A
Project Report
on

POWER QUALITY IMPROVEMENT IN PV SYSYTEM CONNECTED TO GRID

by

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DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

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CERTIFICATE

This is to certify that Project Report entitled **"Power Quality Improvement in PV System"** which is submitted by **Priteesh Ranjan, Pankaj Singh, Pawan Kumar Singh, Paras Goya, Praveen Shishodia** in partial fulfillment of the requirement for the award of degree B. Tech. in Department of Electrical and Electronics Engineering of Dr. A.P.J. Abdul Kalam Technical University, Lucknow, is a record of the candidate own work carried out by him under my/our supervision. The matter embodied in this thesis is original and has not been submitted for the award of any other degree.

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ABSTRACT

The modern power system contains complex circuitry involving transmission lines, generators, loads and transformers etc. As the power demand has increased exponentially over the last few decades, transmission lines are nowadays overloaded. The transmission capacity is limited majorly due to problem of transient stability, which arises due to the increased loading of long transmission lines. A severe fault on this system may cause instability. This leads to FACTs devices being installed in the system. The scarcity of power can be met by using renewable sources like Solar Energy, Wind energy etc. The Solar Energy systems also called PV system can be used in isolated or grid connected mode. PV system has numerous benefits and its use has been increasing in recent years. Beside electricity shortage, a more vulnerable issue in modern power system is related to quality of power delivered. A good quality of power ensures smooth operations of electrical utilities. Non-linear loads in the grid produce harmonic distortion in the grid. This reduces the power quality in the system. Good Power Quality is immensely important for both industrial and domestic sectors. The PV System connected to grid has power quality issues such as Voltage Sag, Voltage Swell, Harmonics etc. harmonics are the most important problem related to Power Quality. Harmonics reduces the power quality by distorting the waveform. By reducing the harmonics, a smooth sinusoidal waveform is obtained.

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LIST OF ABBREVIATIONS

[1]. SVC (Static VAR Compensator)

[2]. TCSC (Thyristor Control Series Capacitor)

[3]. STATCOM (Static synchronous Compensator)

[4]. SSSC (Static Synchronous Series Compensator)

[5]. UPFC (Unified power flow controller)

[6]. FACTs (Flexible AC transmission devices)

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CHAPTER 1

INTRODUCTION

Huge influx of energy demand in the developing nations is countered at the cost of natural resources which are depleting at a very fast rate. So there is urgent need to move towards the non-conventional sources of energy like solar, wind energy etc. These power generating systems can be used standalone or can be connected to the grid to meet the increasing load demand [1]. The power quality issues which includes the voltage sag, voltage swell, harmonic distortion, transients, frequency variations, multiple notches, voltage flicker etc. are the sensitive energy sources in grid connected renewable energy sources. [2]. And thus, due to the power quality issues, the grid will experience loss of generation which may cause grid instability. One of the major issues of power quality issues, harmonic distortion is caused by non-linear loads connected to the electrical power system possess a major challenge [3]. A harmonic is a voltage or current at a multiple of the fundamental frequency of the system, produced by the action of non-linear loads such as rectifiers, discharge lighting, or saturated magnetic devices. The harmonic current flowing through the power system will cause power loss in transmission lines and reduces its usable load capacity. Harmonic frequencies in the power grid are a frequent cause of power quality problems. Harmonics in power systems result in increased heating in the equipment and conductors, misfiring in variable speed drives, and torque pulsations in motors. Nowadays, the use of grid connected Photovoltaic (PV) commutated inverters. Systems has become popular in many parts of the world. A large number of grid connected PV generators connected to a distribution network through PV inverters are potentially able to cause harmonic problems. In general, a harmonic problem can be defined as a particular disturbance, which is created by the presence of non-linear components in the electrical system that determines a permanent modification of the voltage and current sinusoidal wave shapes in terms of sinusoidal components at fundamental. In this study, using real data and a simulation program on a computer, harmonic problems in grid connected PV systems have been investigated. In a grid-interconnected photovoltaic power system, the direct current (DC) output power of the photovoltaic array should be converted into the alternating current (AC) power of the utility power system by the use of power diodes which generates harmonics [4]. FACTS controllers are used for the dynamic control of voltage, impedance and phase angle of high voltage AC transmission lines [5]. Power Quality is discussed in the later part of report in Literature review related to the PV system Connected to grid and use of various FACTS devices for improving the Power Quality. Also review of various techniques and methods as suggested by different papers related to PV system Connected to Grid.

1.1 Problems related to Power Quality in Grid Connected System

Power quality, involves sinusoidal voltage and current of rated frequency. 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) [6]. An electrical device (or load) may malfunction, fail prematurely or not operate at all. Due to Power Quality issue low power quality leads to number of consequences such as

- Higher energy usage
- Higher maintenance costs
- Equipment instability and failure
- Overheating of machines
- Damage to sensitive equipments
- Increased distribution losses

- Electronic communication interference

1.1.1 HOW CAN POWER QUALITY BE ADDRESSED?

As mentioned above, power quality issues fall generally into three broad categories.

- Harmonic voltages and currents – are introduced by a range of common electrical devices which distorts the AC wave form and increases power usage. By introducing harmonic filters or reactors the harmonics are eliminated and the result is more efficient power usage and cost savings.
- Poor power factor – refers to an excess of reactive power in the system. This reactive power does not perform any real work and as such is wasteful and costly. Power Factor Correction (PFC) reduces and can almost eliminate this reactive power, reduce energy costs and stop equipment overheating, nuisance tripping and motor failure.
- Voltage instability – is in part a side effect of the high or low voltage electricity supply from the network. High voltage does not increase equipment power and is detrimental to equipment performance and longevity, and low voltage can cause brown outs and reduced productivity. Voltage optimization ensures the voltage supplied to the system is stable as required by the equipment on site.

1.2 Objective of Project

The objective of project was to study the Power Quality and its related Issues when connected to Grid and implementing on hardware to reduce power quality problems to obtain smooth sinusoidal current and voltage waveforms as much as possible. This project also contains a MATLAB based Simulation of PV System connected to Grid and by using harmonic filters harmonics in the output waveform has been reduced to obtain a sinusoidal waveform.

1.3 Methodology

The MATLAB program consist of PV array with MPPT boost converter with inverter control technique and connected to grid. Using the harmonic filters double tuned harmonic filter, which are used to filter lowest order harmonics such as 5th, 7th, 11th, 13th and class c type high pass harmonic filters is used to provide reactive power and avoid parallel resonances. It also allows filtering low-order harmonics (such as 3rd), while keeping zero losses at fundamental frequency. By selecting multiple random values on the basis of observation through MATLAB program.

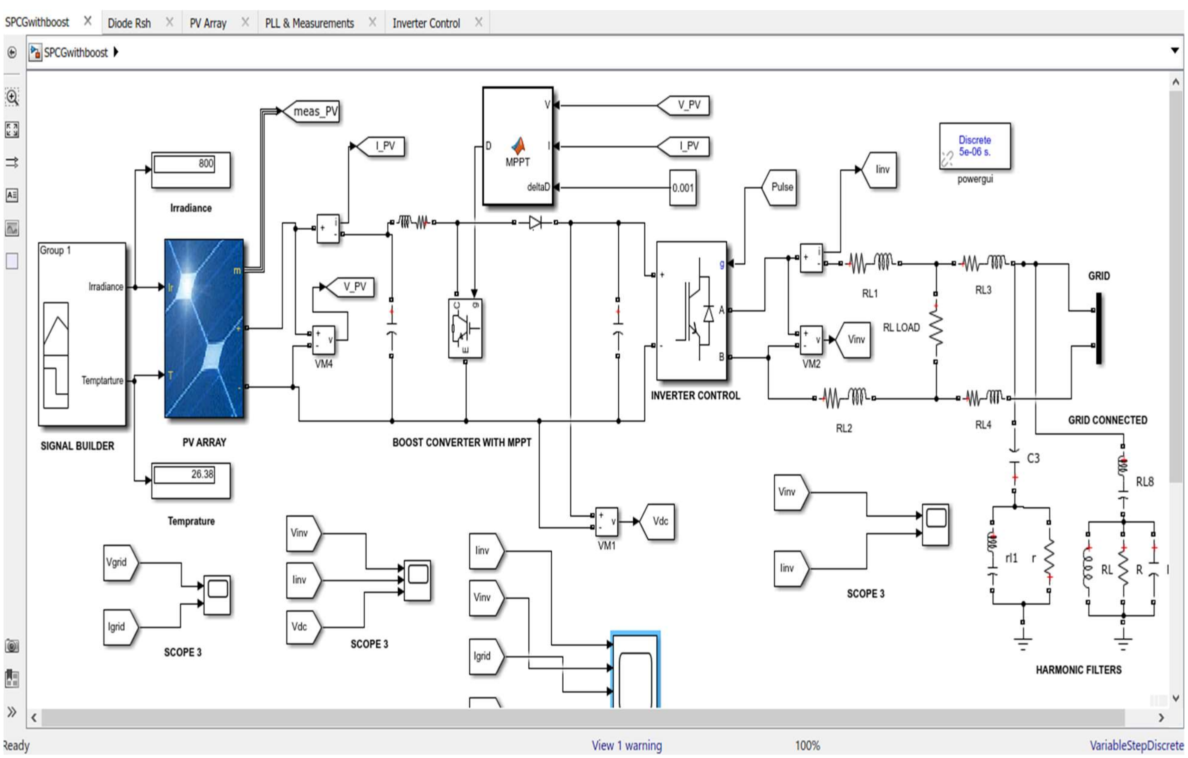


Fig:1 MATLAB Simulink model of PV System Connected to grid

CHAPTER 2

Literature Review

2.1 Energy resources

Energy is the key influencing factor for development in all sectors i.e., Industrial, Commercial, Agriculture, Domestic, etc. as per capita, energy consumption is one of the indicators of national development status. Per capita, energy consumption is about 600 units in our country, whereas it is 1400 units in China, 6898 units in Germany, 13,000 units in the U.S.A. The world average is about 2430 units.

India is the third largest Country in the world in terms of generation and consumption levels. India's energy consumption is expected to grow 4.2 percent per year for the next two decades, overtaking China as the world's largest energy growth market before 2030. In anticipation of rising demand, the Government of India announced several energy initiatives aimed at building power generation capacity, promoting energy efficiency, and increasing clean energy sources in the overall power mix. Currently, India has an installed power generation capacity of 344 gigawatts (GW), making it the fifth largest producer in the world. Coal continues to dominate the energy.

Table 1.1 Percentage of Power Generation through Various sources[2]

Source	**As of March 2016 (GW)**	**As of March 2017 (GW)**	**As of March 2018 (GW)**	**Percentage of the energy mix**
Coal	185.4	192.16	196.95	57%
Gas	24.50	25.33	24.89	7%
Diesel	0.90	0.84	0.83	<1%
Nuclear	5.78	6.78	6.78	2%
Hydro	42.78	44.48	45.40	13%

Renewable	45.92	57.24	69.02	20%
total	305.88	326.83	343.85	100%

mix, but its share is declining as natural gas and renewable energy sources increase their percentage share. India's total installed capacity by various power sources (in GW) is given in Table 1.1

2.2 Renewable Energy

In 2015, the Government of India announced plans to add 175 GW of renewable energy capacity by 2022, to include 100 GW of solar power, 60 GW of wind power, 10 GW of biomass, and five GW of small hydropower. The contribution of various renewable sources in total generation capacity of India is given in Table 1.2

Renewable energy mix(by source)	**As of March 2016 (MW)**	**As of March 2017 (MW)**	**As of March 2018 (MW)**	**The target for,2022 (GW)**
Wind power	26.77	32.280	34046	60
Solar power	6.763	12289	21651	100
Biomass power	8019	8182	8700	10
Small hydro	4.273	4334	4485	5
Waste to energy	91	114	138	NONE
Total	45.924	57244	69022	

2.3 Power Quality

Electric power quality [3], or simply power quality, involves voltage, frequency, and waveform. Good power quality can be defined as a steady supply voltage that stays within the prescribed range, steady a.c. 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 generation (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.

2.4 Brief Introduction to Power Quality Issues

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
- Transient voltages and currents
- Harmonic content in the waveforms for AC power

Today contribution PV power to the grid is increasing at a very fast rate. In grid connected PV system the grid voltage drops during fault in the grid. In order to protect inverters, the PV system voltages drops even more and this creates a huge trouble in the recovery of grid at such low voltages. Hence modification in PV control is necessary.

2.5 POWER QUALITY DEVIATION IN 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.
- "Under voltage" occurs when the nominal voltage drops below 90% for more than 1 minute.[4] 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]

2.6 Power quality deviation in Frequency

- Variations in the frequency.
- Variations in the wave shape – usually described as harmonics at lower frequencies (usually less than 3 kHz) and described as Common Mode Distortion or Interharmonics at higher frequencies.
- Nonzero low-frequency impedance (when a load draws more power, the voltage drops).
- 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).

