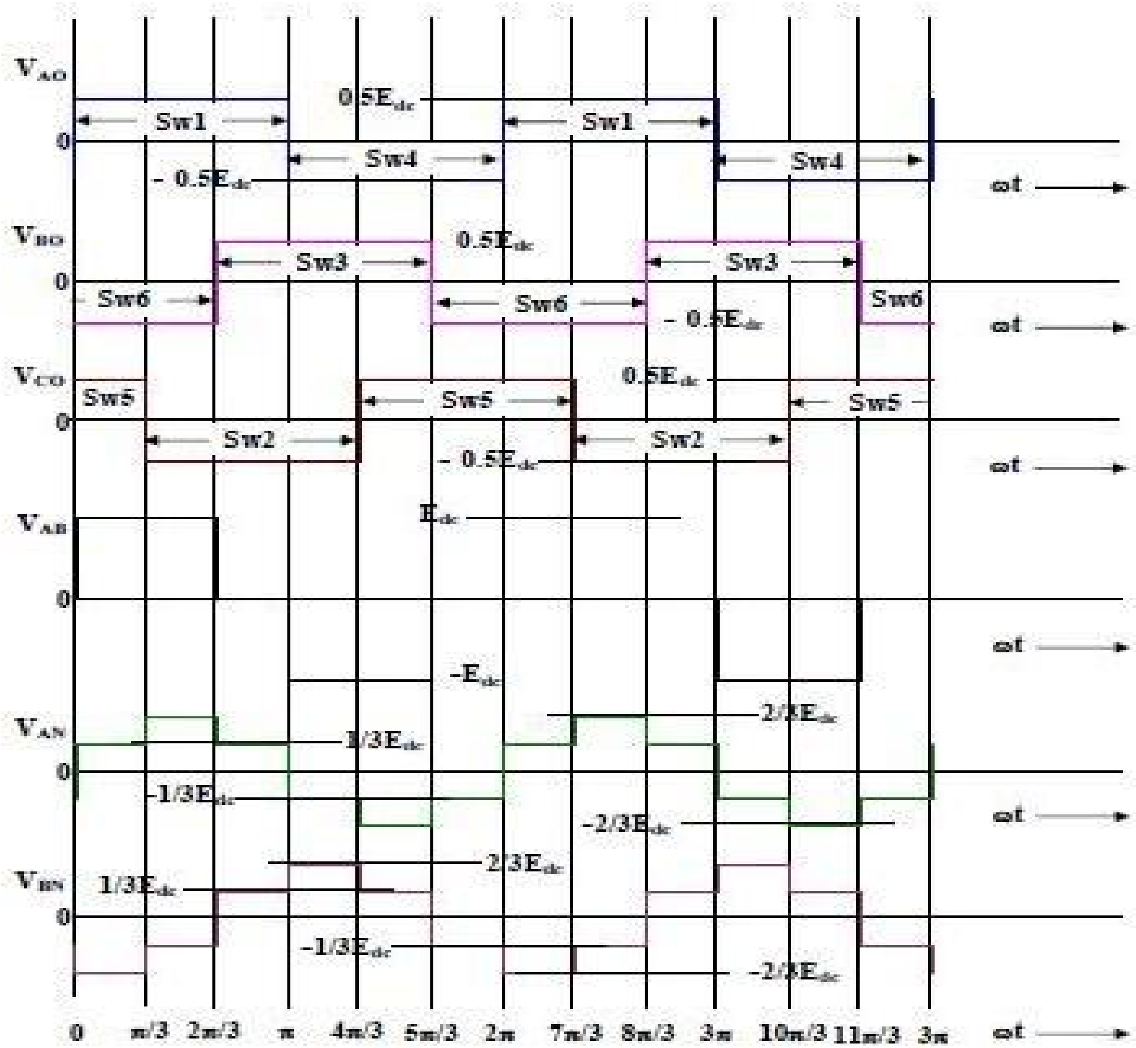


Fig 2.3(i): Some relevant voltage waveforms output by a 3-phase square wave VSI

To appreciate the particular manner in which the switches have been numbered, the conduction-pattern of the switches marked may be noted. It may be seen that with the chosen numbering the switches turn on in the sequence:- Sw1, Sw2, Sw3, Sw4, Sw5, Sw6, Sw1, Sw2, and so on. Identifying the switching cycle time as 360 degrees (2π radians), it can be seen that each switch conducts for 180^0 and the turning on of the adjacent switch is staggered by 60 degrees. The upper and lower switches of each pole (leg) of the inverter conduct in a complementary manner. To reverse the output phase sequence, the switching sequence may simply be reversed. Considering the symmetry in the switch conduction pattern, it may be found that at any time three switches conduct.

It could be two from the upper group of switches, which are connected to positive dc bus, and one from lower group or vice-versa (i.e., one from upper group and two from lower group). According to the conduction pattern indicated. there are six combinations of conducting switches during an output cycle:- (Sw5, Sw6, Sw1), (Sw6, Sw1, Sw2), (Sw1, Sw2, Sw3), (Sw2, Sw3, Sw4), (Sw3, Sw4, Sw5), (Sw4, Sw5, Sw6). Each of these combinations of switches conducts for 600 in the sequence mentioned above to produce output phase sequence of A, B, C. As will be shown later the fundamental component of the three output line-voltages will be balanced.

2.4 Maximum Power Point Tracking (MPPT)

Maximum power point tracking (MPPT) or sometimes just power point tracking (PPT), is a technique used commonly with wind turbines and photovoltaic (PV) solar systems to maximize power extraction under all conditions. Although it primarily applies to solar power, the principle applies generally to sources with variable power: for example, optical power transmission and thermophotovoltaics[21].

PV solar systems exist in many different configurations with regard to their relationship to inverter systems, external grids, battery banks, or other electrical loads. Regardless of the ultimate destination of the solar power, the central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on the amount of sunlight falling on the solar panels, the temperature of the solar panel and the electrical characteristics of the load. As these conditions vary, the load characteristic that gives the highest power transfer efficiency changes.The efficiency of the system is optimized when the load characteristic changes to keep the power transfer at highest efficiency.

This load characteristic is called the maximum power point (MPP). MPPT is the process of finding this point and keeping the load characteristic there. Electrical circuits can be designed to present arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable power out.

Solar cells have a complex relationship between temperature and total resistance that produces a non-linear output efficiency which can be analysed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the PV cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated This load characteristic is called the maximum power point (MPP). MPPT is the process of finding this point and keeping the load characteristic there. Electrical circuits can be designed to present arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable power out.

Solar cells have a complex relationship between temperature and total resistance that produces a non-linear output efficiency which can be analysed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the PV cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated The power at the MPP (P_{mpp}) is the product of the MPP voltage (V_{mpp}) and MPP current (I_{mpp}). Photovoltaic cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor, abbreviated *FF*, is a parameter which characterizes the non-linear electrical behaviour of the solar cell. Fill factor is defined as the ratio of the maximum power from the solar cell to the product of open circuit voltage V_{oc} and short-circuit current I_{sc}. In tabulated data it is often used to estimate the maximum power that a cell can provide with an optimal load under given conditions, $P=FF*V_{oc}*I_{sc}$. For most purposes, FF, V_{oc}, and I_{sc} are enough information to give a useful approximate model of the electrical behaviour of a photovoltaic cell under typical conditions.

For any given set of operational conditions, cells have a single operating point where the values of the current (*I*) and voltage (*V*) of the cell result in a maximum power output.[9] These values correspond to a particular load resistance, which is equal to *V* / I as specified by Ohm's law. The power P is given by $P=V*I$.

A photovoltaic cell, for the majority of its useful curve, acts as a constant current source.[10] However, at a photovoltaic cell's MPP region, its curve has an approximately inverse exponential relationship between current and voltage. From basic circuit theory, the power delivered from or to a device is optimized where the derivative (graphically, the slope) dI/dV of the I-V curve is equal and opposite the I/V ratio (where $dP/dV=0$).[11] This is known as the *maximum power point* (MPP) and corresponds to the "knee" of the curve.

