A

Dissertation Report on

Energy management for solar-PV system with energy storage

Submitted

in partial fulfilment of the requirements for the degree of

Master of Technology

in

Electrical Power System

by

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CERTIFICATE

This is to certify that, Ms. Shital Shivaji Thorat (Roll No - 1729004) has successfully completed the dissertation work and submitted dissertation report on " Energy management for solar-PV system with energy storage " for the partial fulfilment of the requirement for the degree of Master of Technology in Electrical Power System from the Department of Electrical Engineering, as per the rules and regulations of Rajarambapu Institute of Technology, Rajaramnagar, Dist: Sangli.

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DECLARATION

I declare that this report reflects my thoughts about the subject in my own words. I have sufficiently cited and referenced the original sources, referred or considered in this work. I have not misrepresented or fabricated or falsified any idea/data/fact/source in this my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute.

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ABSTRACT

This thesis introduces energy management system (EMS) which includes real and reactive power management. The EMS system includes two important modes: PV-STATCOM mode and islanding mode. For PV-STATCOM mode PI control strategy is used whereas for islanding mode voltage frequency control strategy is used. PV solar system is generally connected to distributed generation (DG) with utility grid. When the irradiation is insufficient, real power is not produced by solar inverter. The solar inverter has remaining capacity after active power generation. Reactive power compensation can be done by utilizing remaining capacity of solar PV inverter. This dissertation work proposes the energy management of reactive power by utilizing the solar photovoltaic (PV) inverter as static synchronous compensator (PV-STATCOM). Therefore, other additional flexible AC transmission system controllers or series/shunt capacitors are not required. During islanding mode loads needs supply. Proposed control system provides power to load during islanding condition.

Keywords:PV-STATCOM, reactive power control, Voltage Frequency (VF) control strategy, Islanding mode.

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ABBREVIATIONS

PV	Photovoltaic
PV-STATCOM	Photovoltaic Static Synchronous Compensator
VSI	Voltage Source Inverter
VSC	Voltage Source Converter
MPPT	Maximum Power Point Tracking
PO	Perturb and Observe
IC	Incremental Conductance

Chapter 1

Introduction

1.1 General

The power system is highly complicated interconnected system. Day by day growth of industrial area is increase in the electrical power sector and there are several interconnections in distribution system. Thus there is lot of stress in the distribution system. This intern affects the transmission capacity of the existing system

Power demand is increasing day by day. The electrical power sector is largely interconnected and it is having wide range. Due to interconnection, stresses are increasing on distributed system. The energy management at generation side and customer demand side is important for energy saving. The energy saving and efficiency has top priorities in all over power sector. The energy security is necessary for critical installation like health care facilities, military base area, universities and central and state government offices. These areas need to provide electricity services at all time.

The inventions taken place in the FACTS devices, control of active and reactive power in AC transmission networks was done by regulating transmission voltages using generator excitation control and by tap changing transformer. Changing the line impedances can change the active and reactive power flow in the lines. At that time, series and shunt impedances were employed to effectively change line impedances. The interconnection of renewable energy sources with battery energy storage systems are one of the complex and innovative areas in the power system. For enhancing grid connection, renewable energy sources requires novel control strategies and energy management schemes for their stability and reliability control [1].

Normally, the PV system is mostly implemented near the load center, which can reduce the transmission and distribution cost. Therefore, such a integration of renewable energy sources can delay the need of investment to improve the load profile of the feeder, reduces the loading stress on the transformers and grid, reduction in the electrical losses as well as due to the eco-friendly operation of renewable energy sources, it is beneficial for the environment. A topology of inverter has been proposed to interconnect grid to PV panel. The active power which is produced at day time and reactive power is produced during weak insolation condition, is supplied by inverter. Based on requirement at the point of common coupling, reactive power is provided by inverter. In this dissertation work PI controlled PV farm inverter control scheme is proposed. The main factor which is responsible for increasing losses in reactive power. This power is required to maintain the voltage profile throughout the transmission lines. In absence of reactive power, it has to be supplied from auxiliary sources of reactive power such as STATCOM and other FACTS devices. In terms of stability issues, voltage instability is big challenge in power system. In recent post, the number of power stability problems are linked with the voltage instability. Reactive power compensation is to increase voltage stability under critical operating condition. The huge PV farms are capable to inject reactive power to the grid.

The big producers of electricity are located away from exiting power lines therefore they require more space. Thus the PV systems offers benefits as it can be located anywhere to generate power. Islanding requires the continuous operation of a solar power generation. If the grid malfunctions, this malfunctioning is not detected by solar power generation system and thus it is disconnected immediately. This immediate disconnection leads to severe problems. Therefore, an adoptive control scheme must be used in protective devices for detecting and terminating islanding operations. The renewable energy sources are connected in parallel to the power distribution network. A malfunctioning utility grid can increase the damage chances. Therefore, protective equipment's should act actively in detecting and terminating islanding condition quickly. In normal operating condition, active and reactive power required by loads are supplied by the PV power gen-

eration and grid. PCC is balanced under normal conditions. Under islanding condition, when grid is disconnected, PCC becomes unbalance. So, as a result, the PV generation system can be connected. PCC remains balanced when the output power of the PV generation system is equal to the load demand. When the frequency and voltage of PV generation system are same to normal functioning grid, protective relays are prevented from functioning unnecessarily. The common islanding detection methods can be classified into passive and active detection method. Passive islanding detection method monitors the frequencies, phases and voltages at the load end. This leads to detection of the occurrence of islanding condition operations. The disturbances in system frequency and voltage are not equal to set limit for relay detection when the power output of PV generation system and total consumption difference is limited. Thus, the drawbacks of this method are that they possess a non-detection zone.
In this project work passive voltage frequency (VF) method is used for islanding operation. This dissertation is based on energy management and contributes in active and reactive power management and islanding mode control. The proposed energy management system provides reactive power support during night time when solar system is idle. Therefore, FACTS devices are not required. The cost of extra implementation of FACTS devices are reduced. During islanding mode of operation, system provides continuous supply to load. This contribution of energy management system in power sector is helpful to manage the power.

1.2 Motivation of the present work

The reactive power is the main issue in the power system. Actually, reactive power is non-useful power required to produce magnetism in the device. To maintain the voltage problem throughout the transmission lines reactive power is required. If reactive power is lacking in the transmission line then it has to be supplied from separate reactive power sources like STATCOM and other FACTS devices. Reactive power compensation is required in case of voltage sag and voltage swell to maintain the voltage at 1 Pu. Therefore for distribution of the essential amount of power through the transmission line, it is necessary to compensate reactive power. FACTS devices are the SVC, STATCOM, and UPFC. They are most commonly used. FACTS device is the STATCOM. STATCOM is the Static Synchronous

Compensator used for compensation of reactive power. Voltage source converter (VSC) is the main part of the solar system and also it is an important part of FACTS device such as STATCOM. For installation of STATCOM the overall cost of the system increase, therefore, the solar farm inverter is utilized as STATCOM by providing a PI controller to the inverter

because of growing energy needs and growing environmental concerns, it is necessary to focus on another solution for conventional sources in order to follow the current trend towards using the renewable energy system. Among all renewable energy sources, the solar photovoltaic park is in the form of green energy sources, which can play a key role in the program to reduce greenhouse gas emissions. Recently, the PV system has become popular for both small and large scales integrated into the network To meet the power demand, grid power transfer capacity needs to be improved. Reactive power compensation is important for controlling voltage and power flow. Voltage is controlled in transmission and distribution network by injecting or absorbing reactive power using FACTS devices. However, the installation of such FACTS device is very expensive. The construction of the solar farm inverter is similar to STATCOM construction. So that by applying some controlling methods to the solar inverter can perform the function of STATCOM. Therefore, reduces the cost of the system and utilizes the solar farm during nighttime for reactive power compensation.

Islanding operations can lead to voltage unbalance, voltage and frequency instability in power system, increasing the chances of damage. The islanding condition creates many problems in power system i.e. interference, power quality, safety, voltage unbalance, voltage and frequency stability [2]. Under emergency condition loads requires continues power supply, due the islanding condition power supply to load is cut off. To avoid thus problems regarding power system, the control of islanding is required. The islanding control strategies controls the voltage and frequency of the system and tries to provide continuous supply to load.

1.3 Layout of the thesis

Based on the thesis work objectives, flow of dissertation work is divided into the following chapters:

Chapter 1: Brief introduction about grid integrated PV solar plant operated as

STATCOM (PV-STATCOM) and islanding mode of operation are discussed in this chapter.

Chapter 2: Literature about PV-STATCOM, Islanding mode is discussed in this chapter. Published documents on control methods for operating PV Solar inverter as STATCOM and controlling of islanding mode are discussed.

Chapter 3: Description of proposed system is discussed in this chapter. This includes a detailed description of solar system, PV-STATCOM system, FACTS devices, STATCOM principle and operation, Islanding mode of operation, solar farm inverter and their control methods.

Chapter 4: Operation and implementation of PV-STATCOM and islanding mode is discussed in this chapter. It consists of modelling of the proposed system, solar system modelling and designing of control system along with the MPPT technique. The designing and working of all circuits with their components and features used in the hardware are described.

Chapter 5: Simulation and hardware results are explained in this chapter. The comparison of simulation results and analysis of THD of voltage are discussed. This also consists of the experimental setup of hardware of the proposed system and its results.

Chapter 6: Conclusion and future scope are described in this chapter.