- 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.

2.7 Power quality deviation in Wave Form

- 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.

2.8 Power Quality Issues

Following are some major PQ issues in a modern power system:

2.8.1 VOLTAGE SAG (OR DIP)

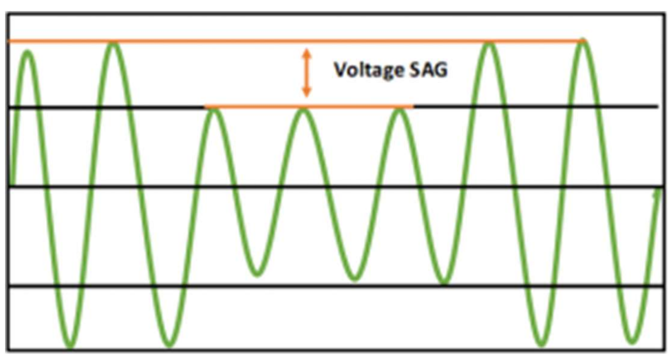


Fig:2Voltage Sag

Description: A decrease of the normal voltage level between **10% and 90%** of the nominal rms voltage at the power frequency, for durations of 0,5 cycle to 1 minute.

Causes: Faults on the transmission or distribution network (most of the times on parallel feeders). Faults in consumer's installation. Connection of heavy loads and start-up of large motors.

Consequences: Malfunction of information technology equipment, namely microprocessor-based control systems (PCs, PLCs, ASDs, etc) that may lead to a process stoppage. Tripping of contactors and electromechanical relays. Disconnection and loss of efficiency in electric rotating machines.

2.8.2 VERY SHORT INTERRUPTIONS

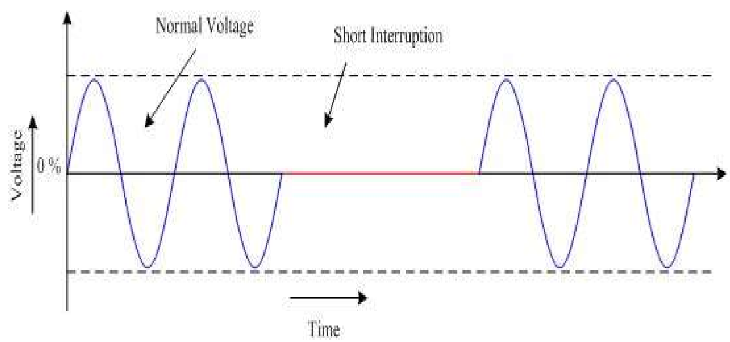


Fig:3 Very short interruptions

Description: Total interruption of electrical supply for duration from few milliseconds to one or two seconds.

Causes: Mainly due to the opening and automatic reclosure of protection devices to decommission a faulty section of the network. The main fault causes are insulation failure, lightning and insulator flashover.

Consequences: Tripping of protection devices, loss of information and malfunction of data processing equipment. Stoppage of sensitive equipment, such as ASDs, PCs, PLCs, if they're not prepared to deal with this situation.

2.8.3 LONG INTERRUPTIONS

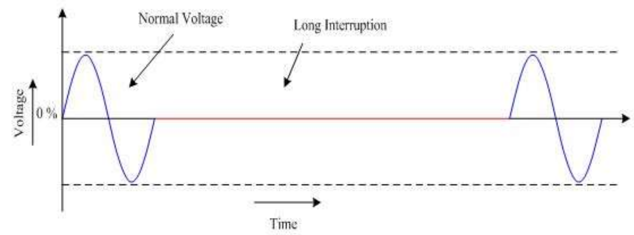


Fig:4 Long interruptions

Description: Total interruption of electrical supply for duration greater than 1 to 2 seconds

Causes: Equipment failure in the power system network, storms and objects (trees, cars, etc) striking lines or poles, fire, human error, bad coordination or failure of protection devices.

Consequences: Stoppage of all equipment.

2.8.4 VOLTAGE SPIKE

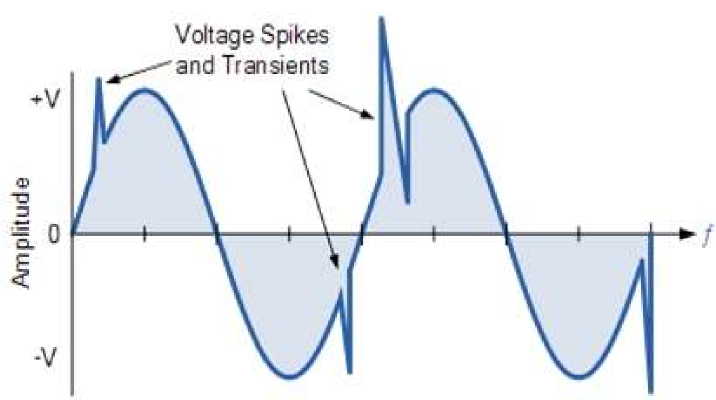


Fig :5 Voltage spike

Description: Very fast variation of the voltage value for durations from a several microseconds to few milliseconds. These variations may reach thousands of volts, even in low voltage.

Causes: Lightning, switching of lines or power factor correction capacitors, disconnection of heavy loads.

Consequences: Destruction of components (particularly electronic components) and of insulation materials, data processing errors or data loss, electromagnetic interference.

2.8.5 VOLTAGE SWELL

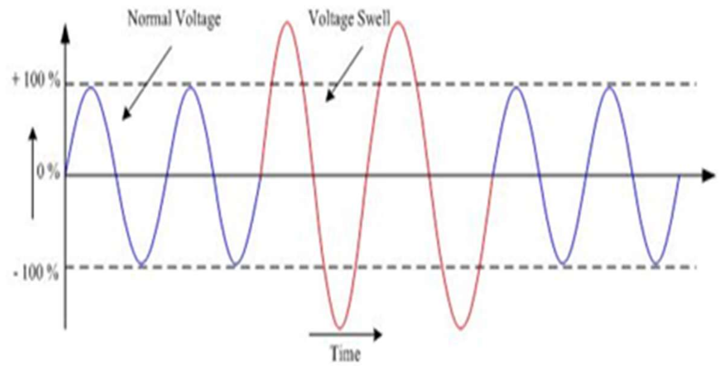


Fig:6 (Voltage swell)

Description: Momentary increase of the voltage, at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few seconds.

Causes: Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers (mainly during off-peak hours).

Consequences: Data loss, flickering of lighting and screens, stoppage or damage of sensitive equipment, if the voltage values are too high.

2.8.6 Harmonic distortion

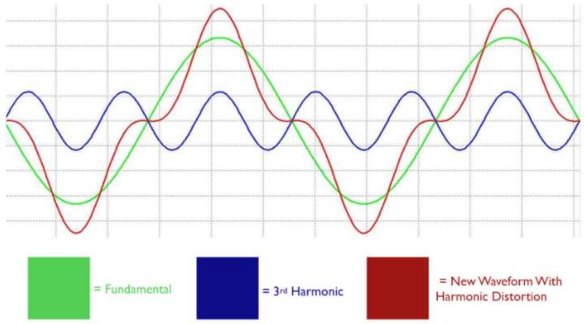


Fig:7Harmonic distortion

Description: Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to the sum of different sine-waves with different magnitude and phase, having frequencies that are multiples of power-system frequency.

Causes: Classic sources: electric machines working above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers, and DC brush motors.

Modern sources: all non-linear loads, such as power electronics equipment including ASDs, switched mode power supplies, data processing equipment, high efficiency lighting.

Consequences: Increased probability in occurrence of resonance, neutral overload in 3-phase systems, overheating of all cables and equipment, loss of efficiency in electric machines, electromagnetic interference with communication systems, errors in measures when using average reading meters, nuisance tripping of thermal protections.

2.8.7 Voltage fluctuation

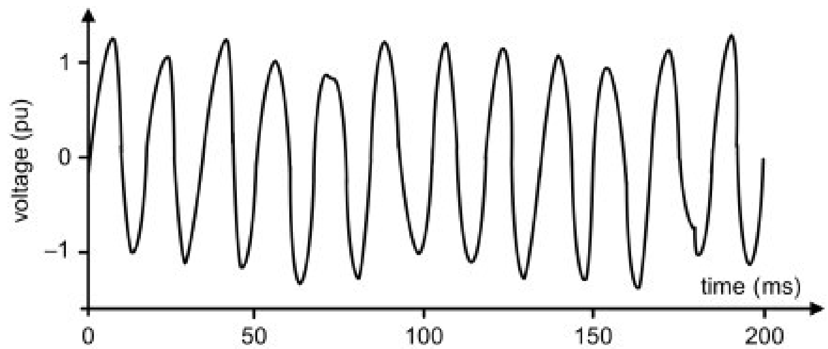


Fig: 8Voltage fluctuation

Description: Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz.

Causes: Arc furnaces, frequent start/stop of electric motors (for instance elevators), oscillating loads.

Consequences: Most consequences are common to undervoltages. The most perceptible consequence is the flickering of lighting and screens, giving the impression of unsteadiness of visual perception.

2.8.8 Noise

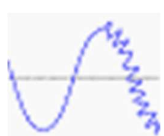


Fig:6 Noise

Description: Superimposing of high frequency signals on the waveform of the power-system frequency.

Causes: Electromagnetic interferences provoked by Hertzian waves such as microwaves, television diffusion, and radiation due to welding machines, arc furnaces, and electronic equipment. Improper grounding may also be a cause.

Consequences: Disturbances on sensitive electronic equipment, usually not destructive. May cause data loss and data processing errors.

2.8.9 VOLTAGE UNBALANCE

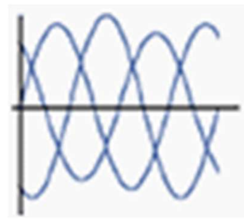


Fig: 7 Voltage Unbalance

Description: A voltage variation in a three-phase system in which the three voltage magnitudes or the phase-angle differences between them are not equal.
Causes: Large single-phase loads (induction furnaces, traction loads), incorrect distribution of all single-phase loads by the three phases of the system (this may be also due to a fault).
Consequences: Unbalanced systems imply the existence of a negative sequence that is harmful to all three- phase loads. The most affected loads are three-phase induction machines.

2.9 POWER QUALITY IMPROVEMENT

Power quality, involves sinusoidal voltage and current of rated frequency. 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) [6]. An electrical device (or load) may malfunction, fail prematurely or not operate at all. Due to Power Quality issue low power quality leads to number of consequences.

2.9.1 INTRODUCTION TO FACTS DEVICES

Flexible Ac Transmission System (FACTS), is recently emerged as a critical component in power system controllers due to advancement in area of power electronics. These devices such as SVC, STATCOM, SSSC etc. are able to act in a very fast manner for controlling the network condition due to this reason FACTS devices is being used to mitigate the power quality issues like voltage sag, swell, harmonics etc. of the connected system [6]. Some critical FACTS devices are introduced below.