A load with resistance $R=V/I$ equal to the reciprocal of this value draws the maximum power from the device. This is sometimes called the 'characteristic resistance' of the cell. This is a dynamic quantity which changes depending on the level of illumination, as well as other factors such as temperature and the age of the cell. If the resistance is lower or higher than this value, the power drawn will be less than the maximum available, and thus the cell will not be used as efficiently as it could be. Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

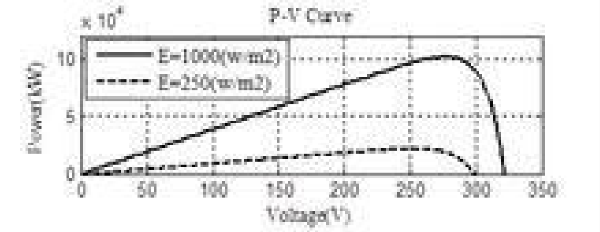


Fig.2.4 (a)Power-voltage (P -V) curve

If a full power-voltage (P -V) curve is available, then the maximum power point can be obtained using a bisection method.

Implementation

When a load is directly connected to the solar panel, the operating point of the panel will rarely be at peak power. The impedance seen by the panel determines the operating point of the solar panel. Thus, by varying the impedance seen by the panel, the operating point can be moved towards peak power point. Since panels are DC devices, DC-DC converters must be utilized to transform the impedance of one circuit (source) to the other circuit (load). Changing the duty ratio of the DC-DC converter results in an impedance change as seen by the panel. At a particular impedance (i.e. duty ratio) the operating point will be at the peak power transfer point.

The I-V curve of the panel can vary considerably with variation in atmospheric conditions such as irradiance and temperature. Therefore, it is not feasible to fix the duty ratio with such dynamically changing operating conditions.

MPPT implementations utilize algorithms that frequently sample panel voltages and currents, then adjust the duty ratio as needed. Microcontrollers are employed to implement the algorithms. Modern implementations often utilize larger computers for analytics and load forecasting.

Classification

Controllers can follow several strategies to optimize the power output of an array. Maximum power point trackers may implement different algorithms and switch between them based on the operating conditions of the array.

2.4.1 Perturb and observe

In this method the controller adjusts the voltage by a small amount from the array and measures power; if the power increases, further adjustments in that direction are tried until power no longer increases. This is called the perturb and observe method and is most common, although this method can result in oscillations of power output. It is referred to as a hill climbing method, because it depends on the rise of the curve of power against voltage below the maximum power point, and the fall above that point.[15] Perturb and observe is the most commonly used MPPT method due to its ease of implementation.[13] Perturb and observe method may result in top-level efficiency, provided that a proper pred 2.4.1ictive and adaptive hill climbing strategy is adopted.

Current sweep

The power-voltage curve by calculating the relation of the change of current/voltage and the current voltage themselves.

Constant voltage

The term "constant voltage" in MPP tracking is used to describe different techniques by different authors, one in which the output voltage is regulated to a constant value under all conditions and one in which the output voltage is regulated based on a constant ratio to the measured open .

Temperature method

This method of MPPT estimates the MPP voltage by measuring the temperature of the solar module and comparing it against a reference.[25] Since changes in irradiation levels have a negligible effect on the maximum power point voltage, its influences may be ignored - the voltage is assumed to vary linearly with the temperature changes.

Advantages

- Simplicity: This algorithm solves one linear equation. Therefore, it does not consume much computational power.
- Can be implemented as an analog or digital circuit.
- Since temperature varies slowly with time, there are no steady-state oscillation and instability.
- Low cost: temperature sensors are usually very cheap.
- Robust against noise.

Disadvantages

Estimation error might not be negligible for low irradiation levels (e.g. below 200 W/m^2).

2.4.2 Incremental Conductance method

The 5kW solar system with single string configuration is integrated with single MPPT logic. IC method is used to track the maximum power point voltage. As per the proposed method, IC will generate change of voltage ΔV from solar array. ΔV is positive in left hand side of PV curve and negative in right hand side of PV curve .This ΔV is changed until conductance equation become zero and thus maximum power and maximum power point (MPP) voltage are found. For MPPT mode the operating point is OP 1. In case of off-MPPT mode, if PV power increases from the reference power (off-MPPT mode power reference), a fractional voltage change $\Delta V'$ will be generated and it will reduce the MPP voltage to off-MPP voltage and operating point will shift to OP 2. From this new operating point OP 2, off-MPPT mode voltage and active power will be calculated.

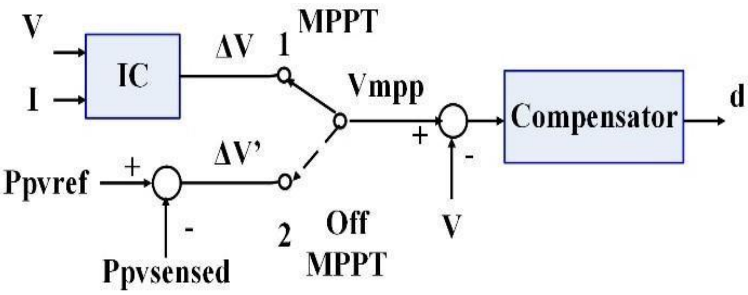


Fig.2.4.2(a) fractional voltage based incremental conductance method

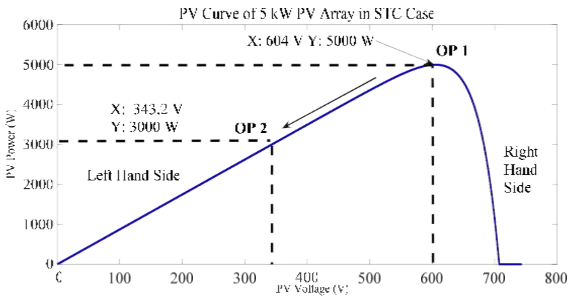


Fig 2.4.2(b) Shift operating point from mppt to off-mppt PV curve

2.4.3 Comparison of two methods

Both perturb and observe, and incremental conductance, are examples of "hill climbing" methods that can find the local maximum of the power curve for the operating condition of the PV array, and so provide a true maximum power point.

The perturb and observe method requires oscillating power output around the maximum power point even under steady state irradiance.The incremental conductance method has the advantage over the perturb and observe (P&O) method that it can determine the maximum power point without oscillating around this value .

It can perform maximum power point tracking under rapidly varying irradiation conditions with higher accuracy than the perturb and observe method.[13] However, the incremental conductance method can produce oscillations (unintentionally) and can perform erratically under rapidly changing atmospheric conditions.

The sampling frequency is decreased due to the higher complexity of the algorithm compared to the P&O method.

In the constant voltage ratio (or "open voltage") method, the current from the photovoltaic array must be set to zero momentarily to measure the open circuit voltage and then afterwards set to a predetermined percentage of the measured voltage, usually around 76 Energy may be wasted during the time the current is set to zero.

The approximation of 76% as the ratio is not necessarily accurate. Although simple and low-cost to implement, the interruptions reduce array efficiency and do not ensure finding the actual maximum power point. However, efficiencies of some systems may reach above 95%.

MPPT placement

Traditional solar inverters perform MPPT for the entire PV array (module association) as a whole. In such systems the same current, dictated by the inverter, flows through all modules in the string (series). Because different modules have different I-V curves and different MPPs (due to manufacturing tolerance, partial shading, etc.) this architecture means some modules will be performing below their MPP, resulting in lower efficiency [22].

2.5 Power quality

Electric power quality is the degree to which the voltage, frequency, and waveform of a power supply system conform to established specifications. Good power quality can be defined as a steady supply voltage that stays within the prescribed range, steady AC frequency close to the rated value, and smooth voltage curve waveform (resembles a sine wave).

In general, it is useful to consider power quality as the compatibility between what comes out of an electric outlet and the load that is plugged into it.[1] The term is used to describe electric power that drives an electrical load and the load's ability to function properly.

Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality power.

The electric power industry comprises electricity (AC power), electric power transmission and ultimately electric power distribution to an electricity meter located at the premises of the end user of the electric power. The electricity then moves through the wiring system of the end user until it reaches the load. The complexity of the system to move electric energy from the point of production to the point of consumption combined with variations in weather, generation, demand and other factors provide many opportunities for the quality of supply to be compromised.

While "power quality" is a convenient term for many, it is the quality of the voltage rather than power or electric current that is actually described by the term. Power is simply the flow of energy and the current demanded by a load is largely uncontrollable.