1.4 Closure

In this chapter, a generalized concept of PV-STATCOM. Need of PVSTATCOM and islanding mode is also discussed. The layout of the thesis is presented.

Chapter 2

Literature Review

2.1 Introduction

This chapter consists of a detailed literature survey on the several PV-STATCOM control techniques and islanding mode control techniques used till date. There are various control schemes proposed by several authors which are used in controlling of reactive power and islanding mode of operation. This section gives the brief summary of all these research documents.

2.2 Literature review

Gilbert M. Masters presented the charge of electricity based on power drown by utilities during peak demand. At peck demand time the rate of electricity charges are more. The power control is closely related to the power shaving. The peck shaving is a method to minimize electricity charge with considering the time of use concept [1].

Giovanna Oriti et al. demonstrate the functionality of energy management system. The energy management system (EMS) contains digital controlled single phase voltage source converter and storing device battery. Presented EMS guarantees that providing power supply to critical load when grid is failed and peak demand is controlled by providing battery pack. Authors introduced peck saving concept for minimize cost of electricity. The presented energy management system operates at grid connected mode and islanding mode [2].

Giovanna Oriti et al. introduce the energy management system with storage into power system for temporary military base area. It improves efficiency of system by ensuring generator selection for load. Presented energy management system provides interface between energy storage element, source and load [3].

Hristiyan Kanchev et al. presented determinist energy management and operational planning of grid, including advanced PV generator with gas turbine as well as embedded storage unit. Presented scheme is relies on PV power prediction and load forecasting. The EMS is implemented with different function. Basically the system is implemented in 2 parts: local power management at consumer demand side and central energy management at generation side and . In demand side management, batteries and supercapacitor are two types of storage technologies used. The central and local power management system are exchange the data by using communication network [4].

N. Hajilu et al. proposes the mains voltage source The inverters (VSI) can be operated in active reactive power (PQ) mode, in active voltage mode (PV mode) and in voltage / frequency (VF) mode. The operation of the MG is influenced by the High Strategy Selection controller. Thus, in this study, two typical control schemes The VSI schemes (PQ and VF) are explained in general and the network required for the active / reactive power is shared between the VSIs. In this control strategy, the power control for all VSIs must cover the total requirements of the MG, so that the power of the DG PQ is measured at the maximum power point (MPP) and the DG VF units. divide the remaining power after the slowing control strategy. The results of the simulation are displayed to confirm the proposed control strategy. [5].

R. K. Varma et al. proposed a new control of solar farm to improve grid power transfer capability presented. During night period, the solar system is not useful for power generation. At night time, the PV inverter acts as a STATCOM and provides reactive power support to AC grid. Three controllers are proposed for controlling of PV inverter. The conventional reactive power controller is proposed for controlling of reactive power at point of power coupling. Damping controller is used for damp out rotor oscillations of synchronous generator. Voltage controller is used for maintain voltage within limit at PPC [6].

R. K. Varma et al.suggested a novel control concept in which solar farm is acts as a STATCOM. During night period solar farm is idle. Solar PV inverter can be used as STATCOM during night time as well as day time for reactive power compensation and also used for damping out rotor oscillations. Therefore there is no need of use extra FACTS devices for reactive power compensation. Hence cost of FACTS devices are rescued [7].

Fabio L. Albuquerque et al.presented a comparison between current source inverter and voltage source inverter. It concludes that the voltage source inverter having better reactive power compensation ability than current source inverter. The main advantage of voltage source inverter is to provide reactive power during night time that is photovoltaic solar farm acts as a STATCOM. Utilization of photovoltaic inverter as STATCOM during night time is called as PV STATCOM. Current source inverters are mainly used for providing active power to grid [8].

Rupesh G. Wandhare et al. Presented topology for enhancement of compensation capability of inverter based on distributed generation. The voltage profile at distribution level is maintained by supplying active and reactive power. Reactive power compensation is done without hampering power quality by using reactive power controlling scheme. The author discussed the conventional methods of compensation which are based on L-C bank [9].

M. A. Hannan et al. proposed a new fuzzy PI logic based voltage and current control scheme for three phase grid connected inverter with both stand-alone and grid connected mode. The authors have discussed the control algorithm for controlling of voltage and current total harmonic distortion [10].

Khomdram J. Singh et al. Proposed Implemented the maximum power point tracking controller on field programmable gate array. Controlled performance is analyzed on the basis of variation of solar insolation as well as temperature. The P and O algorithm is implemented on FPGA board by using VHDL code for tracking maximum power point [11].

Ahmed M. Atallah et al. Implemented perturb and observe algorithm for maximum power point tracking system by using buck-boost converters. If suddenly external environment changes then system can track MPP quickly. Buck convert is more effective to suppress the oscillation produced due to the use of P and Q technique than boost converter[12].

Tekeshwar P. Sahu et al. presented comparative analysis of constant duty cycle and perturb and observe algorithm for photovoltaic system. Maximum power point tracking perturb and observe algorithm is implemented by using cuk converter.

The P and O MPPT technique is a direct control method. This technique is easy to implement with less complexity [13].
I William et al. shows comparison between perturb and observe algorithm and incremental conductance algorithm of maximum power point tracking technique. Authors prove that the incremental conductance algorithm of MPPT technique gives better performance than perturb and observe algorithm [14].

2.3 Objectives of research work

In this dissertation work it is proposed to carry out analysis of Energy Management for solar-PV System with energy storage system, using MATLAB SIMULINK.
The objectives of the research work are:

1. Reactive power support to grid by using PV-STATCOM.
2. To provide power supply to load during islanding mode.
3. To control charging and discharging of battery to increase battery life.

Chapter 3

System Description

3.1 Introduction

Figure 3.1 shows the block diagram of proposed system. This chapter gives description of system components which is used in this dissertation work.

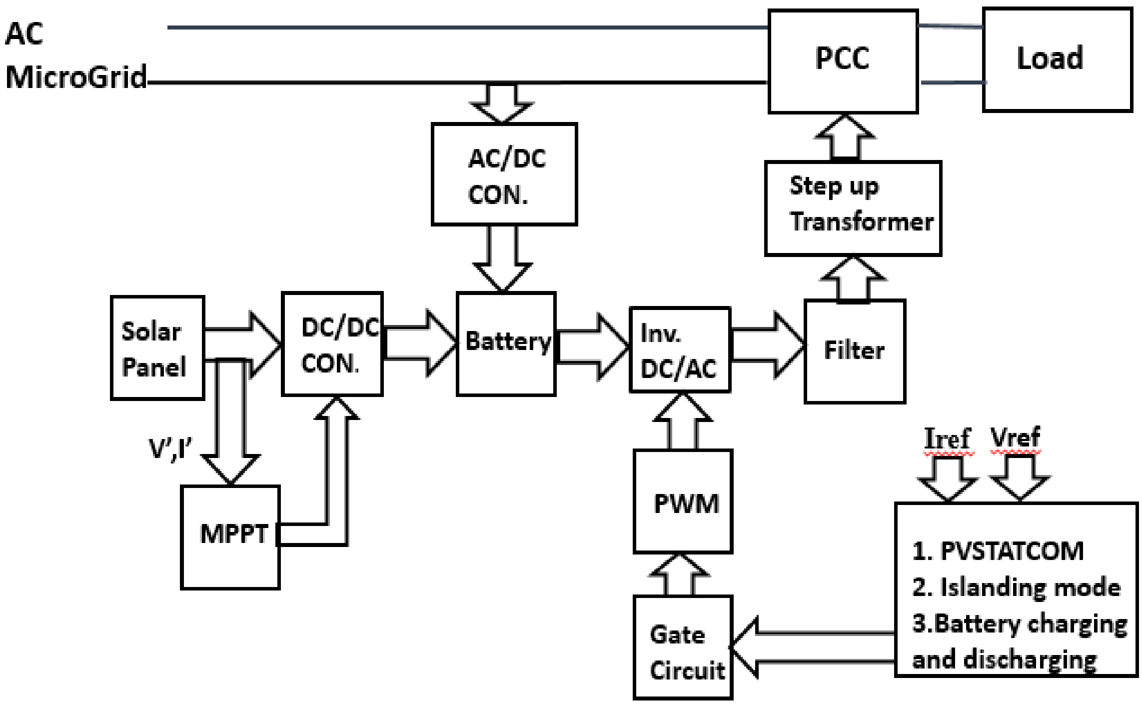

Figure 3.1: Block Diagram Energy Management System

Main components of Energy Management system are:

1. PV panel

2. Maximum Power Point Traking (MPPT)
3. Boost converter
4. Inverter
5. Battery

The components are described in detailed in following sections.

3.2 PV panel

The photovoltaic effect is based on conversion of solar energy into electricity. A simple solar cell made by semiconductor material and it consist of p-n junction. This forms an electron-hole pair that is freely movable electrons. These freely movable electrons are responsible for electricity production. This represents photovoltaic effect. A solar cell is the basic component of photovoltaic module. Power generated by using module is not sufficient to meet required power demand. Several PV modules are arranged in either parallel or series to increase the current (I) and voltage (V). The different types of semiconducting materials are employed to manufacture photovoltaic cells.