- **Static VAR Compensator (SVC)**

  Fig. 1 shows the circuit configuration of a SVC. It is controllable device that is used to control voltage at the particular bus to improve the voltage profile of the system. It provides reactive power support to the connected bus. By proper controlling reactive VARs, the voltage at a particular bus is maintained at its rated value. The compensation is achieved by controlling the firing angle of the thyristors as per requirement [7]. In shunt compensation, SVCs have a key role which improves steady state and transient voltage dynamics. Its performance is much better than fixed shunt compensation. Beside voltage control, SVCs are also used to damp power swings, reduce system losses and improve transient stability by optimized reactive power control. The reactance which is variable is given by Eq. (1)

$$B_{SVC} = \frac{X_L - \left(\frac{X_C}{\pi}\right)(2(\pi - \alpha) + \mathrm{Sin}2\alpha)}{X_C X_L} \quad (1)$$

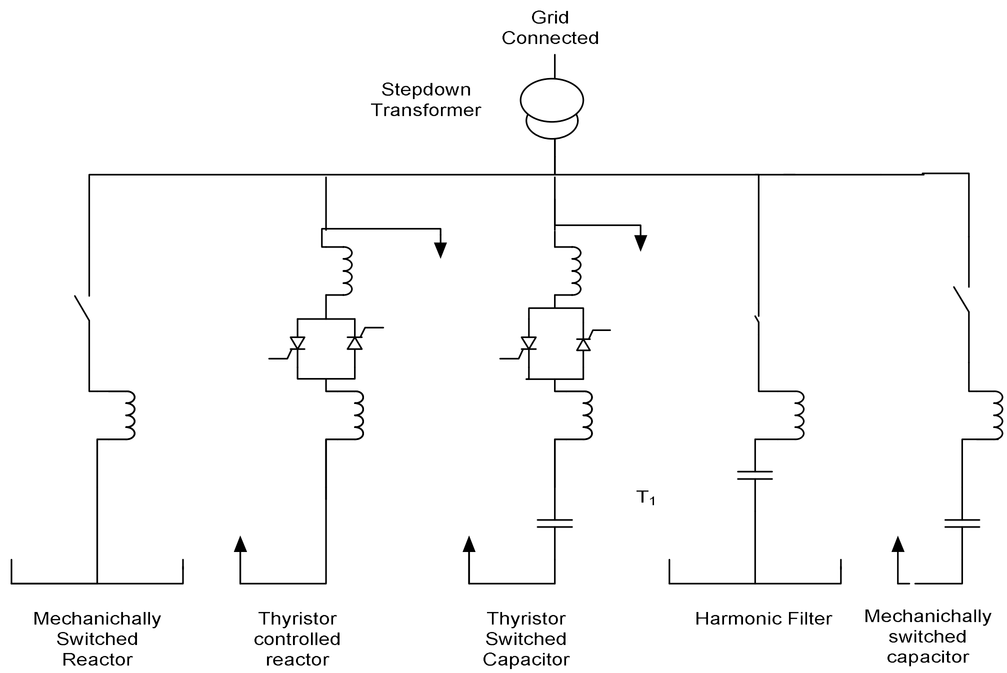


Fig : 8 SVC

❖ Thyristor Controlled Series Capacitor (TCSC)

Fig. 2 shows the circuit configuration of a TCSC. A TCSC is also an important FACTS device. It is used with long transmission lines for controlling the line reactance in modern power systems. TCSCs perform various functions such as power flow control, system losses reduction, lowering of unsymmetrical components, short-circuit currents reduction, provide voltage support at a particular bus. TCSC also play critical role for mitigating Sub Synchronous Resonance (SSR), damping power oscillation and enhancing transient stability of the connected power system [8].

$$X_{TCSC} = \frac{X_C X_L(\alpha)}{X_L(\alpha) - X_C} \qquad (1)$$

where, $X_{SVC} = \frac{1}{jB_{SVC}}$

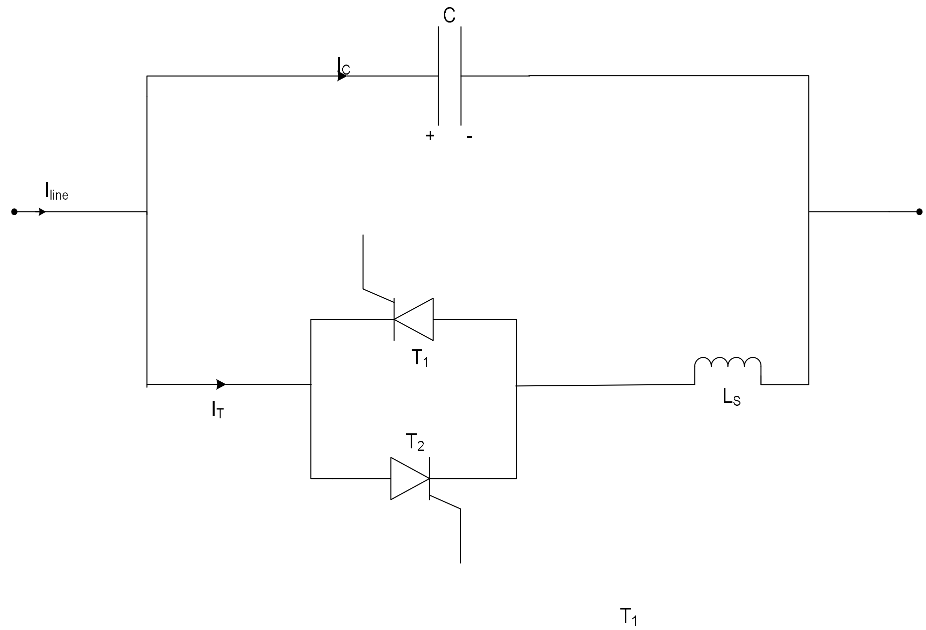


Fig.9 Thyristor Control Series Capacitor (TCSC)

- **Static Compensator (STATCOM)**

  Fig. 3 shows circuit configuration of STATCOM. Static Compensator or STATCOM is a power electronic device. It uses switching devices such as IGBT, GTO etc., which can be gate commuted. The main function of STSTCOM is to control the reactive power flow in a power network and thereby increasing the stability of power network. STATCOM is basically shunt connected device. STATCOM is also termed as Static Synchronous Condenser (STATCON). It is also an important member of the Flexible AC Transmission System (FACTS) [9].

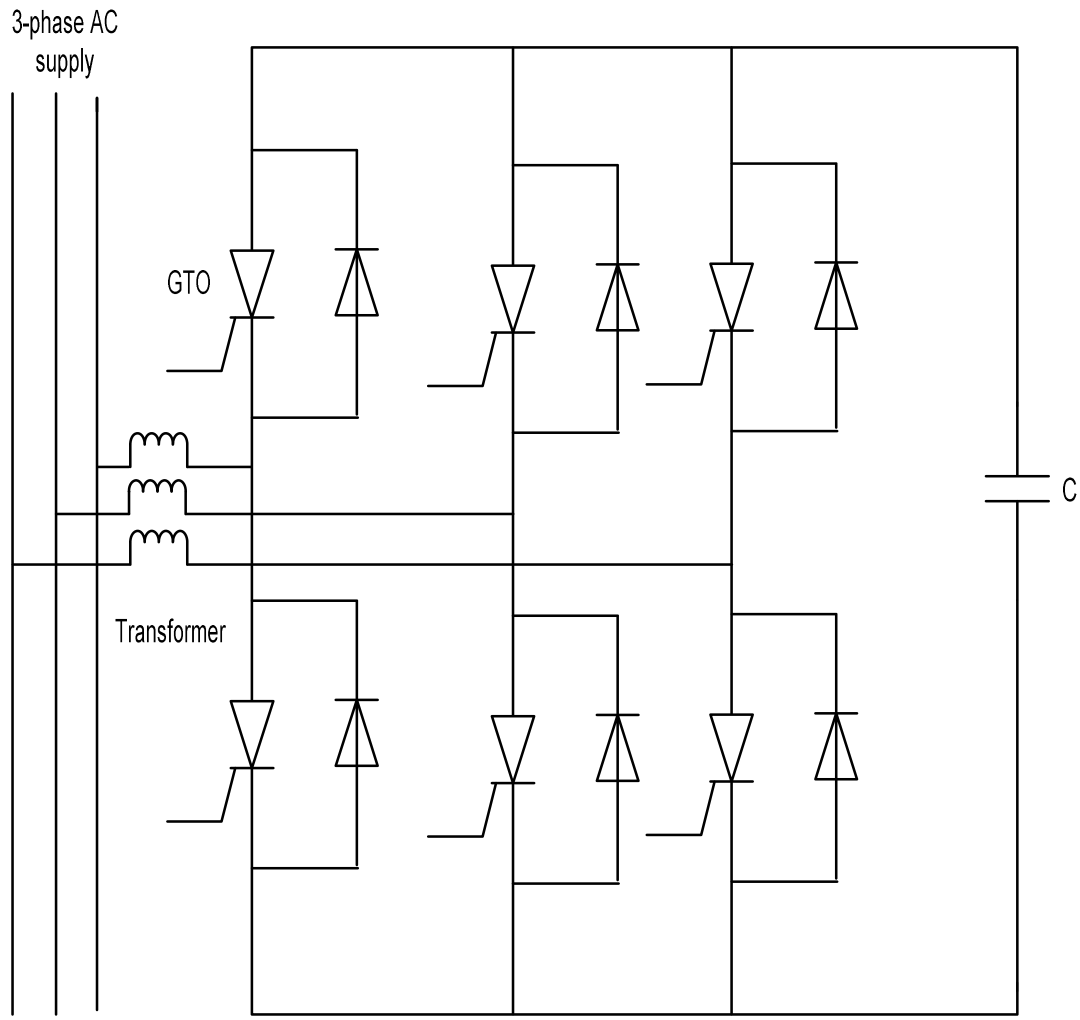


Fig.10 Static Compensator (STATCOM)

❖ **Static Synchronous Series Compensator (SSSC)**

Fig. 4 shows the circuit configuration of SSSC. It is one of the newest FACT device used for series compensation of power transmission system. In the modelling it is shown as a synchronous voltage source because it can generate voltage synchronous to the connected system and also injects this variable magnitude sinusoidal voltage of proper frequency and controllable phase angle, in series with a transmission

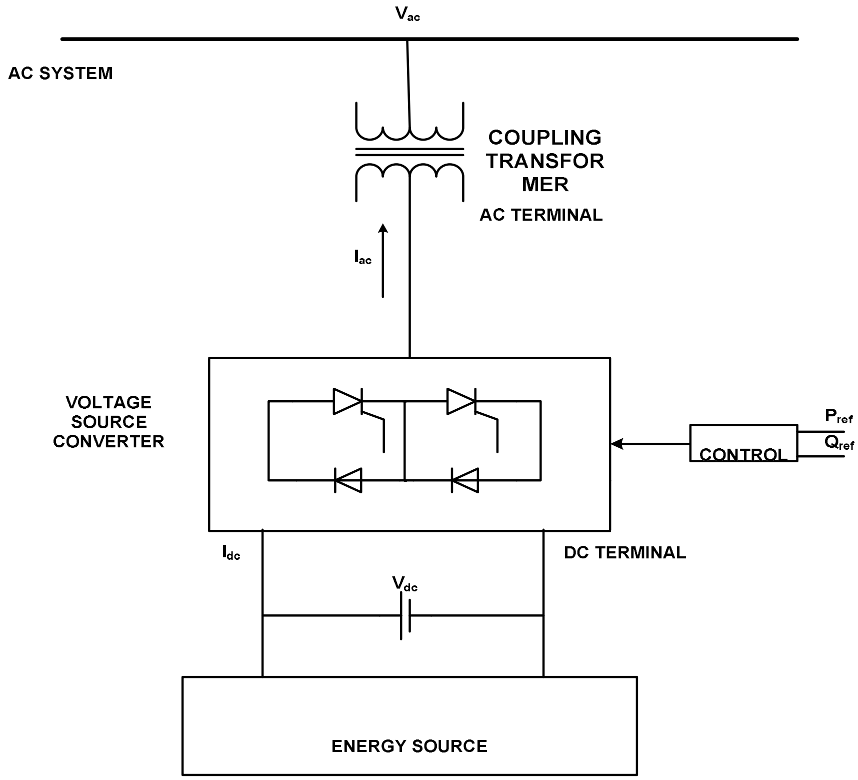


Fig.11 Static Synchronous Series compensator

- **Unified Power Flow Controller (UPFC)**

  Line voltage is injected in phase quadrature with the line current to boost the transmission line voltage. The effect of inserting an inductive or capacitive reactance is realized by injected phase voltage at different phase angle w.r.t line current of the transmission line. There are losses in the inverter because of high switching speed in the SSSC. Thus a small part of injected voltage is made in phase with the transmission line current. The variable reactance thus obtained is used to change dynamically the transmission line reactance which affects the transmission line power flow.