The quality of electrical power may be described as a set of values of parameters, such as:

- Continuity of service (Whether the electrical power is subject to voltage drops or overages below or above a threshold level thereby causing blackouts or brownouts
- Variation in voltage magnitude (see below)
- Transient voltages and currents
- Harmonic content in the waveforms for AC power

It is often useful to think of power quality as a compatibility problem: is the equipment connected to the grid compatible with the events on the grid, and is the power delivered by the grid, including the events, compatible with the equipment that is connected. Compatibility problems always have at least two solutions: in this case, either clean up the power, or make the equipment tougher.

The tolerance of data-processing equipment to voltage variations is often characterized by the CBEMA curve, which give the duration and magnitude of voltage variations that can be tolerated

Voltage

- Variations in the peak or RMS voltage are both important to different types of equipment.
- When the RMS voltage exceeds the nominal voltage by 10 to 80% for 0.5 cycle to 1 minute, the event is called a "swell".
- A "dip" (in British English) or a "sag" (in American English the two terms are equivalent) is the opposite situation: the RMS voltage is below the nominal voltage by 10 to 90% for 0.5 cycle to 1 minute.
- Random or repetitive variations in the RMS voltage between 90 and 110% of nominal can produce a phenomenon known as "flicker" in lighting equipment. Flicker is rapid visible changes of light level. Definition of the characteristics of voltage fluctuations that produce objectionable light flicker has been the subject of ongoing research.
- Abrupt, very brief increases in voltage, called "spikes", "impulses", or "surges", generally caused by large inductive loads being turned off, or more severely by lightning.
- "Undervoltage" occurs when the nominal voltage drops below 90% for more than 1 minute. The term "brownout" is an apt description for voltage drops somewhere between full power (bright lights) and a blackout (no power – no light). It comes from the noticeable to significant dimming of regular incandescent lights, during system faults or overloading etc., when insufficient power is available to achieve full brightness in (usually) domestic lighting. This term is in common usage has no formal definition but is commonly used to describe a reduction in system voltage by the utility or system operator to decrease demand or to increase system operating margins.
- "Overvoltage" occurs when the nominal voltage rises above 110% for more than 1 minute.[4]

Frequency

- Variations in the frequency.
- Nonzero low-frequency impedance (when a load draws more power, the voltagedrops).
- Nonzero high-frequency impedance (when a load demands a large amount of current, then suddenly stops demanding it, there will be a dip or spike in the voltage due to the inductances in the power supply line).
- Variations in the wave shape – usually described as harmonics at lower frequencies (usually less than 3 kHz) and described as Common Mode Distortion or Inter harmonics at higher frequencies.

Waveform

- The oscillation of voltage and current ideally follows the form of a sine or cosine function, however it can alter due to imperfections in the generators or loads.
- Typically, generators cause voltage distortions and loads cause current distortions. These distortions occur as oscillations more rapid than the nominal frequency, and are referred to as harmonics.
- The relative contribution of harmonics to the distortion of the ideal waveform is called total harmonic distortion (THD).
- Low harmonic content in a waveform is ideal because harmonics can cause vibrations, buzzing, equipment distortions, and losses and overheating in transformers.

Each of these power quality problems has a different cause. Some problems are a result of the shared infrastructure. For example, a fault on the network may cause a dip that will affect some customers; the higher the level of the fault, the greater the number affected. A problem on one customer's site may cause a transient that affects all other customers on the same subsystem. Problems, such as harmonics, arise within the customer's own installation and may propagate onto the network and affect other customers. Harmonic problems can be dealt with by a combination of good design practice and well proven reduction equipment.

Power conditioning

Power conditioning is modifying the power to improve its quality.

An uninterruptible power supply can be used to switch off of mains power if there is a transient (temporary) condition on the line. However, cheaper UPS units create poor-quality power themselves, akin to imposing a higher-frequency and lower-amplitude square wave atop the sine wave. High-quality UPS units utilize a double conversion topology which breaks down incoming AC power into DC, charges the batteries, then remanufactures an AC sine wave. This remanufactured sine wave is of higher quality than the original AC power feed[5].

A **Dynamic Voltage Regulator (DVR)** and **Static Synchronous Series Compensator (SSSC)** are utilized for series voltage sag compensation . A surge protector or simple capacitor or varistor can protect against most overvoltage conditions, while a lightning arrester protects against severe spikes. Electronic filters can remove harmonics.

Smart grids and power quality

Modern systems use sensors called phasor measurement units (PMU) distributed throughout their network to monitor power quality and in some cases respond automatically to them. Using such smart grids features of rapid sensing and automated self healing of anomalies in the network promises to bring higher quality power and less downtime while simultaneously supporting power from intermittent power sources and distributed generation, which would if unchecked degrade power quality.

2.6 Power quality compression algorithm

A **power quality compression algorithm** is an algorithm used in the analysis of power quality. To provide high quality electric power service, it is essential to monitor the quality of the electric signals also termed as power quality (PQ) at different locations along an electrical power network. Electrical utilities carefully monitor waveforms and currents at various network locations constantly, to understand what lead up to any unforeseen events such as a power outage and blackouts. This is particularly critical at sites where the environment and public safety are at risk (institutions such as hospitals, sewage treatment plants, mines, etc.).

Power quality challenges

Engineers have at their disposal many meters,[6] that are able to read and display electrical power waveforms and calculating parameters of the waveforms. These parameters may include, for example, current and voltage RMS, phase relationship between waveforms of a multi-phase signal, power factor, frequency, THD, active power (kW), reactive power (kVAr), apparent power (kVA) and active energy (kWh), reactive energy (kVArh) and apparent energy (kVAh) and many more. In order to sufficiently monitor unforeseen events, Ribeiro et al.[7] explains that it is not enough to display these parameters, but to also capture voltage waveform data at all times. This is impracticable due to the large amount of data involved, causing what is known the "bottle effect". For instance, at a sampling rate of 32 samples per cycle, 1,920 samples are collected per second. For three-phase meters that measure both voltage and current waveforms, the data is 6-8 times as much. More practical solutions developed in recent years store data only when an event occurs (for example, when high levels of power system harmonics are detected) or alternatively to store the RMS value of the electrical signals. This data, however, is not always sufficient to determine the exact nature of problems.

Non-linear loads

Passive filters connected between the non-linear load and the series active power filter play an important role in the compensation of the load current harmonics. With the connection of the passive filters the series active power filter operates as an harmonic isolator. The harmonic isolation feature reduces the need for precise tuning of the passive filters and allows their design to be insensitive to the system impedance and eliminates the possibility of filter overloading due to supply voltage harmonics. The passive filter can be tuned to the dominant load current harmonic and can be designed to correct the load displacement power factor.

However, for industrial loads connected to stiff supply, it is difficult to design passive filters that can absorb a significant part of the load harmonic current and therefore its effectiveness deteriorates. Specially, for compensation of diode rectifier type of loads, where a small kVA passive filter is required, it is difficult to achieve the required tuning to absorb significant percentage of the load harmonic currents. For this type of application, the passive filter cannot be tuned exactly to the harmonic frequencies because they can be overloaded due to the system voltage distortion and/or system current harmonics.