1. Single-crystalline silicon (n=20-25%),
2. Thin film cell (n=20%),
3. Polycrystalline and semicrystalline silicon, (n=22%)
4. Amorphous silicon (n=7-10%)
5. Spherical cell (n=58% with hybrid mode)

3.2.1 Modelling of PV panel

Figure 2 shows the equivalent electrical circuit model of photovoltaic cell. Characteristics of PV cell described by using following equations

$$I = I_L - I_D \tag{3.1}$$

The diode current can be expressed as

$$I_D = I_o \left(exp \left(\frac{q * (V + IR_s)}{\gamma * kT_c} \right) - 1 \right) \tag{3.2}$$

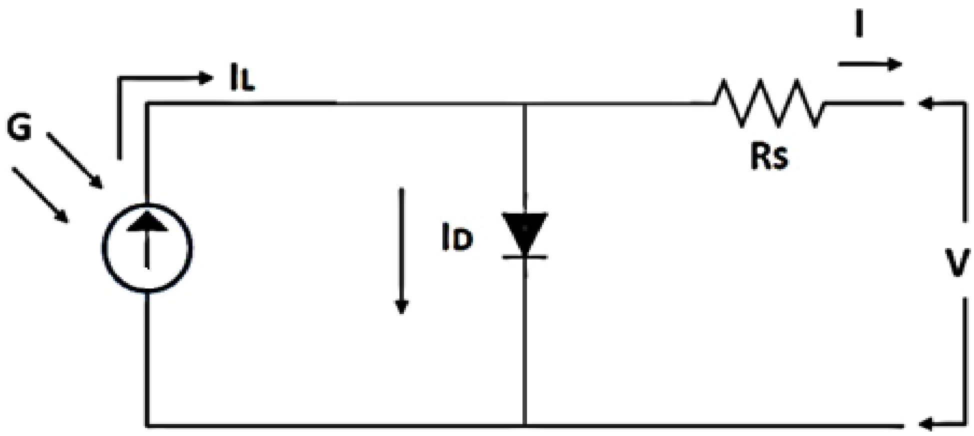

Figure 3.2: Equivalent electrical circuit of PV cell

Put equation (1) in equation (2)

$$I = I_L - I_o \left(exp \left(\frac{q * (V + IR_s)}{\gamma * kT_c} \right) \right) \tag{3.3}$$

Where

$$\gamma = A * N_{CS} * N_s \tag{3.4}$$

$$I_L = \left[\frac{G}{G_R} \right] (I_{LR} + \mu_{ISC} (T_C - T_C R)) \tag{3.5}$$

$$I_O = I_O R \left[\frac{T_C}{Y_{CR}} \right]^3 exp \left[\left(\frac{q\epsilon_o}{kA} \right) \left(\frac{1}{T_{CR}} - \frac{1}{T_C} \right) \right] \tag{3.6}$$

Where, I_L = Light generated current; I_D = Diode current; R_S = Series resistance; G = Actual irradiance; k = Boltzmann constant; A= Completion factor; q = Electron charge; γ = Shape factor; G_R = Irradiance at reference condition; μ_{ISC} = Manufacturer supplied temperature coefficient of short circuit current; T_C = Actual cell temperature; $T_{C.R}$ = Cell temperature at reference condition; ϵ_o = Material band gap energy; NS = Number of series connected modules; NCS = Number of series connected cell per module;

The I-V curves of photovoltaic cell gives a detailed description its solar energy conversion ability and efficiency. In order to determine the device's performance and efficiency, knowledge of these characteristics is vital. I-V curve of PV cell are graphical representation of the operation of the solar cell which summarizes the relationship between current and voltage at existing irradiation and temperature conditions. The intensity of the solar radiations that are incident on PV cell controls the current whereas increase in temperature results in decrease in the cell voltage. Figure 3.3 and Figure 3.4 illustrates the I-V and P-V characteristics of PV module under different irradiance from 1000 W/m2 to 200 W/m2 in steps of 200 W/m2.

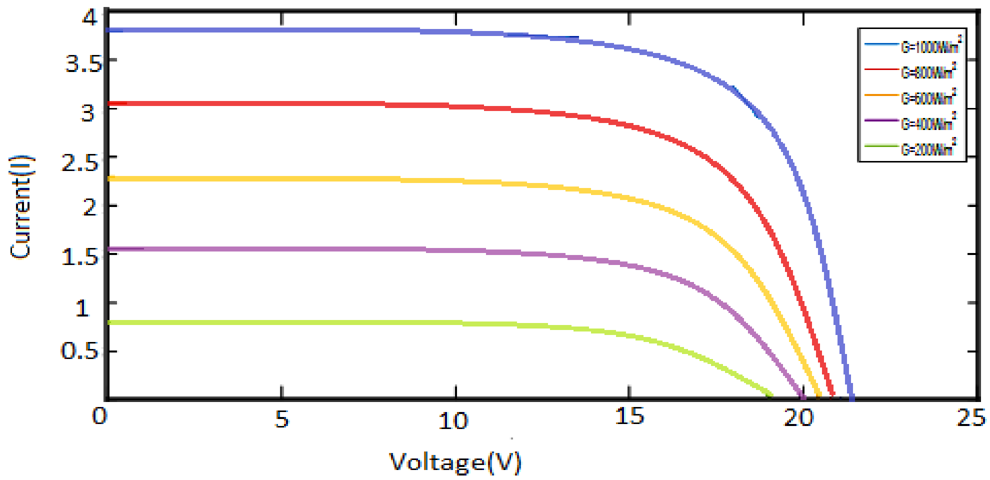

Figure 3.3: I-V characteristics under different irradiance

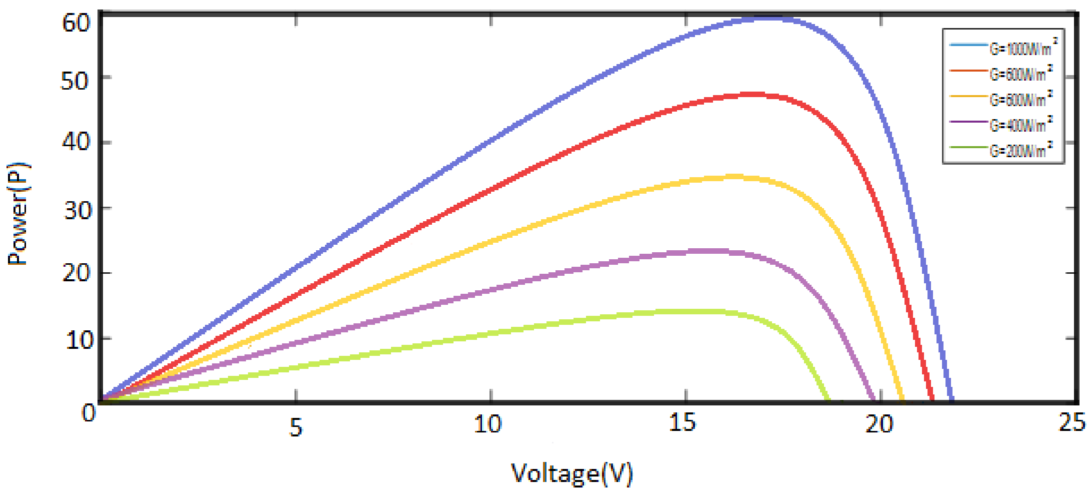

Figure 3.4: P-V characteristics under different irradiance

3.3 Maximum Power Point Traking (MPPT)

I-V curve having a point at that power is extreme for some particular irradiation condition; therefore it is needed to track these maximum power points (MPP) which is said as MPPT. There are many MPPT systems used such as P&O, Incremental conductance (IC), Fuzzy logic and Artificial Neural Network (ANN). Out of which the P and O method is generally used for the reason that of the simplicity and easy to implement [12]. This methods perturbs of the PV procedure point by increasing or decreasing the PV voltage to find the maximum power point (MPP). In this proposed system P&O method is used to track MPP. The most widely used tracking algorithm is Perturb and Observe [14]. The highlight of this technique is that it compares present PV power with previous sample of PV power. PV power can be determined by measuring current I and voltage V. When the difference between present and previous power is not zero, the algorithm will try to find the optimal point in the right or left side of recent position. The perturbation and observation method, also known as the perturbation method, is the most commonly used MPPT algorithm in commercial PV products. It is essentially a method of "trial and error". The PV controller slightly increases the reference of the output power of the inverter, then detects the actual output power. If the output power is actually increased, it will increase again until the output power starts to decrease, value at which the controller decreases the reference to avoid sagging of the PV output due to the highly PV characteristic non-linear. In these MPPT techniques initial value of voltage and current are measured. Then power is estimated from voltage and current values. After that this condition is checked for power that is a comparison of calculated power and change in power. If the determined power is greater than change in power, after that it goes to next step of checking if voltage is finer than change in voltage or not. If yes. Afterwards flow is as follows there is the increment in reference voltage. If no, after that there is decrement in reference voltage. If calculated power is greater than change in power this condition is not true, then flow chart will go to another path in which also there is checked for calculated voltage is finer than change in voltage and later decrement and increment in voltage take place [11]. Figure 3.5 shows the Flow chart of P&O algorithm.