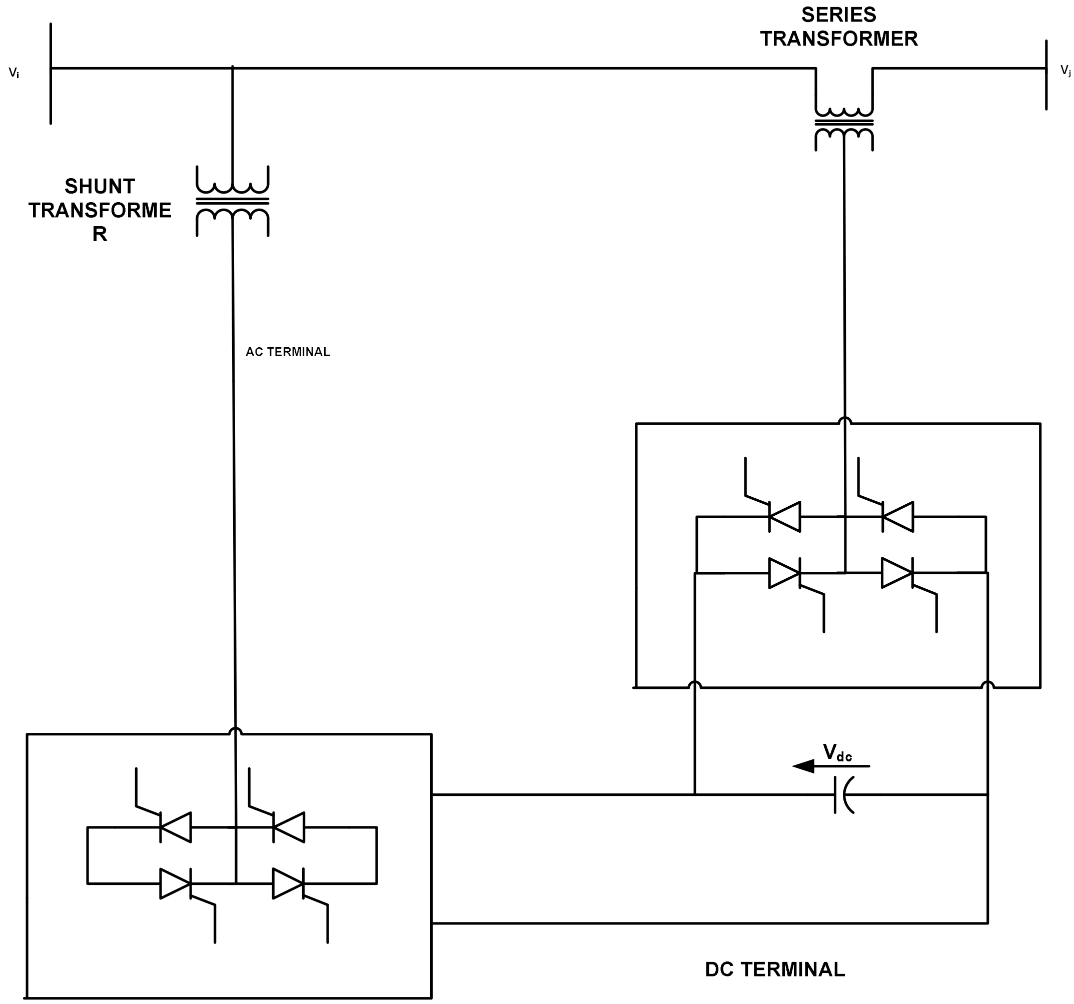


Fig.12 Unified Power Flow Controller (UPFC)

❖ 2.5 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.[8] This data, however, is not always sufficient to determine the exact nature of problems.

2.10 STABILITY AND POWER QUALTY IMPROVEMENT IN GRID CONNECTED PV SYSYTEM

In three phase modified dual stage inverter is used for integrating PV and grid System. The technique mainly focuses on series resonant three phase isolated DC- DC converter in a dual stage inverter. Approximately 96 - 97.5 % efficiency is measured for the DC-DC stage. In this paper it is shown that inverter is responsible for MPPT as well as grid current.

Stability control of dispatch able grid-connected PV System is studied in paper [8]. This paper focuses on requirement of energy storage for improving power quality of system for improving power quality of system. Effect of voltage variation in solar plants due to factors like low sunlight during cloudy days, snowy days, during nights.

Effect of shadow for different configuration of PV System connected to Grid and model is discussed in this paper. Different PV array configuration was used on a three-phase two-stage system for deducing shadow effect on PV. Total cross Tied

(TCT) was better than the SP configuration and the efficiency was increased approximately 4% in TCT configuration.

The Importance of cleaning of PV panels in desert environment for Grid-Connected PV Systems is shown in this Paper. The efficiency of the PV system is analyzed in dusty or desert climatic condition. This paper shows the effect of loss of energy generated by dust deposition on the solar panel.

The new system designed has low cost and more efficiency. Cost of grid connected PV system having battery energy storage system. The smart grid explained in the paper [9] integrates all the major components such as main grid, renewable energy generation, Battery system and load side management with the help of communication technology, control system and electronic sensors etc.

A Grid Connected PV system and a three-level control scheme of a single-phase power system is analysed in [10]. The maximum power point tracker is modelled in presence of irradiance and temperature variation. The voltage source inverter is able to maintain constant voltage and filter out ripples in output voltage of PV system. For this a simple PI control algorithm is used. The load is shared among PV and grid as the output from PV is varied due to environmental effects. System is also tested for different loading conditions and grid and PV both are analysed for amount of load shared.

The reactive power control in presence of PV is also a major challenge in the modern power system. This Paper address the above problem and envisage the solution. It also focuses to improve the voltage profile and the stability in grid connected PV system.

CHAPTER 3

PV System

3.1 PV module and PV Array

3.1.1 PV module :

A unit comprised of several PV cells, and the principal unit of a PV array; it is intended to generate direct current power under un-concentrated sunlight.

The term solar panel is used colloquially for a photo-voltaic (PV) module [11]. A PV module is an assembly of photo-voltaic cells mounted in a frame work for installation. Photo-voltaic cells use sunlight as a source of energy and generate direct current electricity. A collection of PV modules is called a PV Panel, and a system of Panels is an Array. Arrays of a photovoltaic system supply solar electricity to electrical equipment. The most common application of solar energy collection outside agriculture is solar water heating systems.

3.1.2 Basics of Solar Cell :

Solar energy is the ultimate source of energy, which is naturally replenished in a short period of time, for this reason it is called "renewable energy" or "sustainable energy" source. To take advantages of solar energy, the variety of technologies is used to covert solar energy to heat and electricity. The use of solar energy involves 'energy conservation' because it is the way to use energy source that comes from the nature and uses it more wisely and efficiently. That way includes Solar Cell, which is described as follows:

3.1.3 What is Solar Cell :

Solar Cell or Photovoltaic (PV) cell is a device that is made up of semiconductor materials such as silicon, gallium arsenide and cadmium telluride, etc. that converts sunlight directly into electricity. When solar cells absorb sunlight, free electrons and holes are created at positive/negative junctions. If the positive and negative junctions of solar cell are connected to DC electrical equipment, current is delivered to operate the electrical equipment.

3.1.3Solar cell types:

There are three major cell types that classified by its manufacturing technology and the semiconductor.

1. Crystalline Silicon PV Module: Two types of crystalline silicon are used to produce PV module; single crystalline silicon or known as mono-crystalline silicon and multi-crystalline silicon, also called polycrystalline silicon. The polycrystalline silicon PV module has lower conversion efficiency than single crystalline silicon PV module but both of them have high conversion efficiencies that average about 10-12%.

2. Amorphous Silicon PV Module: Amorphous silicon) PV module or thin-film silicon PV module absorbs light more effectively than crystalline silicon PV module, so it can be made thinner. It suits for any applications that high efficiency is not required and low cost is important. The typical efficiency of amorphous silicon PV module is around 6%.

3. Hybrid Silicon PV Module: A combination of single crystalline silicon surrounded by thin layers of amorphous silicon provides excellent sensitivity to lower light levels or indirect light. The Hybrid silicon PV module has highest level of conversion efficiency about 17%.

3.2 Solar cell structure

The most semiconductor material currently use for solar cell production is silicon, which has some advantages as; it can be easily found in nature, does not pollute, does not harm the environment and it can be easily melted, handled and formed into mono crystalline silicon form, etc. The commonly solar cell is configured as a large-area p-n junction made from silicon.

3.2.1How solar cell works?

When sunlight strikes solar cell surface, the cell creates charge carrier as electrons and holes. The internal field produced by junction separates some of positive charges (holes) from negative charges (electrons). Holes are swept into positive or p-layer and electrons are swept into negative or n-layer. When a circuit is made, free electrons have to pass through the load to recombine with positive holes; current can be produced from the cells under illumination.

The individual solar cells are connected together to make a module (called 'solar module' or 'PV module') to increase current and the modules are connected in an array (called 'solar array' or 'PV array'). Depending on current or voltage requirement, solar arrays are connected in a variety of ways:

If the solar arrays are connected in parallel, the output current will increase.

If the solar arrays are connected in series, the output voltage will increase.

3.3 Solar PV system

Solar cells produce direct current (DC), therefore they are only used for DC equipments. If alternating current (AC) is needed for AC equipments or backup energy is needed, solar photovoltaic systems require other components in addition to solar modules. These components are specially designed to integrate into solar PV system, that is to say they are renewable energy products or energy conservation products and one or more of components may be included depending on type of application. The components of solar photovoltaic system are

1. Solar Module is the essential component of any solar PV system that converts sunlight directly into DC electricity.
2. Solar Charge Controller regulates voltage and current from solar arrays, charges the battery, prevents battery from overcharging and also performs controlled over discharges.
3. Battery stores current electricity that produces from solar arrays for using when sunlight is not visible, nighttime or other purposes.
4. Inverter is a critical component of any solar PV system that converts DC power output of solar arrays into AC for AC appliances.
5. Lightning protection prevents electrical equipments from damages caused by lightning or induction of high voltage surge. It is required for the large size and critical solar PV systems, which include the efficient grounding.

3.4 Solar cell advantages :

Solar cell or PV cell produces clean with non-polluting energy source of electricity that is environmental-friendly. Since it uses no fuel other than sunlight, gives off no waste, no burning, and no moving part when it operates. It reduces collection of gases such as carbon monoxide, sulphur dioxide, hydrocarbon and nitrogen, etc., which generated from fuel, coal and fossil fuel burning power plants. All decrease the impacts of energy on the environment like greenhouse effect, global warming, acid rain and air pollution, etc. It is easy to install and transportable. With the modular characteristic, it can be constructed any sizes as required. Moreover, it requires minimal maintenance and has long life span (more than 30 years) and stable efficiency.

Solar cell applications :

1) Home Indoor and outdoor lighting system, electrical equipment, electric gate opener, security system, ventilator, water pump, water filter and emergency light, etc.

2) Lighting system Bus stop lighting, telephone booth lighting, billboard lighting, parking lot lighting, indoor and outdoor lighting and street lighting, etc.

3) Water pumping Consumption, public utility, livestock watering, agriculture, gardening and farming, mining and irrigation, etc.

4) Battery charging system Emergency power system, battery charging centre for rural village and power supply for household use and lighting in remote area, etc.

5) Agriculture Water pumping, agricultural products fumigator, thrashing machines and water sprayer, etc.

6) Cattle Water pumping, oxygen filling system for fish-farming and insect trapped lighting, etc.

7) Health centre Refrigerator and cool box for keeping medicines and vaccines and medical equipment, etc.

8) Communication Air navigational aid, air warning light, lighthouse, beacon navigation aid, illuminated road sign, railway crossing sign, street lighting and emergency telephone, etc.

9) Telecommunication Microwave repeater station, telecommunication equipment, portable communication equipment (e.g. communication radio for service and military exercise) and weather monitoring station, etc.

10) Remote area Hill, island, forest and remote area that the utility grids are not available, etc.

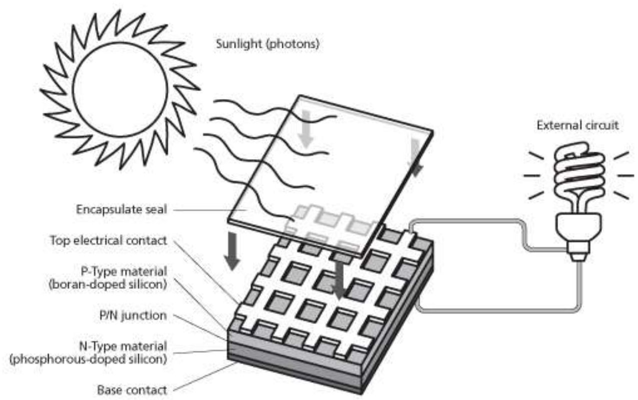


FIG:13 PV panel

3.5 How to Design Solar PV System:

3.5.1Major system components

Solar PV system includes different components that should be selected according to your system type, site location and applications. The major components for solar PV system are solar charge controller, inverter, battery bank, auxiliary energy sources and loads (appliances).

- PV module: converts sunlight into DC electricity.
- Solar charge controller: regulates the voltage and current coming from the PV panels going to battery and prevents battery overcharging and prolongs the battery life.

- Inverter: converts DC output of PV panels or wind turbine into a clean AC current for AC
    - appliances or fed back into grid line.
- Battery: stores energy for supplying to electrical appliances when there is a demand.
- Load is electrical appliances that connected to solar PV system such as lights, radio, TV, computer refrigerator, etc.
- Auxiliary energy sources - is diesel generator or other renewable energy sources

3.5 What is MPPT:

MPPT or Maximum Power Point Tracking is algorithm that included in charge controllers used for extracting maximum available power from PV module under certain conditions. The voltage at which PV module can produce maximum power is called �maximum power point� (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature.

Typical PV module produces power with maximum power voltage of around 17 V when measured at a cell temperature of 25°C, it can drop to around 15 V on a very hot day and it can also rise to 18 V on a very cold day.

3.5.1How MPPT works:

The major principle of MPPT is to extract the maximum available power from PV module by making them operate at the most efficient voltage (maximum power point). That is to say:

MPPT [12] checks output of PV module, compares it to battery voltage then fixes what is the best power that PV module can produce to charge the battery and converts it to the best voltage to get maximum current into battery. It can also supply power to a DC load, which is connected directly to the battery.

MPPT is most effective under these conditions:

- Cold weather, cloudy or hazy days: Normally, PV module works better at cold temperatures and MPPT is utilised to extract maximum power available from them.