Harmonic Power for Nonlinear Loads

If a signal contains harmonics, the Individual Harmonic Distortion (IHD) for any harmonic order is defined as the percentage of the harmonic magnitude respect to the fundamental value.

$$U_h(\%) = 100 \cdot \frac{U_h}{U_1} \quad (1)$$

$$I_h(\%) = 100 \cdot \frac{I_h}{I_1} \quad (2)$$

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \cdot 100 \quad (3)$$

$$THD_U = \frac{\sqrt{\sum_{h=2}^{\infty} U_h^2}}{U_1} \cdot 100 \quad (4)$$

Since the numerators of the equations (3) and (4) are equal to the RMS values of the harmonic contents of voltage and current and respectively, these equations can be written as:

$$I_{rms}^2 = I_1^2 \cdot (1 + THD_I^2) \quad (5)$$

$$U_{rms}^2 = U_1^2 \cdot (1 + THD_U^2) \quad (6)$$

Equations (5) and (6) show that the RMS values of current and voltage for a harmonic polluted waveform are bigger than the fundamental value and this results in bigger apparent power.The apparent power of a signal containing harmonics is calculated by the equation 7.

$$S^2 = (UI)^2 = U_1^2 \cdot (1+THD_U^2) \cdot I_1^2 \cdot (1+THD_I^2) = S_1^2 \cdot (1+THD_U^2) \cdot (1+THD_I^2) \qquad (7)$$

Since the THDU which comes through utility is much smaller than THDI in most cases, it can be ignored. Therefore,

$$S^2 = S_1{}^2 (1 + THD_I^2) \qquad (8)$$

For a sinusoidal waveform, the apparent power *S* is comprised of active power *P* and reactive power *Q*, but presence of harmonics causes the presence of a new type of power, the Distortion Power *D* with units of voltamperes. Distortion power is described in following equations.

$$S^2 = S_1^2 \cdot (1+THD_I^2) = S_1^2 + D^2 \qquad (9)$$

$$S^2 = P^2 + Q^2 + D^2 = S_1{}^2 (1+THD_I^2) \qquad (10)$$

$$D^2 = S_1{}^2 THD_I^2 ==> D = S_1 \; THD_I \qquad (11)$$

Power factor is not only affected by the phase displacement between voltage and current waveforms. The distortion power (*D*) also affects the power factor. Power factor will decrease in presence of harmonics and consequently distortion power (*D*).

In the case of presence of harmonics power factor is composed from two factors, Displacement Power Factor (pf_{disp}) and Distortion Power Factor (pf_{dist}).

$$pf = \frac{P}{S} = \frac{P}{S_1} \cdot \frac{1}{\sqrt{1+THD_I^2}\sqrt{1+THD_U^2}} \qquad (12)$$

$$= pf_{disp} \cdot pf_{dist}$$

$$pf_{disp} = \frac{P}{S_1} \qquad (13)$$

$$pf_{dist} = \frac{1}{\sqrt{1+THD_I^2}\sqrt{1+THD_U^2}} = \frac{S_1}{S} \qquad (14)$$

Nonlinear loads can be considered as harmonic real power sources that inject harmonic real power into the distribution system which is product of the harmonic voltage and harmonic current of the same orders. Although this power is much smaller than the fundamental real power, the presence of the distortion power caused by harmonics will result in increased losses flowing through the utility supply system. For a linear load, the loss of the utility is I_1^2R. With current distortion discussed above, the loss would be as:

$$Loss = RI^2 = R(I_1^2 + \sum_{n=2}^{\infty} I_n^2) = RI_1^2(1+THD_I^2) \qquad (15)$$

So it can be seen that a significant increase in loss of the utility will be occurred in presence of harmonic distortions. For example, with a THD_I=40%, the loss would be increased by 16%.

For a three-phase utility, the total losses are:

$$P = R_p I_p^2 + R_N I_N^2 \qquad (16)$$

Where I_P is the phase current of the balanced network and IN is the neutral line current. The harmonic losses are:

$$\begin{aligned} Loss &= R_P I_P{}^2 + R_N I_N^2 \\ &= R_P \sum_{h=1}^{\infty} (I_{ah}^2 + I_{ah}^2 + I_{ah}^2) + R_N \sum_{h=1}^{\infty} I_{Nh}^2 \end{aligned} \qquad (17)$$

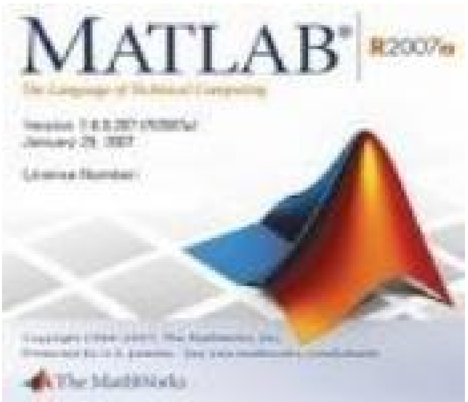
Where I_{ah}, I_{bh}, and Ich are the order *h* harmonic currents in phase A, B and C respectively, and I_{Nh} is the order *h* harmonic neutral current. R_P and R_N are the phase and neutral resistances. The loss of the neutral current can be considerable so that it can be the main part of the harmonic power loss. Two typical problems can overload the neutral conductor. One is unbalanced single phase loads and the other one occurs when the line to neutral voltage is badly distorted by the triple harmonic voltage drop in the neutral condition.

CHAPTER -3

MATLAB

3.1 INTRODUCTION TO MATLAB

MATLAB is a software package for computation in engineering, science, and applied mathematics.



It offers a powerful programming language, excellent graphics, and a wide range of expert knowledge. MATLAB is published by and a trademark of The MathWorks, Inc. The focus in MATLAB is on computation, not mathematics: Symbolic expressions and manipulations are not possible (except through the optional Symbolic Toolbox, a clever interface to maple). All results are not only numerical but inexact, thanks to the rounding errors inherent in computer arithmetic. The limitation to numerical computation can be seen as a drawback, but it's a source of strength too: MATLAB is much preferred to Maple, Mathematical, and the like when it comes to numeric.

On the other hand, compared to other numerically oriented languages like C++ and FORTRAN, MATLAB is much easier to use and comes with a huge standard library.1 the unfavorable comparison here is a gap in execution speed. This gap is not always as dramatic as popular lore has it, and it can often be narrowed or closed with good MATLAB programming (see section 6). Moreover, one can link other codes into MATLAB, or vice versa, and MATLAB now optionally supports parallel computing. Still, MATLAB is usually not the tool of choice for maximum-performance Computing.

The MATLAB niche is numerical computation on workstations for non-experts in computation. This is a huge nicheone way to tell is to look at the number of MATLAB-related books on mathworks.com. Even for supercomputer users, MATLAB can be a valuable environment in which to explore and fine-tune algorithms before more laborious coding in another language.

Most successful computing languages and environments acquire a distinctive character or culture.

In MATLAB, that culture contains several elements: an experimental and graphical bias, resulting from the interactive environment and compression of the write-compile-link-execute analyses cycle; an emphasis on syntax that is compact and friendly to the interactive mode, rather than tightly constrained and verbose; a kitchen-sink mentality for providing functionality; and a high degree of openness and transparency (though not to the extent of being open source software).

The fifty cent tour

When you start MATLAB, you get a multipaneled desktop. The layout and behaviour of the desktop and its components are highly customizable (and may in fact already be customized for your site).The component that is the heart of MATLAB is called the Command Window, located on the 1Here and elsewhere I am thinking of the "old FORTRAN," FORTRAN 77. This is not a commentary on the usefulness of FORTRAN 90 but on my ignorance of it.

Introduction

Right by default. Here you can give MATLAB commands typed at the prompt, >>. Unlike FORTRAN and other compiled computer languages, MATLAB is an interpreted environment—you give a command, and MATLAB tries to execute it right away before asking for another. At the top left you can see the Current Directory. In general MATLAB is aware only of files in the current directory (folder) and on its path, which can be customized. Commands for working with the directory and path include cd, what, add path, and edit path (or you can choose "File/Set path. from the menus). You can add files to a directory on the path and thereby add commands to MATLAB; we will return to this subject.

Next to the Current Directory tab is the **Workspace** tab. The workspace shows you what variable names are currently defined and some information about their contents.

(At start-up it is, naturally, empty.) This represents another break from compiled environments: variables created in the workspace persist for you to examine and modify, even after code execution stops. Below the Command Window/Workspace window is the **Command History** window. As you enter commands, they are recorded here. This record persists across different MATLAB sessions, and commands or blocks of commands can be copied from here or saved to files.

As you explore MATLAB, you will soon encounter some toolboxes. These are individually packaged sets of capabilities that provide in-depth expertise on particular subject areas. There is no need to load them explicitly—once installed, they are always available transparently. You may also encounter Simulink, which is a semi-independent graphical control-engineering package not covered in this document.

Graphical versus command-line usage

MATLAB was originally entirely a command-line environment, and it retains that orientation. But it is now possible to access a great deal of the functionality from graphical interfacesmenus, buttons, and so on. These interfaces are especially useful to beginners, because they lay out the available choices clearly.2 As a rule, graphical interfaces can be more natural for certain types of interactive work, such as annotating a graph or debugging a program, whereas typed commands remain better for complex, precise, repeated, or reproducible tasks.