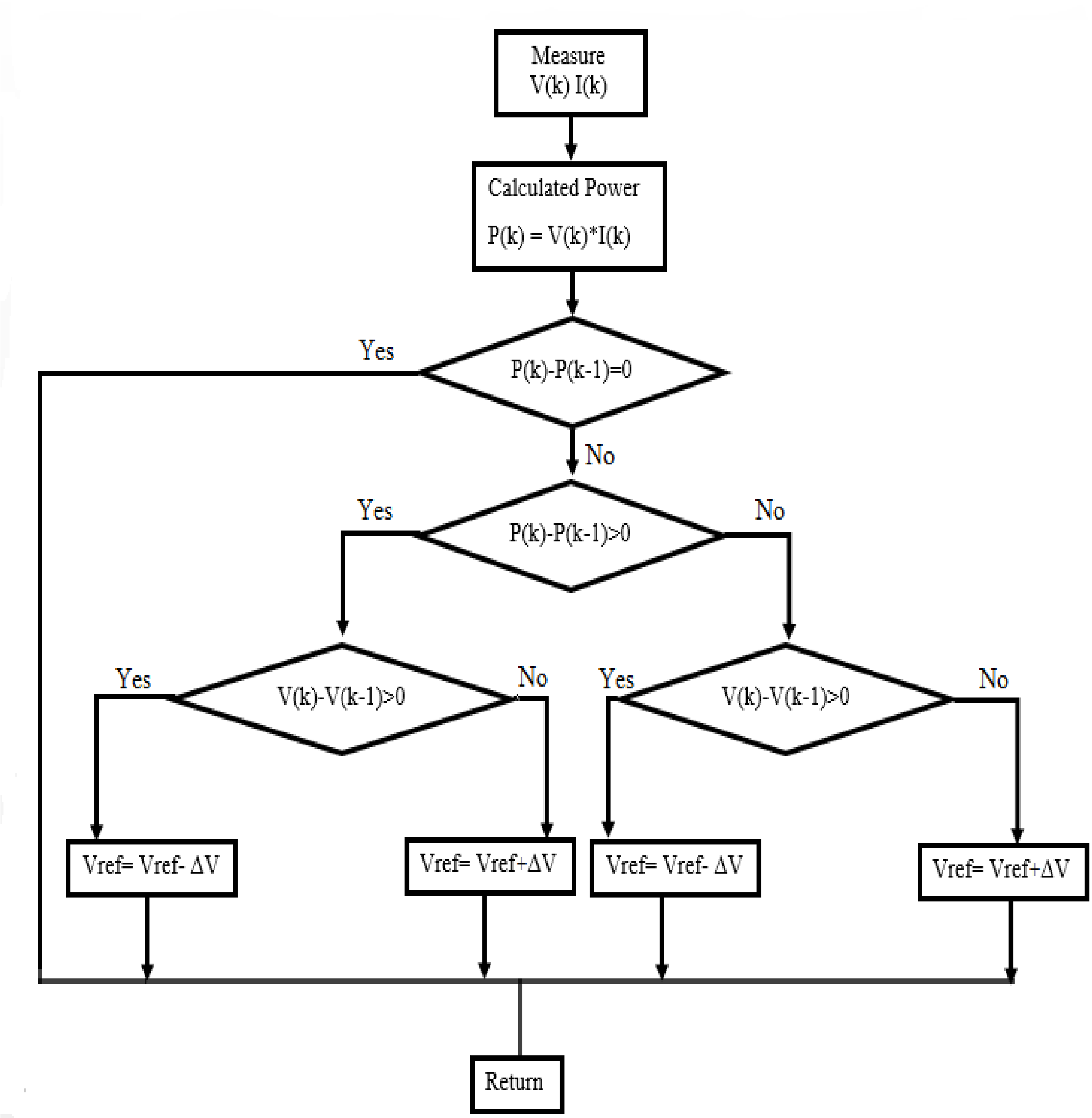

Figure 3.5: Flow chart of P&O algorithm

3.4 Boost Converter

A boost converter converters power DC to DC with steps up voltage level from input to output while step down current. The class of boost converter is switched mode power supply (SMPS). The boost converter contains at least two semiconductors i.e. diode and transistor. It also contains least one energy storage element. To remove voltage ripple, filters made of capacitors are normally added to such a converters load-side filter and supply-side filter [13].

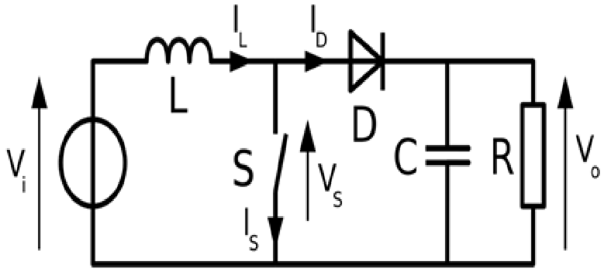

Figure 3.6: Boost Converter

Inductor of the boost converter having tendency to prevent changes in current by using destroying and creating magnetic field. In the boost converter, the output voltage is always more than the input voltage. A schematic diagram of a boost power stage is shown in Figure 3.6. The basic principle of a Boost converter consists of 2 distinct states

1. **Mode I:** When the switch is on, current flows through the inductor in clockwise direction and the inductor stores energy by creating a magnetic field. Polarity of the left side of the inductor is positive. Figure 3.7 shows mode 1

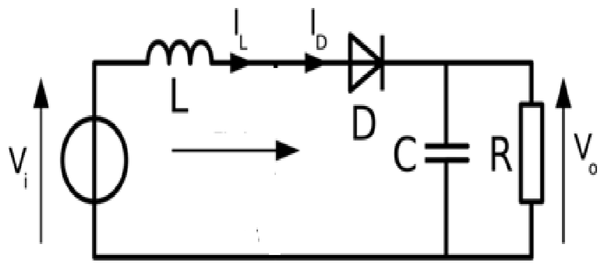

Figure 3.7: Mode I Switch is closed

2. **Mode II:** When the switch is off, the current decreases when the impedance is high. The previously created magnetic field will be destroyed to maintain the current to the load. Thus, the polarity will be reversed (means that the left side of the inductor is now negative). As a result, two sources will be in series, which will cause a higher load to charge the capacitor through the diode D.

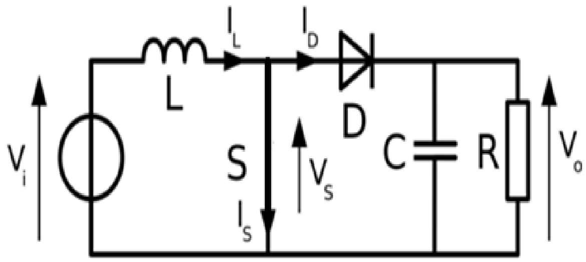

Figure 3.8: Mode II Switch is open

The voltage and current relation for the inductor L is;

$$I = \frac{1}{L}\int_0^t V dt + I_O \tag{3.7}$$

or

$$V = L\frac{di}{dt} \tag{3.8}$$

Where, I=Input current in Amp

I_o=Output current in Amp For rectangular pulse,

$$I = \frac{V_t}{L} + I_O \tag{3.9}$$

When switch is closed (S= Close)

$$I_i = \frac{(V_i n - V_s)T_{on}}{L} + I_O \tag{3.10}$$

Where, $V_i n$=Input voltage in Volt

V_S=Voltage across switch in Volt

I_i=Input current in Amp

I_o=Output current in Amp When switch is closed (S= Close)

$$\Delta I_i = \frac{(V_{in} - V_s)T_{on}}{L} \tag{3.11}$$

When switch is open (S= Open)

$$I_o = I_i - \frac{(V_o - V_{in} + V_D)T_{off}}{L} \tag{3.12}$$

Where, V_O=Output voltage in Volt

V_D=Voltage across diode in Volt

$$\Delta I = I_i - \frac{(V_o - V_{in} + V_D)T_{off}}{L} \tag{3.13}$$

Now, the equation through Delta,

$$\frac{(V_{in} - V_s)T_{on}}{L} = \frac{(V_o - V_{in} + V_D)T_{off}}{L} \tag{3.14}$$

$$(V_{in} - V_s)DL = (V_o - V_{in} + V_D)T_{off}(1 - D) \tag{3.15}$$

$$V_O = \frac{(V_o - V_{in} + V_D)D}{1 - D} \tag{3.16}$$

Now, neglecting the voltage drop across diode and switch

$$V_{out} = \frac{V_{in}}{1 - D} \tag{3.17}$$

So it is clear that the output voltage is directly related to the operating cycle. The main challenge in designing a converter is the type of inductor to be used. It can be seen from the above equations that the inductance is inversely proportional to the breaking current. To reduce deflection, a larger inductor must be used. Now, calculate the component

- Load resistance

$$R_L = \frac{V_O}{I_o} \tag{3.18}$$

- Duty Cycle

$$D = 1 - \frac{V_i n}{V_o} \tag{3.19}$$

- Capacitor

$$C = \frac{I_o * D}{F_s * \Delta V} \tag{3.20}$$

  Where,

$$\Delta V = ESR\left(\frac{I_o}{1 - D} + \frac{\Delta I_{new}}{2}\right) \tag{3.21}$$

- Inductor

$$L = \frac{V_s * D}{F_s * \Delta I_O} \tag{3.22}$$

3.5 DC-AC INVERTER

Inverter is used to provide a continuous supply of 440 Vac to the load connected to its output socket. It provides constant AC power at its output jack, even when AC power is not available [4]. It is a combination of an inverter circuit, a charging circuit and a battery. The inverter circuit uses the DC energy stored in the battery and converts it into a 440V / 50Hz AC power supply, which can be used to power any electronic equipment or common computer system. It plays the inverse role of rectifier where the alternating current is converted into direct current and works by cutting the DC voltage by various means. VSI three-phase Bridge with square pole with square wave tensions were taken into account. The output from this inverter must be fed into a three-phase balance task.