- When battery is deeply discharged: MPPT can extract more current and charge the battery if the state of charge in the battery is lowers.

MPPT solar charge controller:

A MPPT solar charge controller is the charge controller embedded with MPPT algorithm to maximises the amount of current going into the battery from PV module.

MPPT is DC to DC converter which operates by taking DC input from PV module, changing it to AC and converting it back to a different DC voltage and current to exactly match the PV module to the battery.

Basics of Maximum Power Point Tracking (MPPT) Solar Charge Controller

Examples of DC to DC converter are

- Boost converter is power converter which DC input voltage is less than DC output voltage. That means PV input voltage is less than the battery voltage in system.

- Buck converter is power converter which DC input voltage is greater than DC output voltage. That means PV input voltage is greater than the battery voltage in system.

MPPT algorithm can be applied to both of them depending on system design. Normally, for battery system voltage is equal or less than 48 V, buck converter is useful. On the other hand, if battery system voltage is greater than 48 V, boost converter should be chosen.

MPPT solar charge controllers are useful for off-grid solar power systems such as stand-alone solar power system, solar home system and solar water pump system, etc.

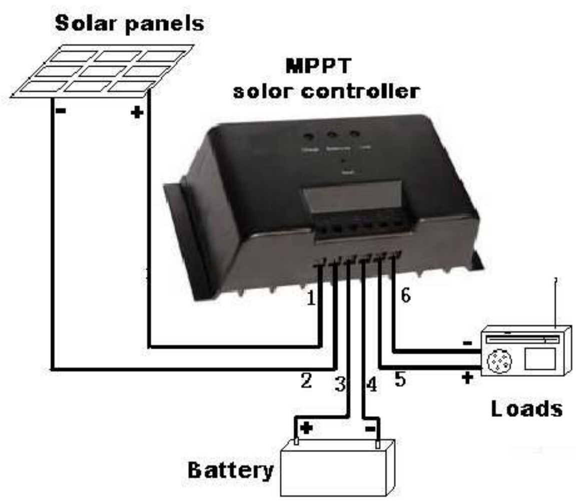


Fig: 14 PV MPPT

Main features of MPPT solar charge controller:

- ❖ In any applications which PV module is energy source, MPPT solar charge controller is used to correct for detecting the variations in the current-voltage characteristics of solar cell and shown by I-V curve.

- ❖ MPPT solar charge controller is necessary for any solar power systems need to extract maximum power from PV module; it forces PV module to operate at voltage close to maximum power point to draw maximum available power.
- ❖ MPPT solar charge controller allows users to use PV module with a higher voltage output than operating voltage of battery system.

For example, if PV module has to be placed far away from charge controller and battery, its wire size must be very large to reduce voltage drop. With a MPPT solar charge controller, users can wire PV module for 24 or 48 V (depending on charge controller and PV modules) and bring power into 12 or 24 V battery system. This means it reduces the wire size needed while retaining full output of PV module.

- MPPT solar charge controller reduces complexity of system while output of system is high efficiency. Additionally, it can be applied to use with more energy sources. Since PV output power is used to control DC-DC converter directly.
- MPPT solar charge controller can be applied to other renewable energy sources such as small water turbines, wind-power turbines, etc.

3.5.2 MPPT Algorithm Used:

```
function D = MPPT( V,I,deltaD)

Dref_init = 0.1;
Dmin = 0;
D_max = 150;

persistent Vold Pold Dref_old;

if isempty(Vold)
    Vold=0;
    Pold=0;
    Dref_old=Dref_init;
end
P=V*I;
dV= V - Vold;
dP= P - Pold;
D= Dref_old;

if dP ~= 0 && V>400
```

```
    if dP < 0
        if dV < 0
            D = Dref_old - deltaD;
        else
            D = Dref_old + deltaD;
        end
    else
        if dV < 0
            D = Dref_old + deltaD;
        else
             D = Dref_old - deltaD;
        end
    end
end

if D >= D_max
    D = D_max;
end
if D<Dmin
    D=Dmin;
end

Dref_old=D;
Vold=V;
Pold=P;
```

3.6 Inverter

Inverter is a critical component used in any PV system where alternative current (AC) power output is needed. It converts direct current (DC) power output from the solar arrays or wind turbine into clean AC electricity for AC appliances. Inverter can be used in many applications. In PV or solar applications, inverter may also be called solar inverter. To improve the quality of inverter's [13] power output, many topologies are incorporated in its design such as Pulse-width modulation is used in PWM inverter.

- Solar inverter - Off-grid inverter, Stand-alone inverter, Grid tie inverter,

- ❖ Hybrid inverter

3.6.1 Types of Inverter

- ❖ **Inverter for Solar electric system**

  Solar pump inverter or solar pumping inverter is designed specially for solar pumping system or solar water pump system without need of battery storage. The solar pump inverter convert DC power from PV array into AC power to drive AC induction motor of automatic pump, submersible pump, centrifugal pump, axial flow pump, etc. Solar water pump inverters is widely use for applications such as irrigation systems, livestock watering, agricultural irrigation system, etc. in remote area where the utility grid is not available.

- ❖ **Stand-alone inverter or off-grid inverter**

  It is designed for remote stand-alone application or off-grid power system with battery backup where the inverter draws its DC power from batteries charged by PV array and converts to AC power. Stand-alone inverters provide variety of size and output waveform depending on your applications. For the best output, the pure sine inverter is required. It suits for solar home system, rural electrification, village electrification in remote area where the utility grid is not available.

- ❖ **Grid connected inverter or grid tie inverter**

  It is designed specifically for grid connected application that does not require battery backup system. Grid connected inverter or grid tie inverter converts DC power produced by PV array to AC power to supply to electrical appliances and sell excess power back to utility grid. With a range of sizes available, we provide grid tie inverter to suit your needs, from small residential solar system to large commercial solar system.

- ❖ **Grid interactive inverter** is designed for residential, commercial and industry applications. The inverter can operate on both grid-tied and stand-alone off-grid operations. When utility power is normal the inverter can operate as grid tie inverter which converts DC power generated by PV panels into AC power for supplying to load and feed the excess energy back to utility grid line. When utility power is not available, the inverter can operate as backup power source to supply power from PV panels and battery. Grid interactive system provide clean, reliable backup power in the event of a utility power failure. It can reduce energy consumption and save the utility cost, while maintaining the ability to use the renewable energy source during power outage.

- **Hybrid inverter or hybrid power inverter** is designed for hybrid power system that combines solar array with diesel generator and other renewable energy sources such as wind turbine generator, hydro generator, etc. Hybrid inverter can operate as either a stand-alone inverter or a grid tie inverter. It is connected to battery bank, the utility grid lines, diesel generator and the house appliances. It suits to use for remote village electrification or remote island electrification to provide continuous reliable power at remote locations.

Inverter for Wind electric system Grid connected inverter or grid tie inverter for wind turbine is designed specifically for grid connected wind power application that does not require battery backup system. Grid connected inverter or grid tie inverter for wind turbine converts DC power produced by wind turbine generator to AC power to supply to electrical appliances and sell excess power back to utility grid. With a range of sizes available, we provide grid tie inverter to suit your needs, from small residential solar system to large commercial solar system.

3.7 PV Array

A photovoltaic array is a linked collection of photovoltaic modules, one of which is shown in the picture to the right. Each photovoltaic (PV) module is made of multiple interconnected PV cells. The cells convert solar energy into direct-current electricity.

PV modules are sometimes called solar panels, although that term better applies to solar-thermal water or air heating panels. Photovoltaic modules distinguish themselves from solar cells in that they are conveniently sized and packaged in weather-resistant housings for easy installation and deployment in residential, commercial, and industrial applications. The application and study of photovoltaic devices is known as photovoltaics.

PV cells operate via the photovoltaic effect which describes how certain materials can convert sunlight into electricity; they absorb some of the energy of the Sun and cause current to flow between two oppositely charged layers. Individual solar cells provide a relatively small amount of power, but electrical output can be significant when connected together. The cells, modules, and arrays can be connected in series or parallel, or typically a combination, to create a desired peak voltage output.

A photovoltaic array (or solar array) is a linked collection of solar panels. The modules in a PV array are usually first connected in series to obtain the desired voltage. Most PV arrays use an inverter to convert the DC power produced by the modules into alternating current that can power lights, motors, and other loads .

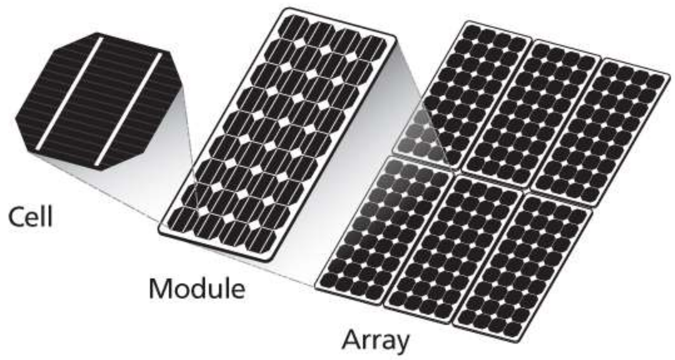


FIG:15 PV Cell

PV Array Description :

The PV Array block implements an array of photovoltaic (PV) modules. The array is built of strings of modules connected in parallel, each string consisting of modules connected in series. This block allows you to model preset PV modules from the National Renewable Energy Laboratory (NREL) System Advisor Model (2018) as well as PV modules that you define.

The PV Array block is a five-parameter model using a light-generated current source (IL), diode, series resistance (Rs), and shunt resistance (Rsh) to represent the irradiance- and temperature-dependent I-V characteristics of the modules.

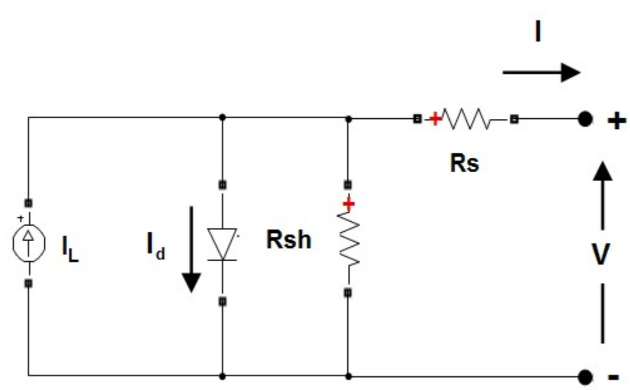


Fig:16 Circuit Diagram

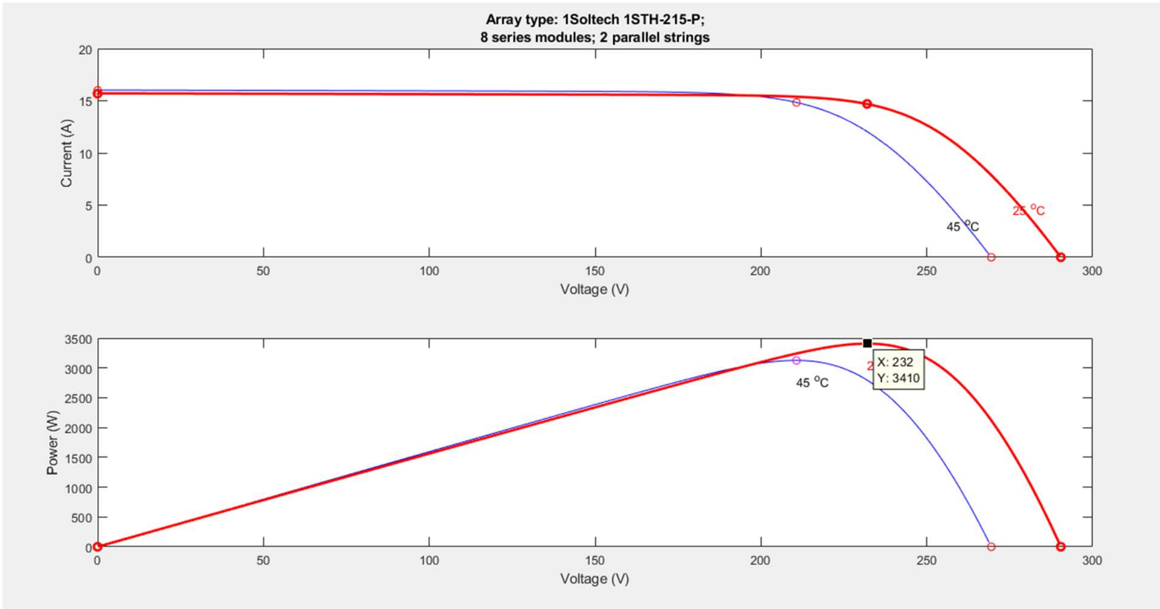


Fig:17 PV Array Output

Difference between PV Module and PV Array:

A photovoltaic module consists of multiple PV cells connected in series to provide a higher voltage output. PV modules are manufactured in standard sizes such as 36-cell, 60-cell and 72-cell modules. The term solar panel is sometimes used interchangeably with solar module. The main difference is that some solar panels models are composed of multiple modules mounted together.