One does not always need to make a choice, though; for instance, it is possible to save a figure’s styles as a template that can be used with different data by pointing and clicking. Moreover, you can package code you want to distribute with your own graphical interface, one that itself may be designed with a combination of graphical and command oriented tools.

In the end, an advanced MATLAB user should be able to exploit both modes of work to be productive. That said, the focus of this document is on typed commands. In many (most?) cases these have graphical interface equivalents, even if I don’t explicitly point them out. In particular, feel free to right-click (on Control-click on a Mac) on various objects to see what you might be able to do to them.

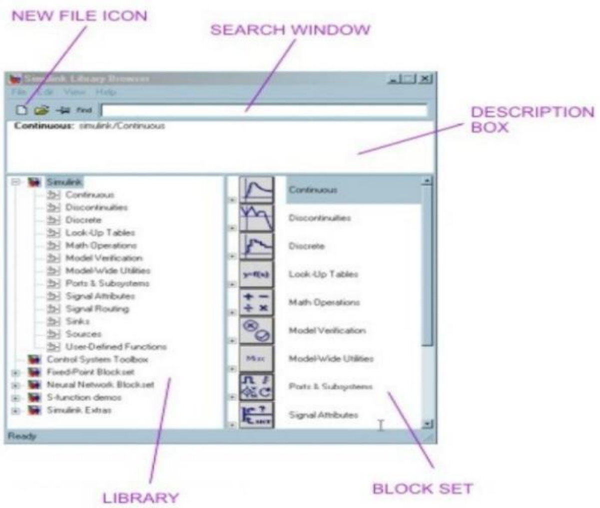
3.2 INTRODUCTION TO SIMULINK

Simulink (Simulation and Link) is an extension of MATLAB by Math works Inc. It works with MATLAB to offer modeling, simulating, and analyzing of dynamical systems under a graphical user interface (GUI) environment. The construction of a model is simplified with click-and-drag mouse operations. Simulink includes a comprehensive block library of toolboxes for both linear and nonlinear analyses. Models are hierarchical, which allow using both top-down and bottom-up approaches. As Simulink is an integral part of MATLAB, it is easy to switch back and forth during the analysis process and thus, the user may take full advantage of features offered in both environments. This tutorial presents the basic features of Simulink and is focused on control systems as it has been written for students in my control systems.

Getting Started

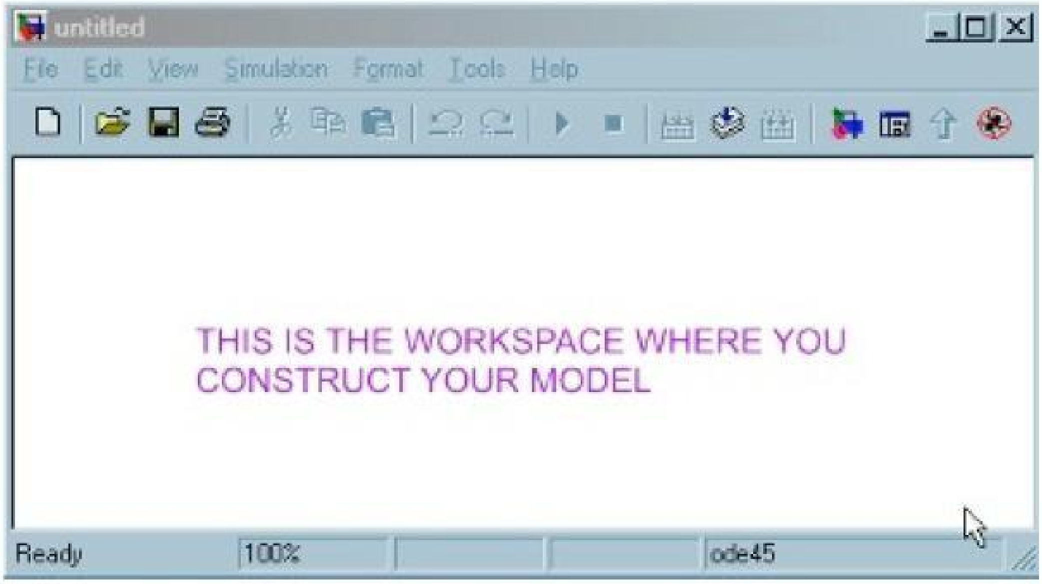
To start a Simulink session, you'd need to bring up MATLAB program first. From MATLAB command window, enter: >> SIMULINK

Alternately, you may click on the Simulink icon located on the toolbar as shown below



To see the content of the block set, click on the "+" sign at the beginning of each toolbox. To start a model click on the NEW FILE ICON as shown in the screenshot above.

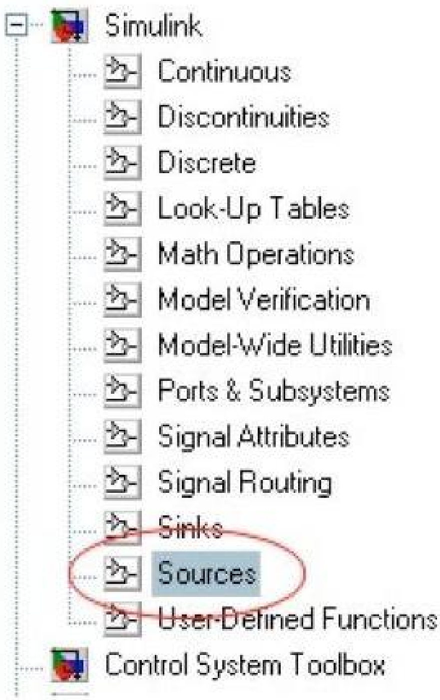
Alternately, you may use keystrokes CTRL+N. A new window will appear on the screen. You will be constructing your model in this window. Also in this window the constructed model is simulated. A screenshot of a typical working (model) window that looks like one shown below:



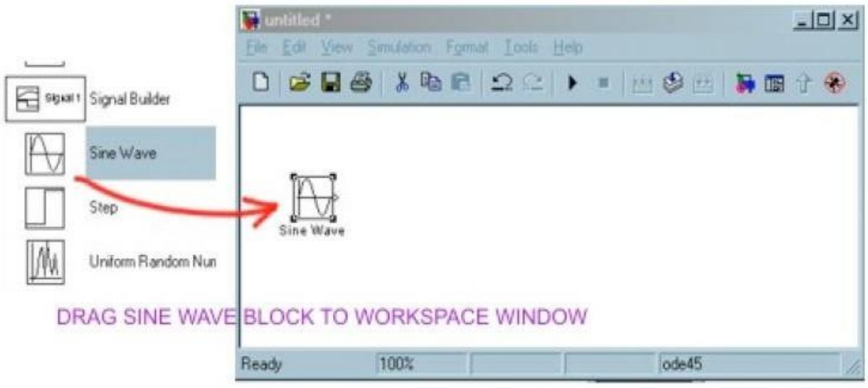
To become familiarized with the structure and the environment of Simulink, you are encouraged to explore the toolboxes and scan their contents. You may not know what they are all about but perhaps you could catch on the organization of these toolboxes according to thecategory. For instant, you may see Control System Toolbox to consist of the Linear TimeInvariant (LTI) system library and the MATLAB functions can be found under Function and Tables of the Simulink main toolbox. A good way to learn Simulink (or any computer program in general) is to practice and explore. Making mistakes is a part of the learning curve. So, fear not, you should be.A simple model is used here to introduce some basic features of Simulink. Please follow the steps below to construct a simple model.

STEP 1: CREATING BLOCKS.

From BLOCK SET CATEGORIES section of the SIMULINK LIBRARY BROWSER window, click on the "+" sign next to the Simulink group to expand the tree and select (click on) Sources.