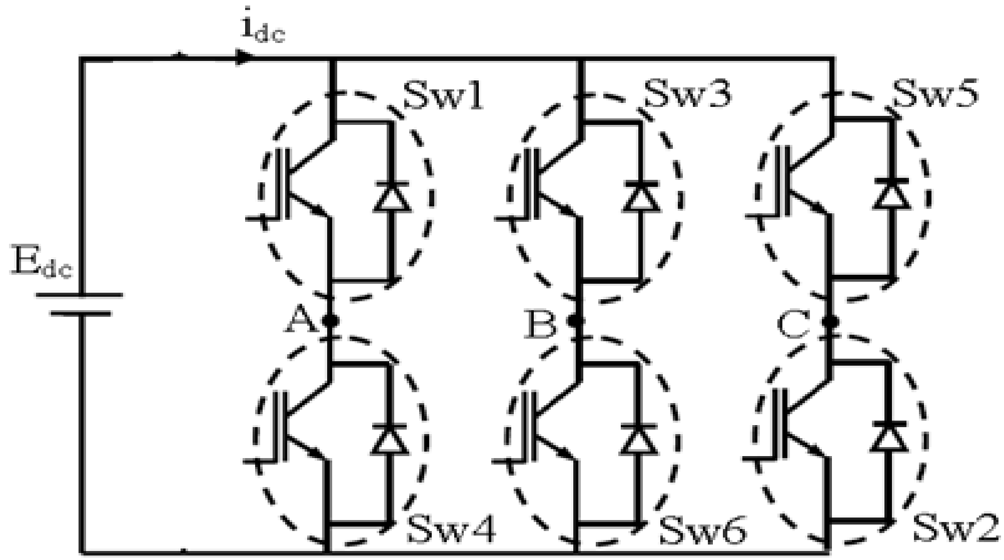

Figure 3.9: Three phase inverter

The three main waveform options were a square wave, a modified sine wave, and a pure sine wave. The difficulty of the system increases considerably with each waveform option, respectively. Figure ref 7 shows the three different waveforms on the same graph. [5] A pure sine wave is required to perform any type of load, but most loads can operate on a modified sine wave. The main side effect of a modified sine wave is a decrease in efficiency and an increase in noise in the system. Here, we must add filters. The desired result would look like an average of the three waveforms presented in Figure 3.10

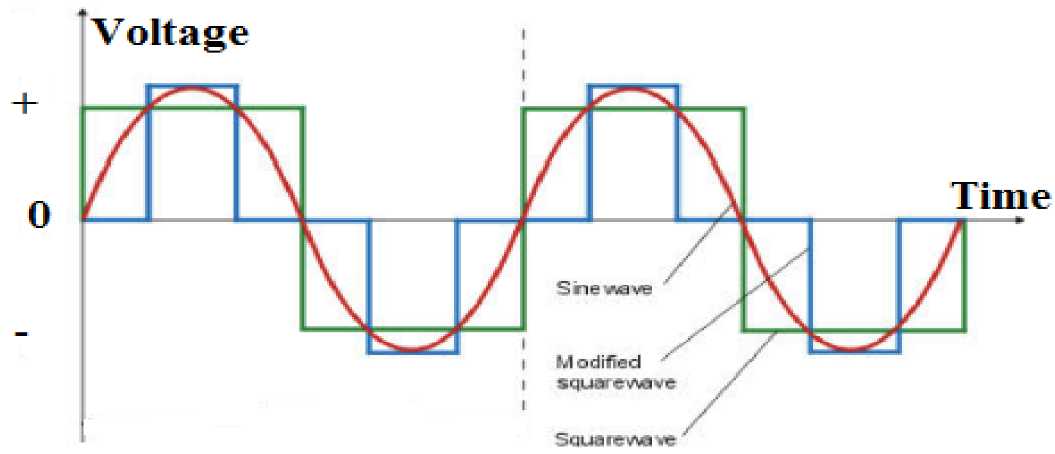

Figure 3.10: Output Wave Form of Inverter

The vertical axis is the voltage, while the horizontal is the time. As can be seen, the red waveform is a pure sine wave, blue is a modified sine wave, and green is square wave. The specified period will vary depending on the desired frequency.

3.6 Battery

Solar batteries are used to store solar energy (solar electricity) and to discharge it if necessary. Rechargeable solar batteries are used in off-grid PV systems to store excess electricity. Some solar battery banks use wet cells, while others use sealed or gel cell batteries. Each of these batteries has different requirements for temperature, mounting and ventilation. In small applications, lead-acid batteries are preferred and most common in solar energy because they give better results in terms of charging and discharging cycles. The batteries are classified into two types:

- Flat Plate Battery
- Tubular Battery

Tubular batteries are taller than flat plate batteries. They are manufactured by using three main chemical compositions: lead acid, lithium ion, and saltwater. The home solar system generates DC electricity. This DC electricity is converter to AC electricity by using Charge Controller and Solar Inverter. The battery stores this AC electricity to be used at night or when there is no sun light. The home solar system generates DC electricity. Battery backup time depends upon Ampere Hour (Ah). Higher the Ah, more will be backup time. Price also depends on Brand. Some of the popular brands in India are – Exide, Luminous, Amaron, Okaya and Sukam

3.7 FACTS Devices

FACTS are nothing but flexible AC Transmission system, which is well recognized during recent years for greater controllability in the power system. It uses power electronic devices for adjusting power flow through the transmission network, and hence it allows the transmission line to be loaded to its full capacity. There are number of FACTS devices for different applications are used in worldwide. Following is the basic application of the FACTS devices.

- Power control
- Increase of transmission capability
- Voltage control
- Reactive power compensation
- Stability improvement
- Power quality improvement
- Interconnection of renewable and distributed generation and storage.

All the systems under FACTS are mainly classified into two groups: series compensator and shunt compensator.

3.7.1 Series Compensator

Series compensator works on voltage injection technique, in series combination voltage is injected into the circuit. Applied series voltage in specific line is calculated by using multiplication of varying impedance with current flowing through the same transmission line. Series compensator supplies or consumes movable reactive power only if and only if the voltage is in phase quadrature (90 degree lead or lag) with the line current. Thus, a series compensator is adjustable impedance (such as capacitor or reactor), which could be electronic-based device.

3.7.2 Shunt Compensator

While operating the shunt compensator the current is injected to the system at the PCC of the compensator. This is obtained by either varying shunt impedance or a voltage source or a current source. Shunt compensator provisions or consumes variable reactive power if and only if when injected current of the line is in phase quadrature with the line voltage. There are different types of shunt compensators which are described as follows,

- Thyristor controlled Reactor
- Thyristor switched capacitor
- Static VAR Compensator
- STATCOM

3.7.3 STATCOM

STATCOM is a shunt connected reactive power compensation device that has a capacity to generate and absorb reactive power and also the output is varied so that it controls the definite constraints of the electric power system. This is generally the solid state switching converter which is capable to generate or absorb separately controllable real and reactive power at this input terminal. The STATCOM discoursed here is the voltage source converter which produces 3-phase AC output from the given dc voltage input, all are in phase and coupled to the corresponding ac system through very small reactance (this small reactor is provided either by interface reactor or from the leakage inductance of the coupling transformer) STATCOM is summarized as follows. Its controller provides voltage support through the generation or abortion of the reactive power at the point of common coupling for that, there is no need to have large external reactors or capacitors banks.

Working principle:

The STATCOM is the controlled reactive power source. It delivers the required reactive power generation and absorption fully by using the electronic processing of voltage and current waveform in the voltage sourced converter (VSC). The single-line power circuit is given in figure3.11 , which indicate through the magnetic coupling the VSC is connected across the utility bus. The Figure 3.12 shows

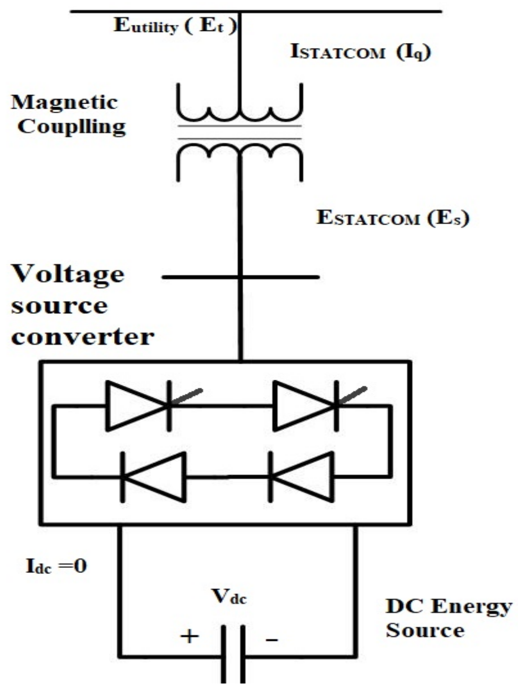

Figure 3.11: STATCOM topology

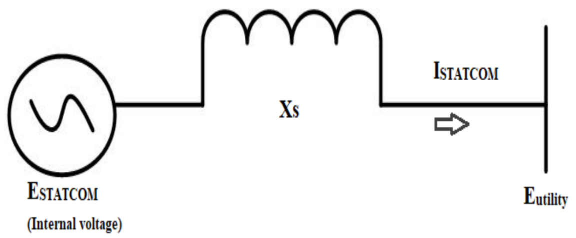

Figure 3.12: STATCOM Equivalent Circuit

that, there is STATCOM acts as changeable voltage source after the reactance which indicates that there is no requirement of capacitor bank and shunt reactors to generates and absorb reactive power, hence provides STATCOM having a compact design or small footprint, also short noise with less magnetic impact. The amplitude of 3-phase AC output voltage E_S is varying to control the reactive power conversation among the converter and the AC system, which is shown in Figure 3.13. From this Figure, if the amplitude or output voltage is improved beyond the utility but voltage E_t at the condition current flows through the reactor in the direction of the converter towards AC system, and the converter produce reactive power which is capacitive in nature for the AC system. Another way if amplitude of output voltage is reduced below the utility bus voltage during this condition the current flows in the direction of ac system to the converter and the converter absorb inductive reactive power from the AC system. If AC system