A photovoltaic array is a system composed of multiple PV modules. They can be connected in one or more series circuits, which are connected to a combiner box to provide a single direct-current output. This output can be used to charge batteries, power DC loads, or fed to an inverter to provide an AC voltage for home appliances or exporting to the electric grid.

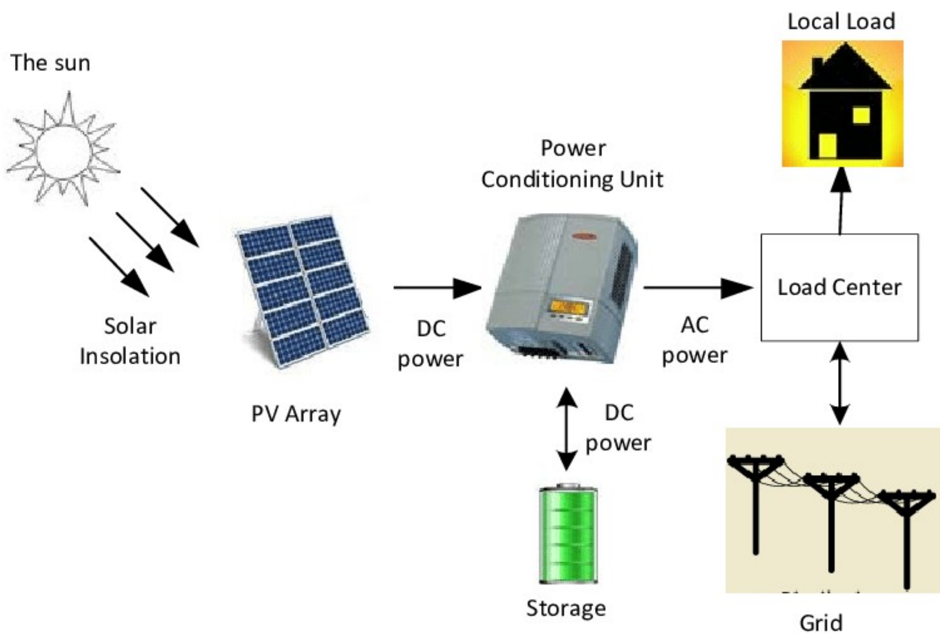


Fig:17 Block diagram of PC System Connected to grid

CHAPTER 4

HARMONIC FILTERS & STATCOM

4.1 HARMONIC FILTERS

4.1.1 Harmonics

Harmonics are unwanted higher frequencies which superimposed on the fundamental waveform creating a distorted wave pattern. Harmonics are higher frequency waveforms superimposed onto the fundamental frequency, that is the frequency of the circuit, and which are sufficient to distort its wave shape. The amount of distortion applied to the fundamental wave will depend entirely on the type, quantity and shape of the harmonics present.

Harmonics [14] have only been around in sufficient quantities over the last few decades since the introduction of electronic drives for motors, fans and pumps, power supply switching circuits such as rectifiers, power converters and thyristor power controllers as well as most non-linear electronic phase controlled loads and high frequency (energy saving) fluorescent lights. This is due mainly to the fact that the controlled current drawn by the load does not faithfully follow the sinusoidal supply waveforms as in the case of rectifiers or power semiconductor switching circuits.

Harmonics in the electrical power distribution system combine with the fundamental frequency (50Hz or 60Hz) supply to create distortion of the voltage and/or current waveforms. This distortion creates a complex waveform made up from a number of harmonic frequencies which can have an adverse effect on electrical equipment and power lines.

The amount of waveform distortion present giving a complex waveform its distinctive shape is directly related to the frequencies and magnitudes of the most dominant harmonic components whose harmonic frequency is multiples (whole integers) of the fundamental frequency. The most dominant harmonic components are the low order harmonics from 2nd to the 19th with the triples being the worst.

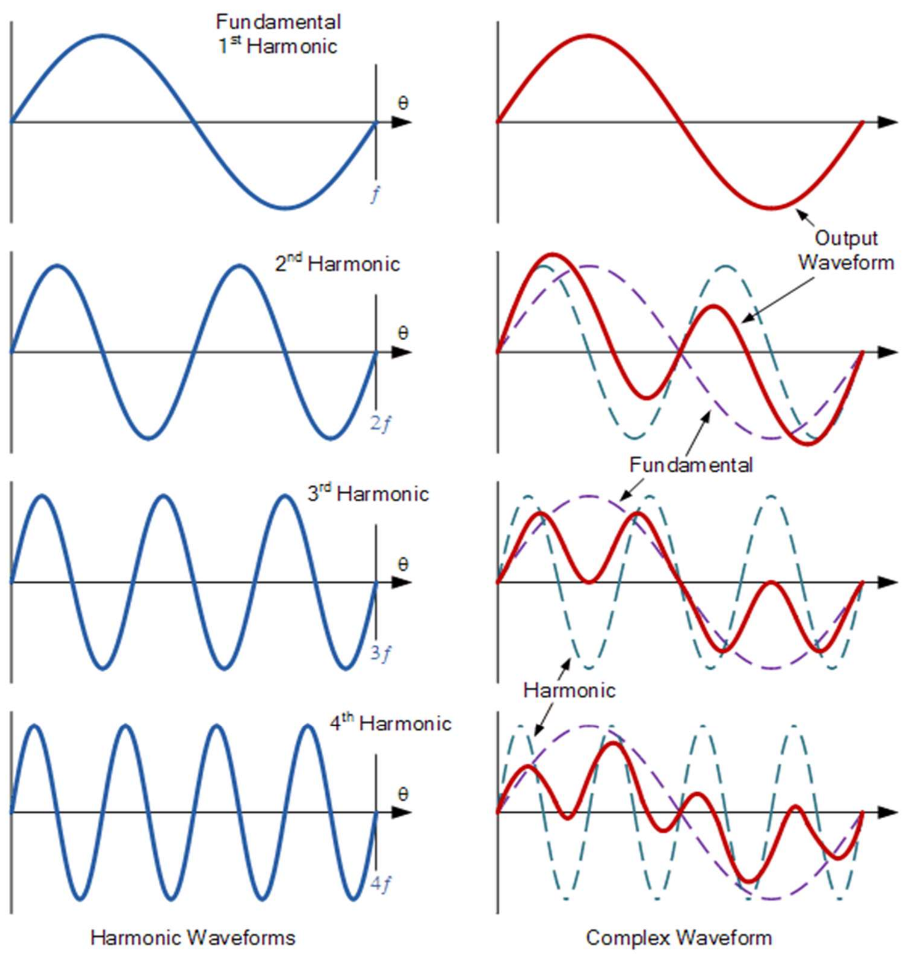


Fig:18 Harmonics

Nowadays, the use of grid connected Photovoltaic (PV) commutated inverters. Systems has become popular in many parts of the world. A large number of grid connected PV generators connected to a distribution network through PV inverters are potentially able to cause harmonic problems. In general, a harmonic problem can be defined as a particular disturbance, which is created by the presence of non-linear components in the electrical system that determines a permanent modification of the voltage and current sinusoidal wave shapes in terms of sinusoidal components at fundamental.

In this study, using real data and a simulation program on a computer, harmonic problems in grid connected PV systems have been investigated. In a grid-interconnected photovoltaic power system, the direct current (DC) output power of the photovoltaic array should be converted into the alternating current (AC) power of the utility power system by the use of power diodes which generates harmonics.

4.1.2 HARMONIC FILTERS

Harmonic filters [15] are series or parallel resonant circuits designed to shunt or block harmonic currents. They reduce the harmonic currents flowing in the power system from the source and thereby reduce the harmonic voltage distortion in the system. Such devices are expensive and should only be used when other methods to limit harmonics have also been assessed. The application of filters in a given situation is not always straightforward. The filters themselves may interact with the system or with other filters to produce initially unsuspected resonances. Hence in all but the simplest cases harmonic studies should be used to assist with the determination of the type, distribution and rating of the filter group. Classical shunt filter circuits and their associated characteristics.

The single- and double-tuned filters are usually used to filter specific frequencies, while the damped filters are used to filter a wide range of frequencies. In applications involving small harmonic producing loads, it is often possible to use one single-tuned filter (usually tuned near the fifth harmonic) to eliminate problematic harmonic currents. In large applications, like those associated with arc furnaces, multiple tuned filters and a damped filter are often used. Equivalent circuits for single- and double-tuned filters are shown in Fig. Equivalent circuits for first, second, third, and “c-type” damped filters.

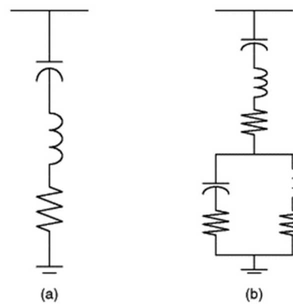


Fig:19 (a)Single tuned and (b)Class C type filter

The selectivity or tuning response of the simple single resonant frequency filter circuit is defined by its *Q* or quality factor:

$$Q = \omega L/R$$

A high *Q* factor gives good selectivity (narrow frequency response) but the filter tuned circuit may be prone to drifting in its tuned frequency owing to changes in temperature or component ageing. Since slight changes in system frequency will cause detuning a less peaky filter response with a lower *Q* factor is more desirable to accommodate these changes. The tuned resonance frequency of a series LCR circuit is given by:

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$$

The Nonlinear elements such as power electronic converters generate harmonic currents or harmonic voltages, which are injected into the power system. The resulting distorted currents flowing through the system impedance produce harmonic voltage distortion. Harmonic filters reduce distortion by diverting harmonic currents in low impedance paths. Harmonic filters are capacitive at the fundamental frequency, so they are also used for producing reactive power required by converters and for power factor correction.

To achieve an acceptable distortion, several banks of filters of different types are connected in parallel. The most commonly used filter types are:

- Band-pass filters, which are used to filter lowest order harmonics such as 5th, 7th, 11th, 13th. Band-pass filters can be tuned at a single frequency (single-tuned filter) or at two frequencies (double-tuned filter).

- High-pass filters, which are used to filter high-order harmonics and cover a wide range of frequencies. A special type of high-pass filter, the C-type high-pass filter, is used to provide reactive power and avoid parallel resonances. It also allows filtering low-order harmonics (such as 3rd), while keeping zero losses at the fundamental frequency.

  The Three-Phase Harmonic Filter is built of RLC elements. The resistance, inductance, and capacitance values are determined from the filter type and from the following parameters:

- Reactive power at nominal voltage
- Tuning frequencies
- Quality factor. The quality factor is a measure of the sharpness of the tuning frequency. It is determined by the resistance value.

  The four types of filters that can be modelled with the Three-Phase Harmonic Filter block are shown below:

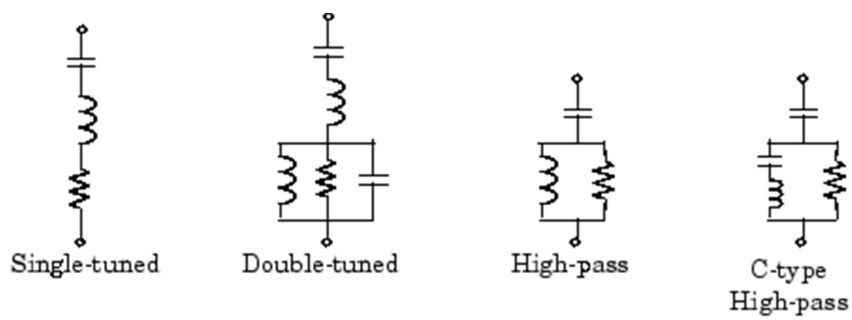


Fig:20 Types of Filters

4.2 STATCOM (Static synchronous compensator)

Static synchronous compensator [16] (STATCOM) is a shunt-connected FACTS device. It is like the static counterpart of the rotating synchronous condenser, but it generates/absorbs reactive power at faster rate because no moving parts are involved. It is operated as a static Var compensator whose capacitive or inductive output currents are controlled to control the bus voltage with which it is connected. In principle, it performs the same voltage regulation as the SVC but in a more robust manner because unlike the SVC, its operation is not impaired by the presence of low voltages. It goes on well with advanced energy storage facilities, which opens the door for a number of new applications, such as energy deregulations and network security. STATCOM operation is based on the principle of voltage source or current source converter. The schematic of a STATCOM is shown in Figure 3.14a and b. When used with voltage source converter, its ac output voltage is controlled such that the required reactive power flow can be controlled at the generator/load bus with which it is connected. Due to the presence of dc voltage source in the capacitor, the voltage source converter converts its voltage to ac voltage source and controls the bus voltage.