A set of blocks will appear in the BLOCKSET group. Click on the Sine Wave block and drag it to the workspace window (also known as model window)A set of blocks will appear in the BLOCKSET group. Click on the Sine Wave block and drag it to the workspace window (also known as model window)



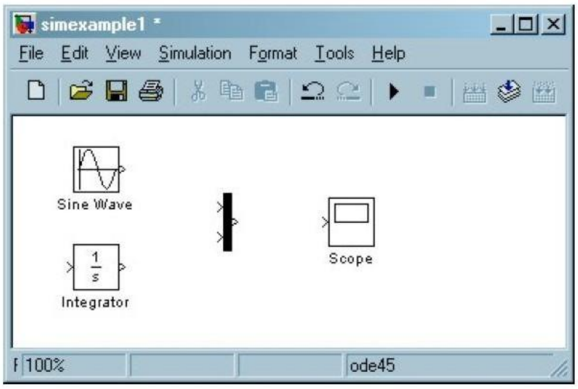
I am going to save this model under the filename: "simexample1". To save a model, you may click on the floppy diskette icon. Or from FILE menu, select Save or CTRL+S. All Simulink model file will have an extension ".mdl".

Simulink recognizes file with .mdl extension as a simulation model (similar to how MATLAB recognizes files with the extension .m as an MFile). Continue to build your model by adding more components (or blocks) to your model window. We'll continue to add a Scope from Sinks library, an Integrator block from Continuous library, and a Mux block from Signal Routing library.

NOTE: If you wish to locate a block knowing its name, you may enter the name in the SEARCH WINDOW (at Find prompt) and Simulink will bring up the specified block.

To move the blocks around, simply click on it and drag it to a desired location.

Once all the blocks are dragged over to the work space should consist of the following components:

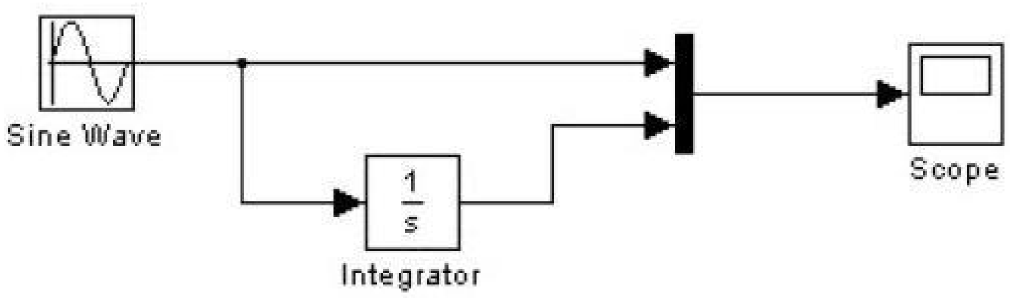


You may remove (delete) a block by simply clicking on it once to turn on the "select mode" (with four corner boxes) and use the DEL key or keys combination CTRL-X.

STEP 2: MAKING CONNECTIONS

To establish connections between the blocks, move the cursor to the output port represented by ">" sign on the block. Once placed at a port, the cursor will turn into a cross "+" enabling you to make connection between blocks.

To make a connection: left-click while holding down the control key (on your keyboard) and drag from source port to a destination port. The connected model is shown below.

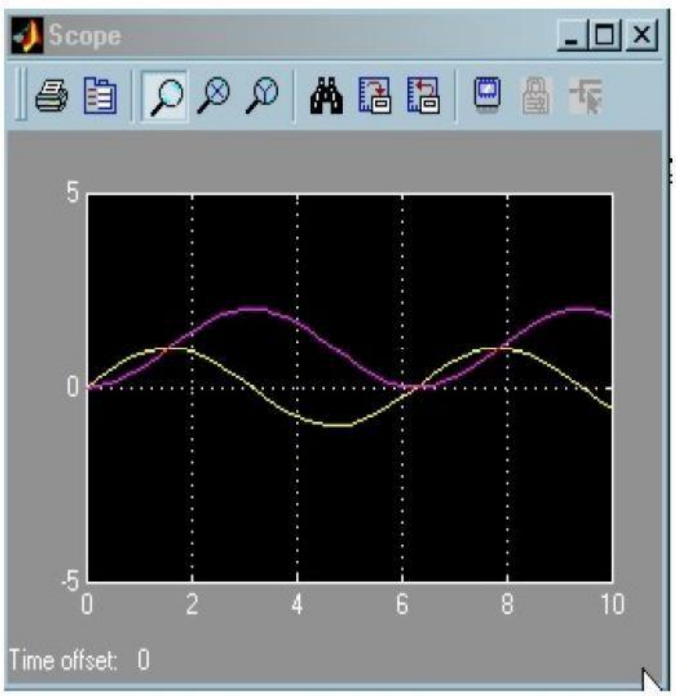


A sine signal is generated by the Sine Wave block (a source) and is displayed by the scope. The integrated sine signal is sent to scope for display along with the original signal from the source via the Mux, whose function is to multiplex signals in form of scalar, vector, or matrix into a bus.

STEP 3: RUNNING SIMULATION

You now can run the simulation of the simple system above by clicking on the play button (alternatively, you may use key sequence CTRL+T, or choose Start submenu under Simulation menu).

Double click on the Scope block to display of the scope.



Introduction

Sim Power Systems and other products of the Physical Modeling product family work together with Simulink® to model electrical, mechanical, and control systems. Sim Power Systems operates in the Simulink environment. Therefore, before starting this user's guide, you should be familiar with Simulink. For help with Simulink, see the Simulink documentation. Or, if you apply Simulink to signal processing and communications tasks (as opposed to control system design tasks), see the Signal Processing Block set documentation.

The Role of Simulation in Design

Electrical power systems are combinations of electrical circuits and electromechanical devices like motors and generators. Engineers working in this discipline are constantly improving the performance of the systems.

Requirements for drastically increased efficiency have forced power system designers to use power electronic devices and sophisticated control system concepts that tax traditional analysis tools and techniques. Further complicating the analyst's role is the fact that the system is often so nonlinear that the only way to understand it is through simulation Land-based power generation from hydroelectric, steam, or other devices is not the only use of power systems. A common attribute of these systems is their use of power electronics and control systems to achieve their performance objectives.

What is Sim Power System

Sim Power Systems is a modern design tool that allows scientists and engineers to rapidly and easily build models that simulate power systems. Sim Power Systems uses the Simulink environment, allowing you to build a model using simple click and drag procedures. Not only can you draw the circuit topology rapidly, but your analysis of the circuit can include its interactions with mechanical, thermal, control, and other disciplines. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modelling library. Since Simulink uses MATLAB® as its computational engine, designers can also use MATLAB toolboxes and Simulink block sets. Sim Power Systems and Sim Mechanics share a special Physical Modelling block and connection line interface.

Sim Power Systems Libraries

You can rapidly put Sim Power Systems to work. The libraries contain models of typical power equipment such as transformers, lines, machines, and power electronics. These models are proven ones coming from textbooks, and their validity is based on the experience of the Power Systems Testing and Simulation Laboratory of Hydro-Québec, a large North American utility located in Canada, and also on the experience of École de Technologies Supérieure and University Laval. The capabilities of Sim Power Systems for modelling a typical electrical system are illustrated in demonstration files. And for users who want to refresh their knowledge of power system theory, there are also self-learning case studies.

The Sim Power Systems main library, power lib, organizes its blocks into libraries according to their behaviour .The power lib library window displays the block library icons and names. Double-click a library icon to open the library and access the blocks. The main Sim Power Systems power lib library window also contains the Powergui block that opens a graphical user interface for the steady-state analysis of electrical circuits.