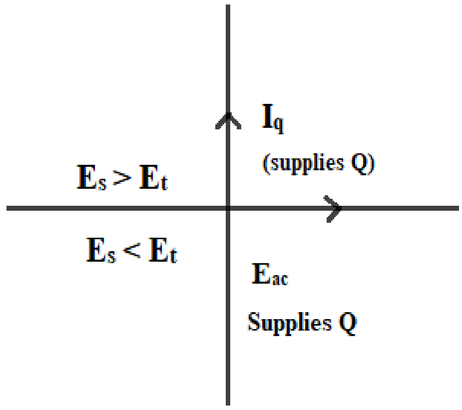

Figure 3.13: STATCOM Power Exchange

voltage and output voltage are equal, then the reactive power exchange within the system becomes zero under the situation STATCOM state is called floating state. The reactive power exchange among the converter and AC system is regulated by modifying the phase shift between converter output voltage and AC system voltage, there is possible to control reactive power exchange between converter and AC system. The real and reactive power exchange through the STATCOM and the AC system can be controlled individually of each other. Any procedure of real power generation or absorption along with VAR generation or absorption is possible if STATCOM is equipped with energy storage device of suitable capacity, with this capacity, very much effective control strategy for modulation of the reactive and actual power output is planned to rises the transient and dynamic system stability limits. A STATCOM can increases power-system performance in the following areas:

- Dynamic voltage control in transmission and distribution systems
- Power oscillation damping in power transmission systems
- Transient stability
- Voltage flicker control
- control of real and reactive power in the connected line.

3.8 Conventional STATCOM and Solar Farm PV Array Based STATCOM

Many compensation devices performing reactive power compensation and voltage regulation have been used, but a device having a structural advantage is required for the assumed system. STATCOM has the structural advantage of acting as a compensation device for the supposed system. The photovoltaic generator and the configuration of the inverter are similar to the conventional STATCOM design. Figure 3.14 clearly shows how the installation of PV panels can be used as STATCOM. A structural advantage that facilitates the use of photovoltaic panels as STATCOM is its output, it is the DC voltage that is used as a capacitor as in the conventional STATCOM system. In addition, the design of the inverter is designed to function as a converter in the arrangement of the photovoltaic generator. Thus, the photovoltaic generator and the inverter are conveniently used as STATCOM for the assumed system.

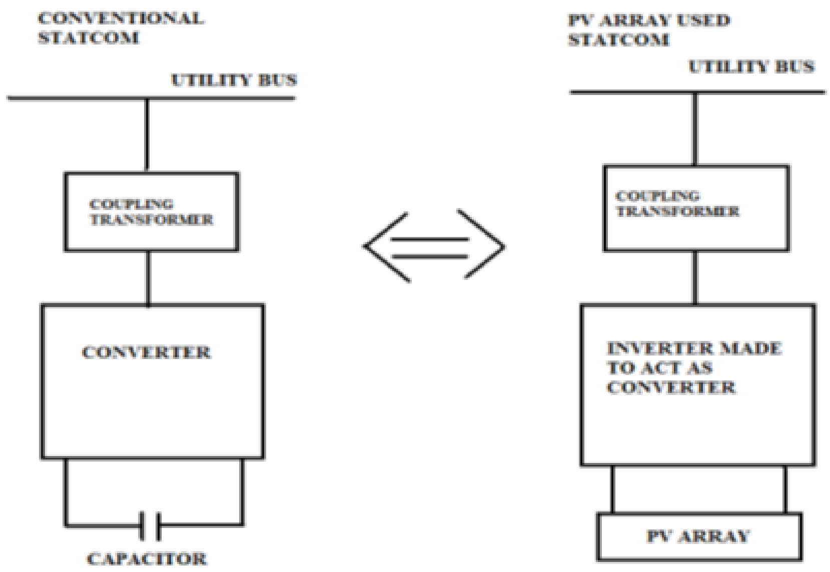

Figure 3.14: Conventional STATCOM vs. PV based basic STATCOM Configuration

3.8.1 Drawbacks of Conventional PV-Solar System

- Power handling capability of grid Reduced , therefore is no any provision of reactive power compensation .
- For improving power factor of system, separate Power factor correction de-

vices are required.

- Poor voltage regulation, due to low lagging power factor.
- Increased overall cost, due to additional cost on power factor. correction equipment.

3.8.2 Benefits of PV Solar controller as STATCOM

This new control technique of PV Solar controller as STATCOM has many advantages over a conventional PV Solar system. The detailed benefits are illustrated below.

- Increased power handling capability of Grid system.
- Improves overall system power factor.
- Improves voltage regulation.
- Cost of PV Solar Controller is lower than a conventional STATCOM.

3.9 Islanding Mode of Operation

EMS Feeds critical loads in case of failure of the power grid. Feeding critical loads in the event of an AC network failure, the EMS detects the network failure and acts as a voltage source. Islanding can be dangerous for utilities, who may not realize that a circuit is still powered and prevent automatic reconnection of devices. In addition, without strict frequency control, the balance between load and generation in the island circuit will be violated, resulting in abnormal voltages and frequencies. For these reasons, distributed generators must detect islanding and disconnect immediately from the circuit; it's called anti-islanding. The inverters are attached to solar panels. In case of power failure, the solar panels will continue to provide energy as long as the irradiance is sufficient. In this case, the circuit detached by the fault becomes an "island". For this reason, solar inverters designed to power the grid must generally have a type of automatic anti-islanding circuit. Inverters are devices that convert DC to alternating current (AC). Most VSC inverters are referred for stand-alone operation An inverter connected to the panels converts the variable DC current provided by the panels into an alternating current suitable for mains supply. If the network is disconnected, the voltage on the trunk might drop to zero, which clearly indicates a service outage. The detection of an islanding condition is the subject of much research. In general, they can be classified as passive (transient on the network) and active (probe) methods by sending signals from the inverter or network distribution point. Utility can use these methods to detect network failure and, once network power has shut down the inverters. In other words, when the AC network is available again, the EMS system restores the loads on the AC grid, thus ending the islanding operating mode [4].

3.10 Closure

This chapter includes brief explanation of PV cell modelling, dc-dc boost converter and inverter. The Perturb and Observe MPPT technique is explained. The FACTS devices and working principle of STATCOM and its inverter topology is discussed. Also the islanding mode of operation is discussed.

Chapter 4

Methodology

4.1 Introduction

This section describes the detailed modelling of proposed system. This includes designing of PV- inverter and control of islanding mode of operation. Hardware implementation of the proposed system is discussed in detail in this section. The proposed system is operated in three modes of operation: PV-STATCOM mode, islanding mode and battery charging and discharging mode. Detail explanation of three modes are given in this section.

4.2 Photovoltaic inverter modelling

Inverter is a main part of PV system that converters voltage which is generated by photovoltaic cell that is DC voltage to corresponds AC values. It is nothing but the voltage source converter. It affects the overall performance of PV system. If there are any problem or issue related to the inverter, then it is very difficult to notice unless the inverter totally shunt down.

4.2.1 Configuration of PV inverter

Two kinds of inverter configurations have been recently presented in solar farms. One is called string technology, in which some modules are connected in a string configuration and power the inverter. These huge inverters are connected together to power the network. The other is not very high, but the micro-inverter is also called AC module technology, in that each module has its own inverter and the outputs of all integrated inverters are grouped together to feed the network. For solar farms connected to the grid, several inverter topologies are used. There is a one-step topology for AC modules. A two-stage topology for several modules, a multiple-inverter topology, return inverters, a current-reversing inverter. In order to build an inverter circuit, the manufacturing uses metal-semiconductor field effect (MOSFET), gate-type (GTO), thyristor and insulated-gate bipolar transistor (IGBT) transistors. Here, MOSFET switches are used because of their lower loss and ease of switching. A typical six-pulse inverter with MOSFET switches is shown in Figure ref 401, which includes six MOSFET switches with an associated protection circuit for smooth switching of the producer. Trigger pulses to trigger the MOSFET switches are created from the inverter controller.