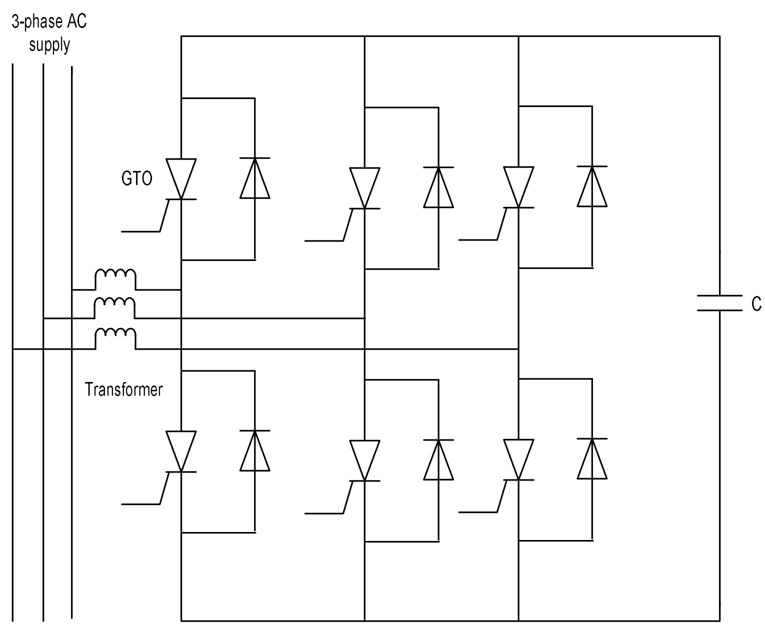


Fig:21 STATCOM

4.2.1 Construction and Operation

A STATCOM is a voltage source converter (VSC)-based device, with the voltage source behind a reactor. The voltage source is created from a DC capacitor and therefore a STATCOM has very little active power capability. However, its active power capability can be increased if a suitable energy storage device is connected across the DC capacitor. The reactive power at the terminals of the STATCOM depends on the amplitude of the voltage source. For example, if the terminal voltage of the VSC is higher than the AC voltage at the point of connection, the STATCOM generates reactive current; conversely, when the amplitude of the voltage source is lower than the AC voltage, it absorbs reactive power. The response time of a STATCOM is shorter than that of a static VAR compensator (SVC)[6], mainly due to the fast switching times provided by the IGBTs of the voltage source converter. The STATCOM also provides better reactive power support at low AC voltages than an SVC, since the reactive power from a STATCOM decreases linearly with the AC voltage (as the current can be maintained at the rated value even down to low AC voltage).

CHAPTER 5
CONCLUSION AND FUTURE SCOPE

CONCLUSION:

In this thesis, the study of the photovoltaic system with maximum power point controller has been developed. From the theory of the photovoltaic, a mathematic model of the PV has been presented. Then, the photovoltaic systems with DC-DC boost converter, maximum power point controller and resistive load have been designed. Finally, the system has been simulated with Simulink MATLAB. The work presents comparison between different MPPT strategies.

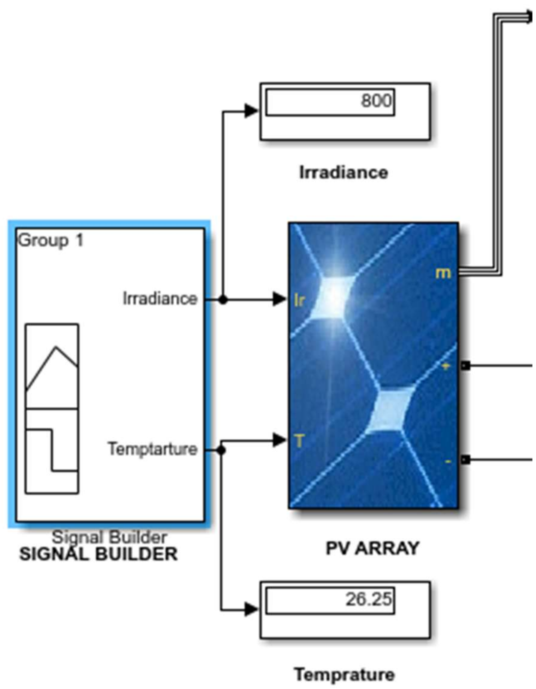


Fig:22 PV array with Signal builder

The following PV array of Soltech 215H consists of 2 parallel strings and 8 Series connected modules per string where each PV module contains 60 cells. The PV simulation set up under MATLAB/Simulink environment has been established by the electrical specifications of the PV module. In chapter 2, the objective is to analyze the different environmental effects on the output characteristics of solar

Photovoltaic system with experimental results. Different characteristics of output current (I) vs voltage (V) and output power (P) vs voltage (V) of the solar PV system were studied under environmental conditions e.g. cleanliness, shading, solar irradiance etc. to realize the energy conversion capability of the module in the existing conditions.

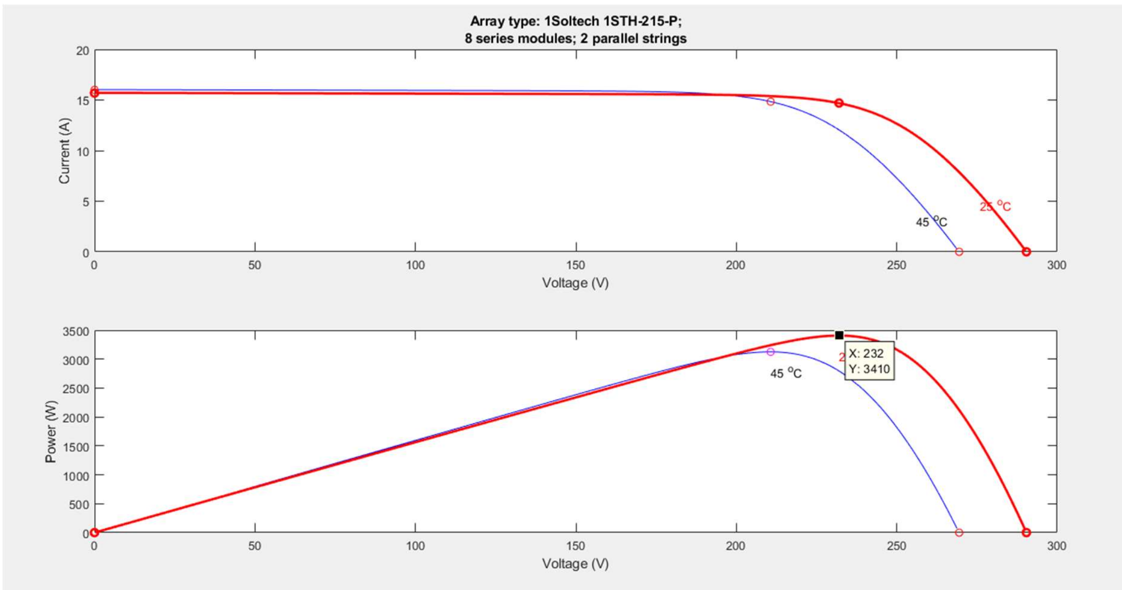


Fig:23 solar power output

The results were validated with the experimental results. The output of solar cell is maximum i.e. Voc = 36.3V and Isc = 7.84A in clean condition with Output Power of 213.15 W. Energy storage technology used for PV system has been depicted in details in the work. To analyze the different control strategies of Maximum power point technique to be used DC-DC boost converter for obtaining maximum output power from solar PV system. The MATLAB module is of the whole PV System Connected to Grid is as shown in fig:

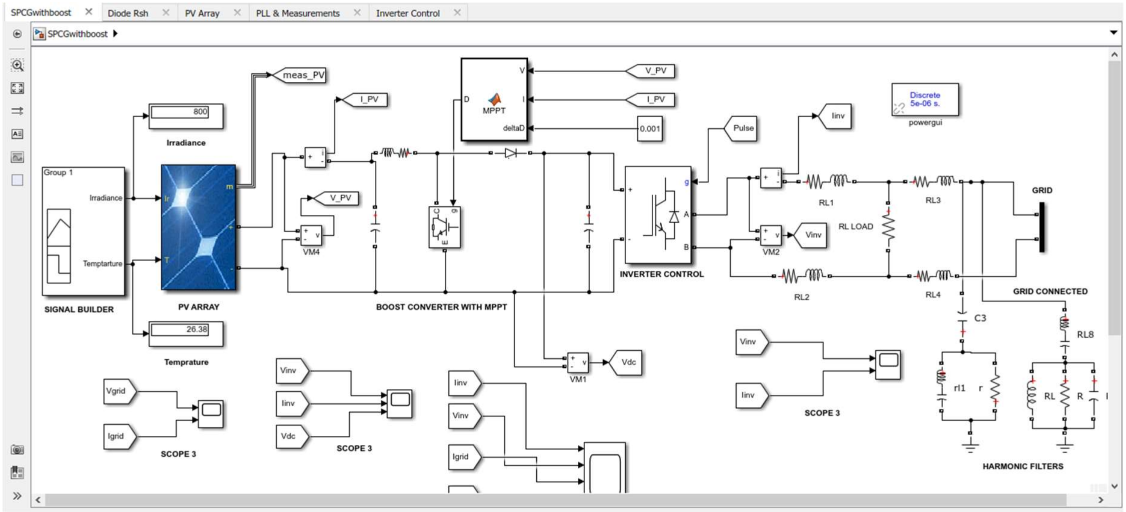


Fig:24 PV System Connected to Grid

The photovoltaic system with DC-DC boost converter and maximum power point controller has been designed and constant voltage of 232V is maintained at the output side of the converter.

The output of the Boost converter is shown as below with Vdc and Vinverter

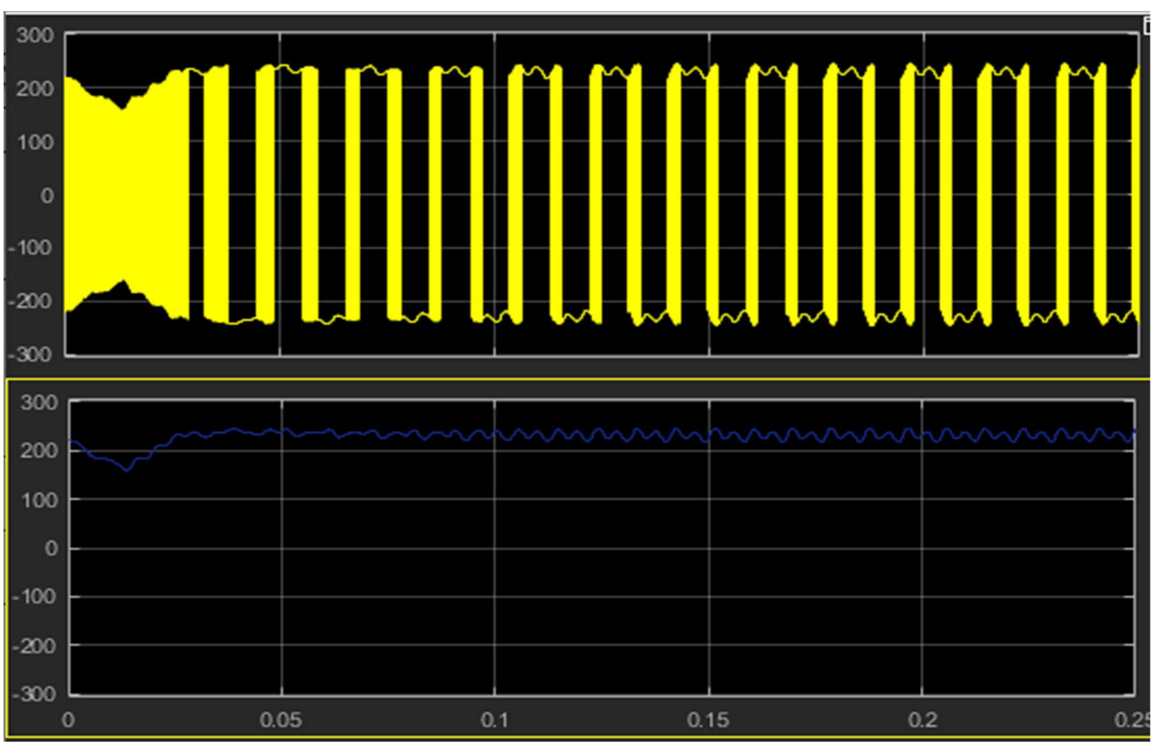


Fig:25 Vinvereter(top) & Vdc (down)

From the modelling of boost converter, it was also observed that the output voltage of the boost converter increases along with the increase in duty cycle. The objective is to design a PV System with harmonic filters to be operated with MPPT technology and to analyse the output characteristics for different irradiation level. The results was found that by using suitable parameters for the filters Harmonics in the system has been removed. Fig shows the output of the inverter voltage and inverter current