Nonlinear Simulink Blocks for Sim Power Systems Models

The nonlinear Simulink blocks of the power lib library are stored in a special\block library named powerlib models. These masked Simulink models are used by Sim Power Systems to build the equivalent Simulink model of your circuit. See Chapter 3, "Improving Simulation Performance" for a description of the powerlib_models library

You must have the following products installed to use Sim Power Systems:

• MATLAB

• SIMULINK

CHAPTER-4
SIMULATION AND RESULTS

4.1 Simulink model

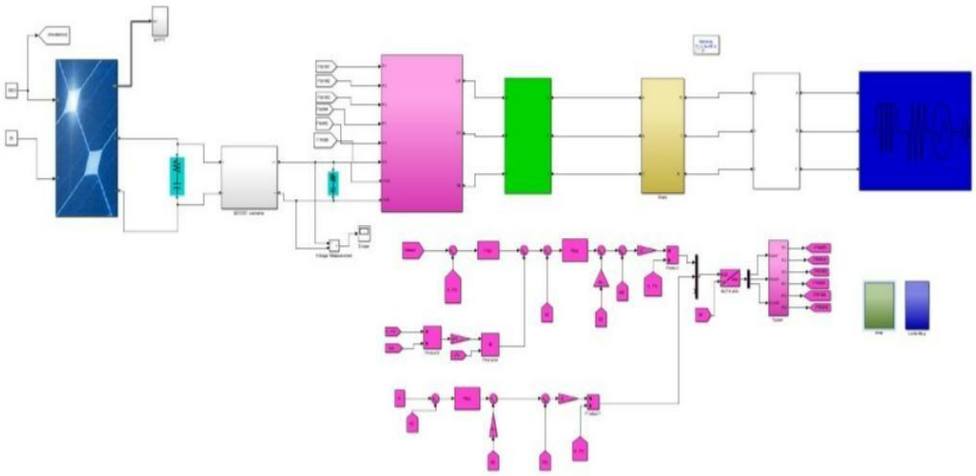


Fig.4.1 Simulink model for active and reactive power compensation

4.2 Simulation results

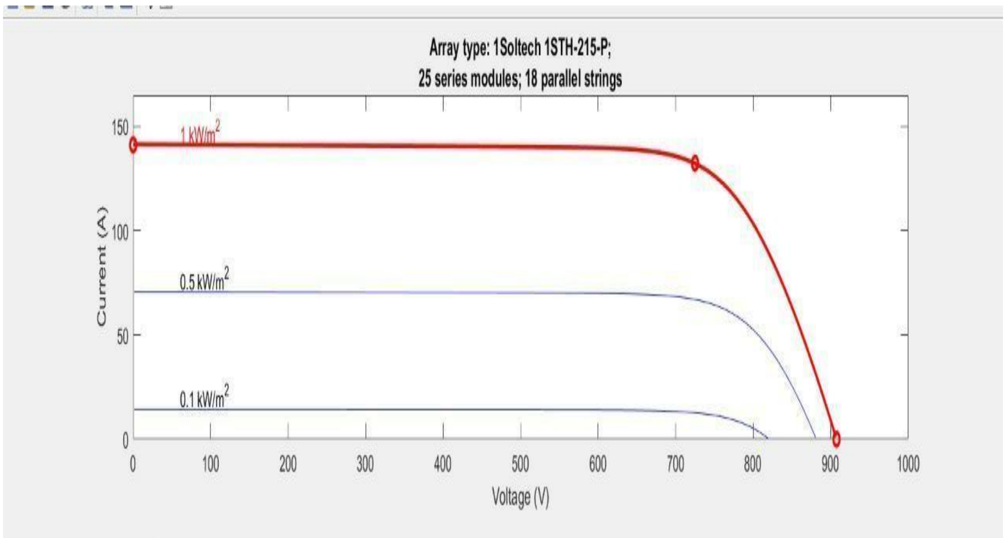


Fig.4.2(a) Irradiation at different voltages and currents

Maximum Power Point Tracking (MPPT) methods which improve conventional Fractional Open Circuit Voltage (FOCV) method.

The main novelty is a switched semi-pilot cell that is used for measuring the open-circuit voltage. In first method this voltage is measured on the semi-pilot cell located at the edge of PV panel.

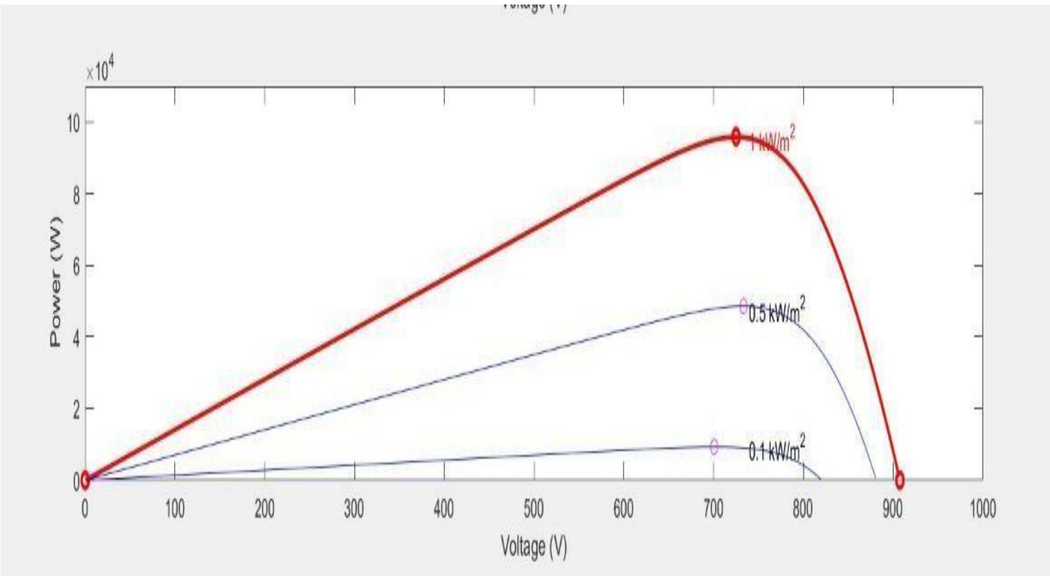


Fig.4.2(b)Irradiation at different voltage and power conditions

The variability of photovoltaic (PV) energy because of atmospheric conditions dependency necessitates employing a maximum power point tracking (MPPT) technique in the installed PV systems. So, finite control set model predictive control (FCS-MPC) is used to extract the maximum power .the figure shows that the irradiation at different voltage and also different power conditions .

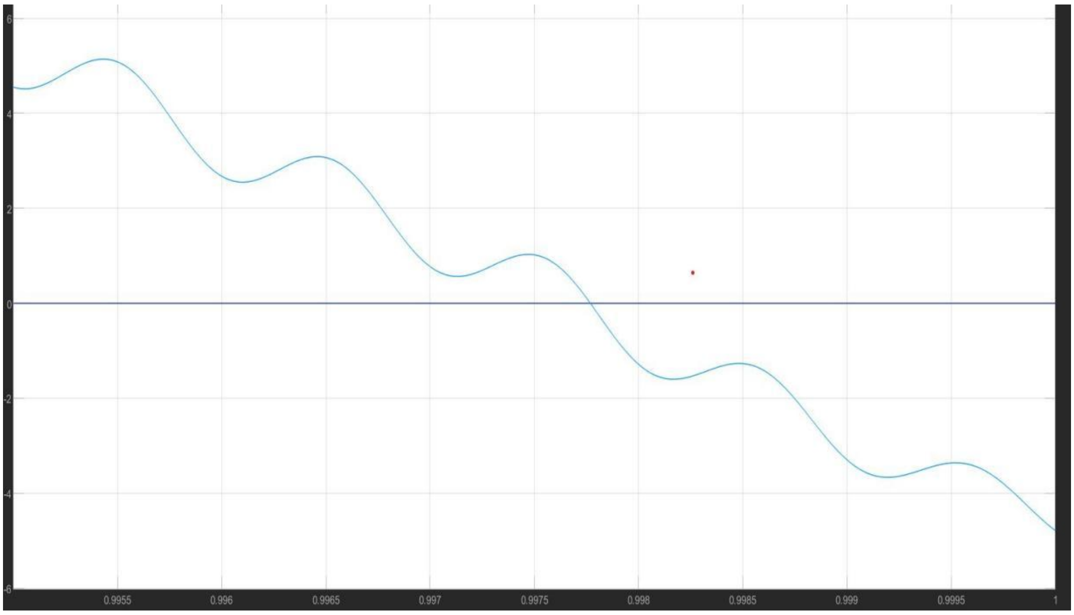


Fig.4.2 (c) Active power w.r.t Temperature

This graph shows that the amount of the active power that is varying at the different temperature values. Electronic components have thermal conductivity to the surrounding environment. It can be expressed in degrees/watt. So if a component dissipates 1watt has heat and it's thermal conductivity to free air is a 100^0C/watt. Then its will raise in temperature 100^0C