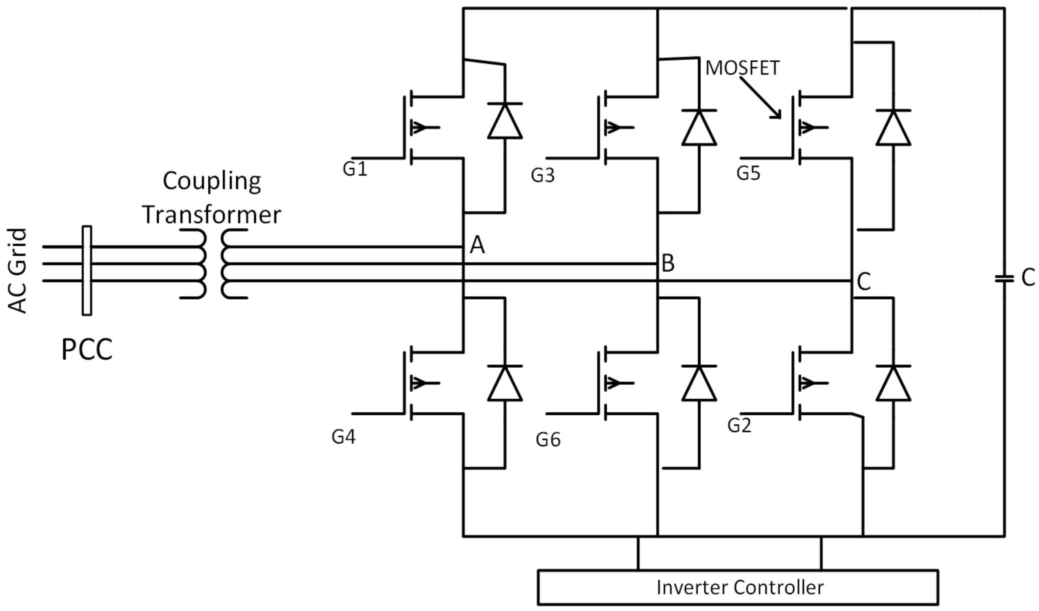

Figure 4.1: Inverter Configuration

4.2.2 Inverter control scheme

The solar photovoltaic park must inject energy into the network with a power factor close to unity, in accordance with several interconnection standards DG. In the control system modeling, two control systems are widely used: the current source inverter (CSI) and the voltage source inverter (VSI) or, alternatively, called the voltage source converter (VSC). . In a CSI scheme, the input of the inverter is maintained as a current source with the use of DC link inductors, while the VSI configuration uses the DC link capacitor to maintain a constant voltage at the same time. input of the inverter. Due to the lower contribution of short-circuit current to network faults, the VSI with the current control strategy is preferred by the industries. Therefore, the rest of the work of this thesis is mainly focused on VSI-based inverter control schemes. To perform trigger pulses for MOSFETs in the inverter, various technologies such as Pulse Width Modulation (PWM) or hysteresis control of the sinusoidal PWM vector are used. Of all these techniques, PWM is widely used for extra high power PV inverter applications.

4.3 PV-STATCOM MODE

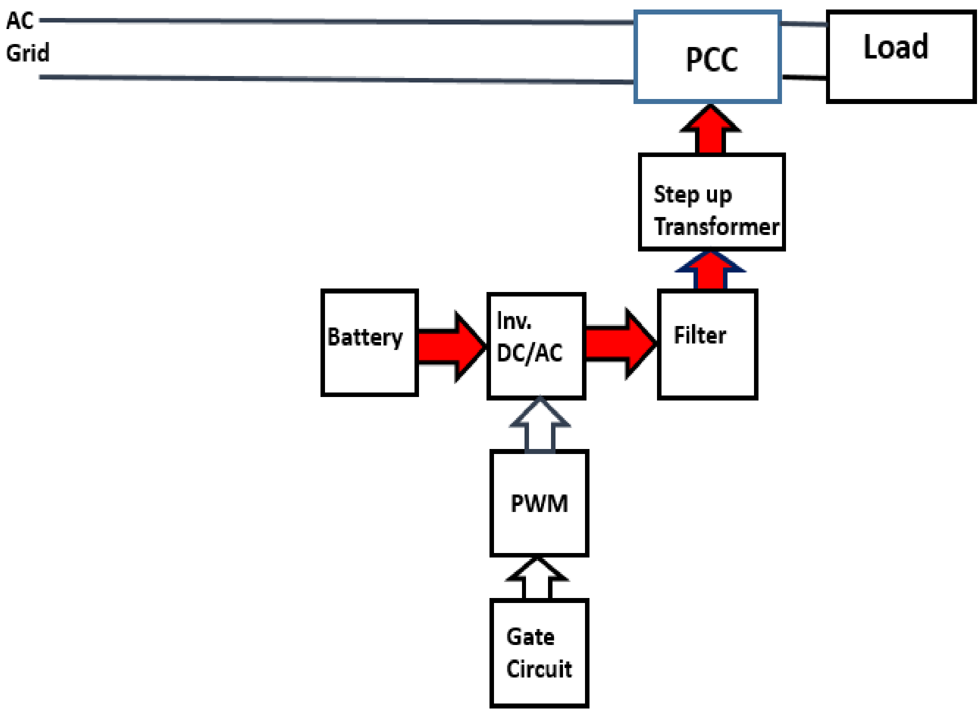

Figure 4.2: Inverter Configuration

The PV solar farm is inoperative at night time period. In this proposed topology of utilizing PV inverter as STATCOM during nighttime increases the utilization factor of inverter [6]. The solar farms are employed as STATCOM for improving the power transfer capacity with utilizing full solar inverter capacity. Also, during day time inverters has capacity remaining after the active power production, this remaining capacity can be employed for increasing the power transfer capability. The battery provides dc supply to the inverter. The gate plues provided through gate circuit. The transformer stepup the voltage level 12V to 230 V. Figure 4.2 shows the block diagram of operation of PV-STATCOM mode.

4.3.1 MOSFET Based STATCOM Configuration

The STATCOM consists of a voltage source converter (VSC) along with the DC link capacitor. The working of DC link capacitor is to preserve the DC link voltage constant hence the voltage at the AC internal is controlled smoothly. The VSC is based on either GTO, thyrisor or MOSFET. The most commonly used system is MOSFET based STATCOM because its cost is low. Snubber circuit is provided with each MOSFET switch, which provides smooth switching operation of MOSFET devices. There are various controlling techniques for MOSFET switches from all that pulse-width modulation (PWM) technique are most commonly used for large size STATCOM. Figure 4.1 indicates typical STATCOM in switch STATCOM output voltage is transform towards the system bus voltage by using the device coupling transformer. After the operation of a PWM technique it is necessary to remove the harmonics of system and maintain the power quality system of the AC side of STATCOM for that purpose filter it used in this system.

4.3.2 Control Topology for PV-STSTCOM

The conventional controllers are only employed to regulate inverter output that is reactive power, along with the dc-link voltage control and maintaining unity power factor [7]. The input of the controller is PCC values, which convert voltage and current from abc to dq0. In conventional controller, PI controllers are utilized for regulating the values of MPPT and dq0. In the PWM switching method, magnitude of the angle of voltage as well as voltage at inverter output are directly proportional to the modulation phase angle and modulation index [8]. The dq0 values are provided for generation of proper switching pulses using PWM to trigger the MOSFET switch i.e. G1, G2, G3, G4, G5, and G6 switches of inverter shown in the Figure 4.1 After the tuning values, they are converted back to abc values from dq0. The PWM converts component of modulating signal to sinusoidal modulating signal which is compared to higher frequency fixed magnitude carrier signal or triangular wave. Exchanging the reactive power between grid and PV-STATCOM plays an important role in the voltage control [9]. For generation of the current reference signal, the output of voltage controller is given to PI controller as shown in the Figure 4.3