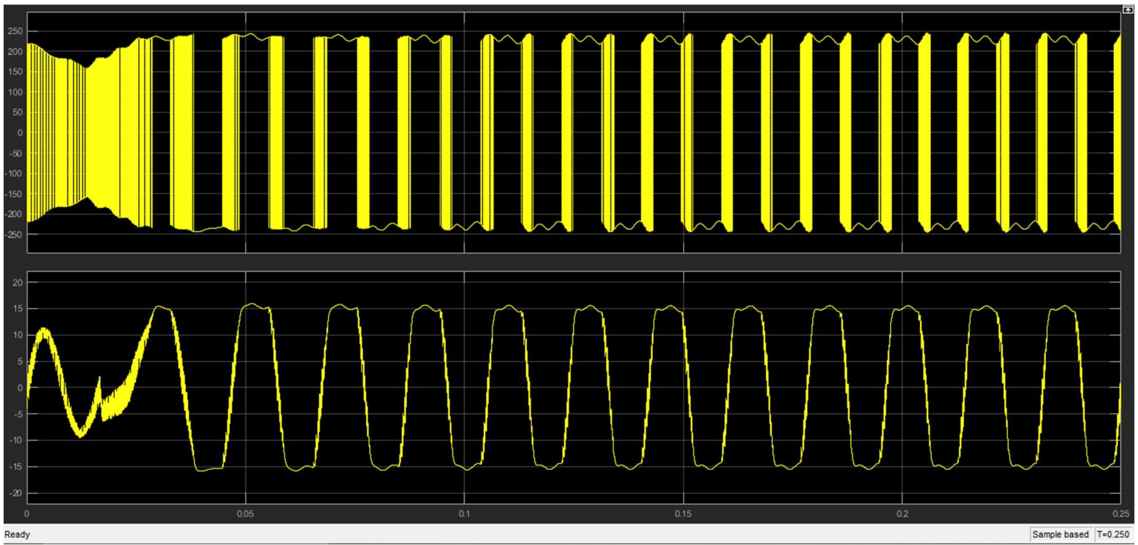


Fig: 26 Vinverter and Iinverter

Different characteristics of output current (I) vs voltage (V) and output power (P) vs voltage (V) of the module. Now working on harmonic filters before sending power to the grid.

This thesis focuses on the static voltage security of a power system using FACTs devices. Different voltage stability and security criteria have been developed and found that FACTs devices are more suitable to use and their use has been increased over the years.

From Simulation and observation it can be concluded that the use of harmonic filters helps in reducing the 3rd , 5th and 7th harmonic from the system and the use of FACTs devices like STATCOM to increase the stability of the Power Network. Application of STATCOM is found to be better to maintain voltage stability.

Present study may be helpful to provide a quick overview regarding voltage stability.

The Harmonic filter here used are of two types first isdouble tuned harmonic filter, which are used to filter lowest order harmonics such as 5th, 7th, 11th, 13th and class c type high pass harmonic filters is used to provide reactive power and avoid parallel resonances. It also allows filtering low-order harmonics (such as 3rd), while keeping zero losses at fundamental frequency.

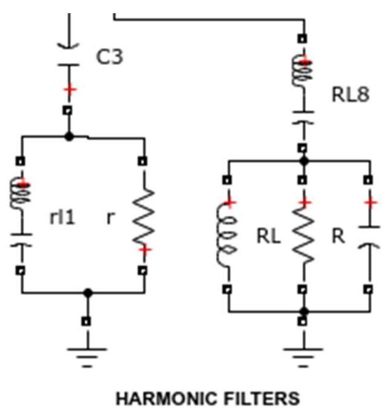


Fig:27 double tuned(left) and class C type high pass filter(right)

The values of rl1 for L=0.1 H and C=0.25e-6F, C3=0.25e-6 r = 0.01ohm RL = 0.1H , R=0.01 ohm , C=0.25e-6F and RL8 for (C =0.25e-6F & L=0.1H) are use obtain the improved waveform as shown

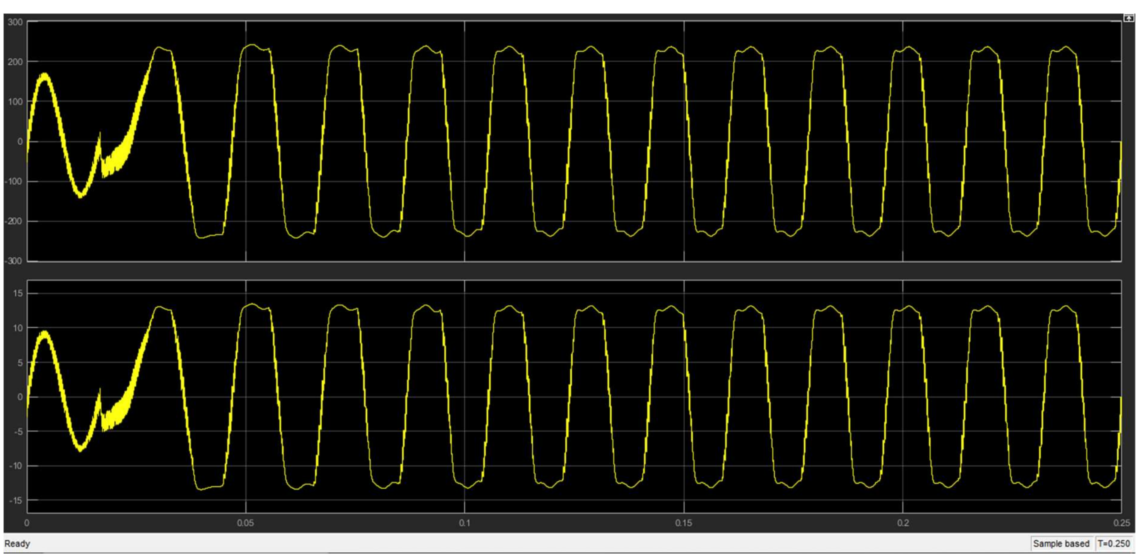


Fig:28 Vgrid & Igrid

The other output of all the parameters in the MATLAB module is shown in the fig:29

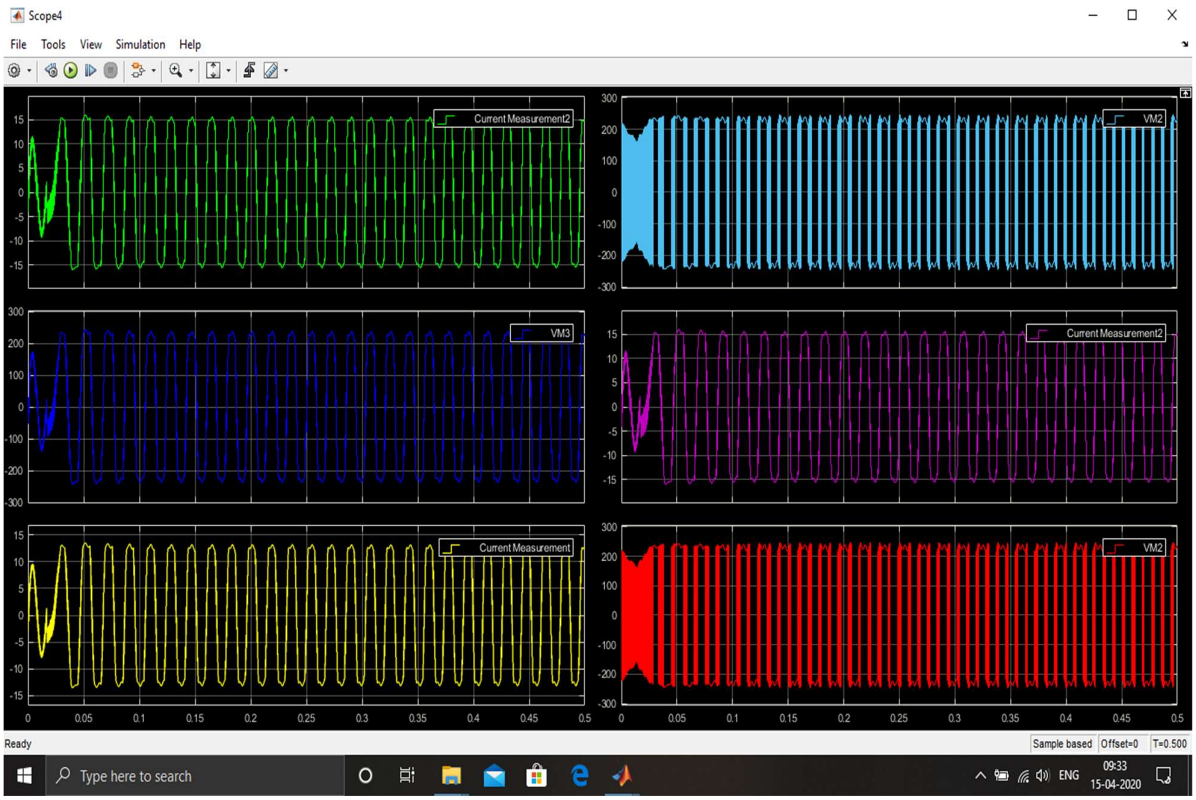
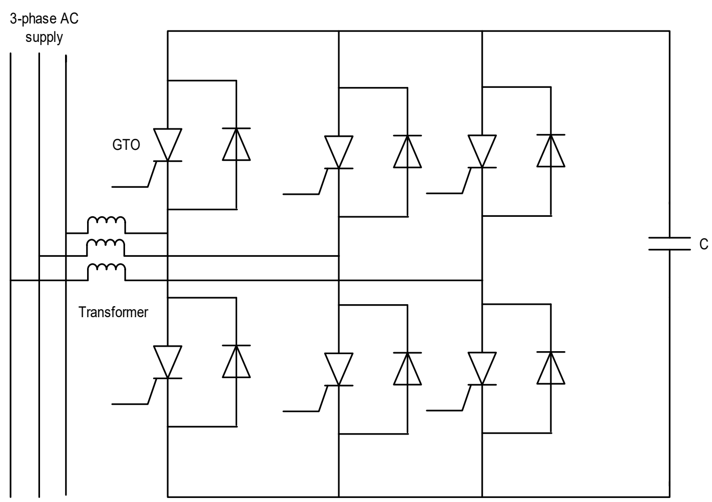


Fig: 29 Respective outputs of different Voltages and Current

And by the further use of STATCOM Power Quality can further more optimized to get almost sinusoidal waveform of voltage and current. The circuit diagram of STATCOM is shown in fig of STATCOM



5.2 MAIN CONTRINBUTION:

- To study the Power Quality issues of PV system Connected to grid.
- Development of PV module with MPPT boost, inverter Control and further connecting to grid and use of Harmonic Filters (double tuned and high pass filter) to remove harmonics from the system.
- Implementing the harmonic filters in the grid connected PV system to have satisfactory output current and voltage waveform.
- Study FACTs devices (STATCOM) their circuit diagram and their uses in power system to improve the power Quality.
- Studying various papers to get information of PV system connected to grid at different conditions, uses, PV cells, climate conditions etc.

5.3 FUTURE SCOPE:

Based upon the results and discussions of the model work reported in this thesis, the possible directions for the future work are the following:

- The present work can be extended towards applying the series network equivalent in real-time assessment and control of voltage stability in PV system connected to grid.
- The model may be applied to find suitable strategy for load shedding based on the voltage stability criterion.
- The power tracing method may be improved to include reactive loss minimization using facts devices.
- Other FACTS controllers like UPFC, UPQC, IPFC can also be modelled and their performance can also be explored in improvement of voltage stability of power system.
- Harmonic filters can be used to remove 3^{rd}, 5^{th}, and 7^{th} harmonics in the systems.

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7.APPENDIX A (Research Papers Published/Acceptance Of Paper)

- **International Journal of Engineering Research & Technology (IJERT)**(ISSN: 2278-0181)www.ijert.org

  Paper Title : Stability and Power Quality Improvement in Grid connected sytem
  Paper Id : IJERTV9IS040281
  Last Date for Registration/Payment: 20-Apr-2020

- **International Journal for Research in Applied Science & Engineering Technology (IJRASET)** UGC approved IISN : 2321- 9653

  Paper Title : Stability and Power Quality Improvement in Grid connected sytem
  Paper Id: IJRASET27505
  Accepted

- **Test Engineering and Management (ISSN: 0193 - 4120)**

  Paper Id: TEST-241

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Acceptance Letter

Dear Author(s): **Pawan Kumar Singh, Priteesh Ranjan, Pankaj Singh, Paras Goyal, Praveen Shishodia, Gauri Katiyar, Prakash Chittora**

Paper ID	TEST-241
Paper Title	Stability and Power Quality Improvement In Grid Connected System- A Review

This is to enlighten you that above manuscript reviewed and appraised by the review committee members of IFERP and it is accepted for the purpose of publication in the **"Test Engineering and Management"** that will be available at http://www.testmagzine.biz/index.php/testmagzine/index.

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