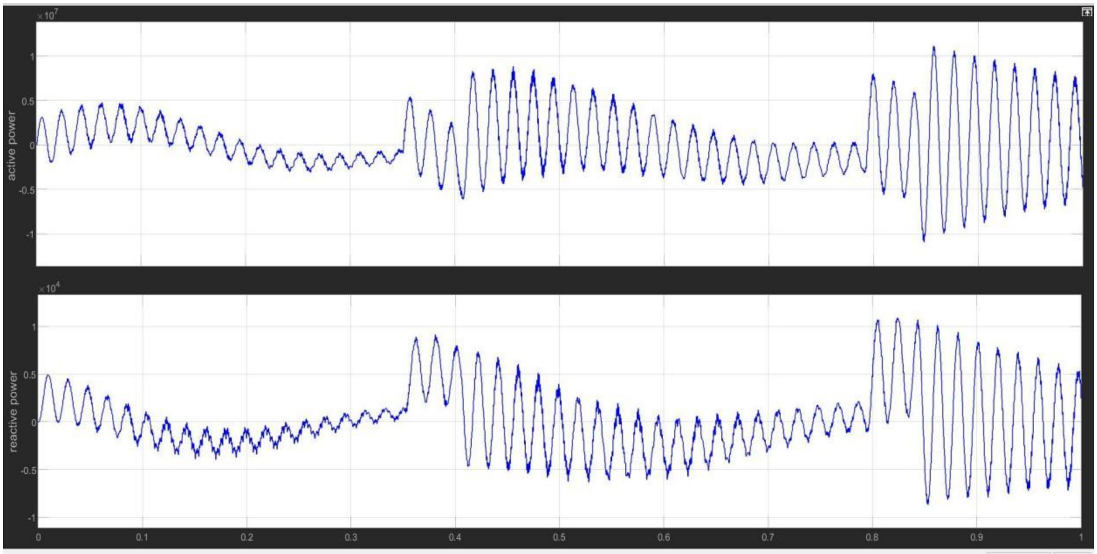


Fig 4.2(d) Active and Reactive power control

CHAPTER-5

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

For large solar PV plant, regulation in penetration level is becoming challenging due to insufficient use of storage devices. More over due to high penetration level of solar PV, the grid voltage and power fluctuation degrade the grid stability. To address the concerning issue the active power injected from solar inverter should be regulated. To control active power from solar inverter, MPPT logic is modified and solar PV is operated in reduced voltage and power mode. For this a fraction voltagebased IC method is proposed in this paper. Regulating MPPT of solar PV by FV-IC the solar power generated from inverter is controlled in any type of ambient situation. For sunny and cloudy day, the solar PV operated in both MPPT and off-MPPT depending on the pre-set active power reference and limited active power is sent to the grid. Additional to the active power control, reactive power control is simulated on unity, legging and leading pf. cases as ancillary service provided by solar inverter.

5.2 Future Scope

1. This type of power co relations are easily adaptive to advanced voltage controlling methods
2. The power quality is improved by increasing the framework of the reactive power.

Chapter-6

REFERENCES

[1] "Energy statistics 2016" central statistics office, ministry of statistics and program implementation, Govt.of India www.mospv.gov.in.

[2] German federal law :Renewable energy sources act,BGNI,std.,july,2014.

[3] Energinet.dk,Technical regulation 3.2.2for PV power plants for a power output above 11KW,Tech.Rep.2015.

[4]Y.Yang. H.Wang,F.Blaabjerg,T.kerekes,A hybrid power concept for PV inverters with reduced thermal loading ,IEEE transaction on power electronics ,vol.29,no.12,pp.6271-6275,December.2014.

[5]Y.Chen,C.Tang,and Y.Chen,PV power system with multi-mode operation and low voltage ride-through capability IEEE Transaction of industrial electronics,vol.62,no.12,pp.7524-7533,December.2015.

[6]A.Sangwongwanich ,Y.Yangand F.Blaabjerg ,High-performance constant power generation grid-connected PV systems ,IEEE Transaction on power Electronics ,Vol.31,no.3,pp.1822-1825,March-2016.

[7]M.G Villalva,J.R Gazoli,and E.R Filho , comprehensive approach to modelling and simulation of photovoltaic arrays ,IEEE Transaction on power Electronics ,vol.24.no.5,pp.1198-1208,may 2009.

[8]R.W. Erickson and D.Maksimovic ,Fundamental of power Electronics,2nd edition ,Springer,2000.

[9] H. D. Venable, "The k factor: A new mathemathical tool for stability analysis and synthesis", Proceedings of POWERCON 10, Tenth International Solid-State Power Electronics Conference, San Diego, California, March 22-24, 1983.

[10]A. Yazdani and R. Iravani, Voltage Sourced Converters in Power Systems: Modeling, Control and Applications, IEEE press, John Wiley & Sons, New Jersey, USA, 2010.

[11]S. Douangsyla and P. Indarack, A. Kanthee, M. Kando, S. Kittiratsatcha and V. Kinnares, "Modeling for PWM voltage source converter controlled power transfer", International Symposh on Communications and Information Technologies, (ISClT 2004), Sappom, Japan, pp. 875- 878, October, 2004.

[12] Jha, Nishant, et al. "Energy-Efficient Hybrid Power System Model Based on Solar and Wind Energy for Integrated Grids." *Mathematical Problems in Engineering* 2022 (2022).

[13] Shivashankar, S., et al. "Mitigating methods of power fluctuation of photovoltaic (PV) sources–A review." *Renewable and Sustainable Energy Reviews* 59 (2016).

[14] Bana, Sangram, and R. P. Saini. "A mathematical modeling framework to evaluate the performance of single diode and double diode based SPV systems." *Energy Reports* 2 (2016).

[15] Amini, Jalal, and Mehrdad Moallem. "Logic-based space-vector modulation for neutral-point-clamped multilevel inverter with DC-link voltage balancing capability." *IET Power Electronics* 13, no. 19 (2020).

[16] Durán, E., et al. "Determination of PV generator IV/PV characteristic curves using a DC-DC converter controlled by a virtual instrument." *International Journal of Photoenergy* 2012 (2012).

[17] Durán, E., Andújar, J. M., Enrique, J. M., & Pérez-Oria, J. M. (2012). Determination of PV generator IV/PV characteristic curves using a DC-DC converter controlled by a virtual instrument. *International Journal of Photoenergy*, *2012*.

[18] A.Sangwongwanich High-performance constant power generation grid-connected PV systems ,IEEE Transaction on power Electronics,March-2016.

[19] Durán E, Andújar JM, Enrique JM, Pérez-Oria JM. Determination of PV generator IV/PV characteristic curves using a DC-DC converter controlled by a virtual instrument. International Journal of Photoenergy. 2012 Jan 1;2012.

[20] Gaber, E. L., and EL-Noby Ahmed Ibrahim. "Elimination of Voltage Harmonic Produced by SSSC by Using Series Active Power Filter."

[21] Hurayb K. Power Optimization, Diagnostic Monitoring, and Modeling of Photovoltaic System.

[22] Baba AO, Liu G, Chen X. Classification and evaluation review of maximum power point tracking methods. Sustainable Futures. 2020 Jan 1.

[23] Hurayb, Khalid. "Power Optimization, Diagnostic Monitoring, and Modeling of Photovoltaic System." (2014).

[24] Gaber, E. L., and EL-Noby Ahmed Ibrahim. "Elimination of Voltage Harmonic Produced by SSSC by Using Series Active Power Filter."

[25] Ehrenreich, Henry; Martin, John H. 1979 (Sept.). "Solar Photovoltaic Energy." Physics Today. Vol. 32 (No.9).

[26] Balzhiser, Richard E. 1977 (June/July). R&D Status Report. "Fossil Fuel and Advanced System Division." EPRI Journal.

[27] Magid, L.M. 1979. "The U.S. Department of Energy National Photovoltaics Program Plan." Proceedings 2nd E.G. Photovoltaic Solar Energy Conference. April 23-26. 1979.

[28] Boston, MA: D. Reidel Publishing Co.; pp.Ross, KG., Jr. 1976. "Interface Design Considerations for Terrestrial Solar Cell Modules." Proceedings 12th IEEE Photovoltaic Specialists Conference1976.

[29] Stiller, P.H.; Eichler, C.H.; and Kilar, L.A. "Interconnection of On-Site Generation with the Electric Utility -Site Owner Concerns." Proceedings 14th IEEE Photovoltaic Specialists Conference-1980.