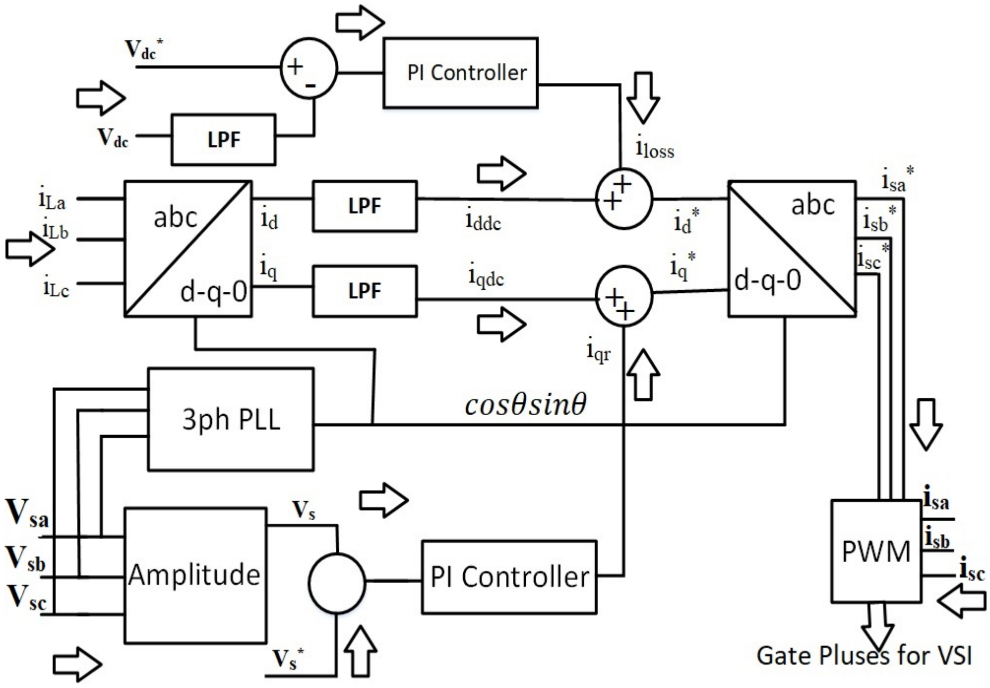

Figure 4.3: Block diagram of proposed control strategy

Figure 4.3 shows block diagram of proposed control strategy. The feedback signals are sensed from PCC voltages and load current. The load current a–b–c frame is converted to d–q–0 frame. The PLL is use to synchronize the signals with PCC voltage. Input currents of three-phase loads are i_{abc}, which are transformed into q axis component i_q and d axis component i_d with d_q transform, including dc component and AC component. The low pass filter (LPF) having cut off frequency 25kHZ which is used to obtaining dc components (i_d and i_q). By passing d–q–0 current component through LPF. The dc component of iq and id are obtained. The error between the sensed dc bus voltage (V_{dc}) and reference dc bus voltage (V_{dc}*) is the input of Proportional Integral (PI) controller. The output of Proportional Integral (PI) controller is i_{loss} i.e. loss component of the current. V_{dc} is difference between sensed dc voltage and reference at nth sampling instant. The K_{id} and K_{pd} are the integral and proportional gains of PI controller. Amplitude of PCC voltage and PCC reference value are given to second PI controller to regulate PCC voltage. To regulate ac voltage, output value of PI controller is add with dc component of iq quadrature component of current is required. Reverse Park's transformation is used to d–q–0 current converted into reference source currents. Reference currents (i_{sa}*, i_{sb}*,i_{sc}*) are used to generate gate pulses for STACOM based voltage source inverter.

4.4 Islanding mode

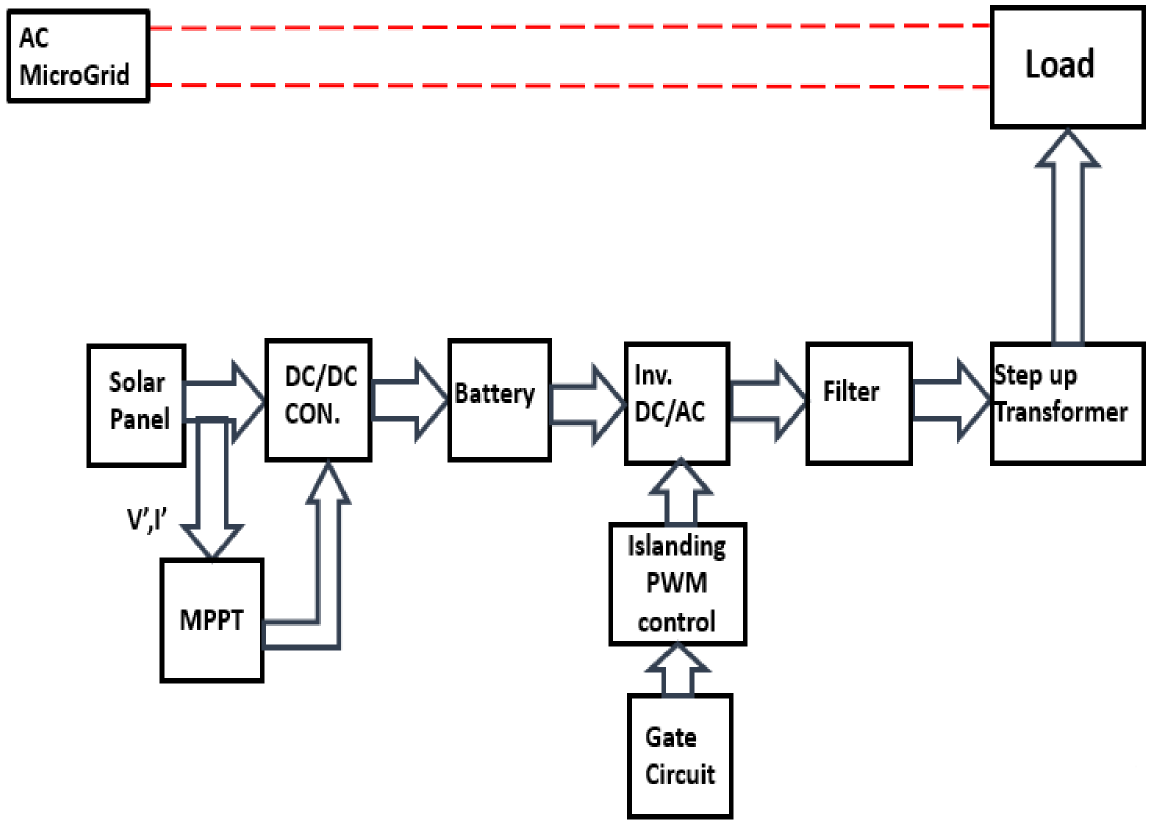

Figure 4.4: Block diagram of operation of islanding mode

Figure 4.4 shows the block diagram of operation of islanding mode. The solar panel is connected to the battery through MPPT and dc-dc converter. MPPT gives constant duty cycle to dc-dc converter and dc-dc converter gives constant output to the battery. The battery provides dc supply to the inverter. The gate plues provided through gate circuit. The transformer stepup the voltage level 12V to 230 V. if grid unable to provide supply to the load at that islanding condition is occure. When grid fails to provide supply to the load, the PV inverter provides the supply to the load.

4.5 Control Topology for islanding mode

Two control technique approaches are used to operate the inverter during islanding mode; active-reactive power (PQ) control mode and voltage-frequency (VF) control mode. In this dissertation work VF control strategy is used. During islanded mode of operation, inverter must be operated in VF mode and synchronized with the main grid. When the microgrid moves to the islanded mode, the system becomes unstable. Here need to set up the system frequency and voltage using this VF operated inverter, as well as properly share the load power. In this case, the reference signals of voltage and frequency are extracted directly from the droop characteristics. If Grid connected to the load, the main grid dictates its voltage and frequency while the microgrid simply exchanges real and reactive powers. In islanded mode, the total power demand of the load has to be supplied by the renewable energy units while regulating the system frequency and voltage. Since the PCC voltage constant after islanding. The droop based controllers of the units increase their power injection to the microgrid. The frequency is set by the main grid, each distributed generator unit is supposed to deliver its rated active power regardless the loading condition. The purpose of using VF control is that no matter the inverter power how to change, the amplitude and frequency of output voltage remain the same, the inverter of V/F control can provide voltage and frequency support for microgrid during islanded operation [3]. Regulation of frequency and voltage in islanding condition distributed generators (DGs) operates under the voltage frequency control. In islanding mode of operation, VSI must be used in VF control mode to regulate the system voltage and frequency within acceptable limits [4], [5]. The excellence of this control strategy lies in the fact that no communication infrastructure is needed. The block diagram of a VF control adopted by VSI is shown in Figure 4.5. For these units, the classic droop control strategy is used. As shown in Figure 4.5, the VF controller. Includes three sections: lowering controller, voltage controller and current controller. The attenuation controller determines the amplitude and frequency of the output voltage of the inverter as a function of the characteristics of sagging and sharing of the active and reactive powers. The voltage and current controllers are designed to reject high frequency disturbances and provide a desirable value for the output voltage of a VSI. The main advantage of this control topology is that no additional communication device is required. It only includes local measurements and plug-and-play operation. The basic scheme for controlling the voltage frequency adopted by the voltage source inverter is shown in Figure 4.5.

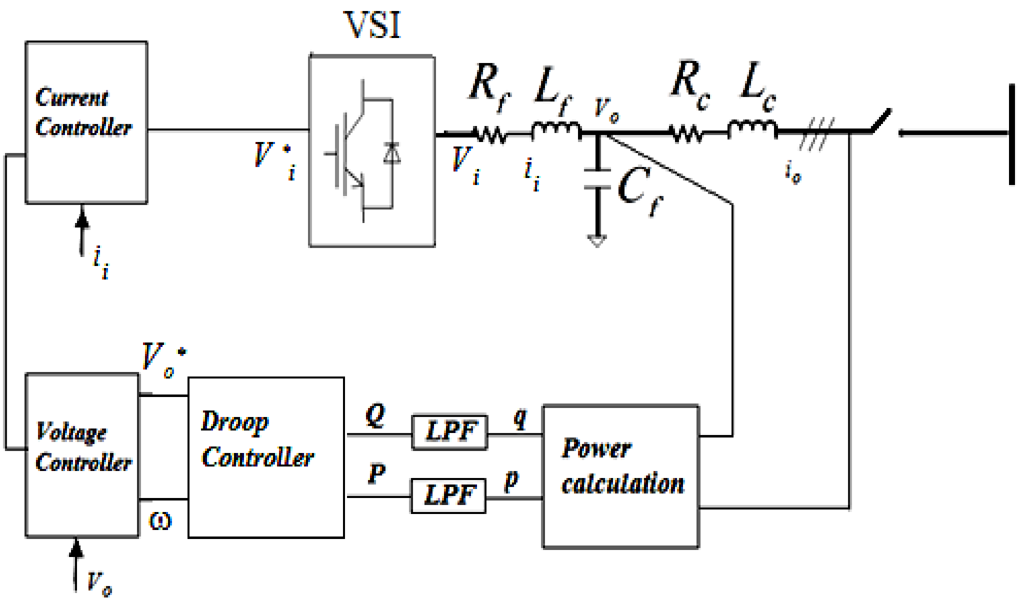

Figure 4.5: General block diagram of VF control topology

This control strategy includes three controllers i.e. current controller, voltage controller and droop controller. According to real and reactive powers sharing and droop characteristics, the droop controller determine the frequency and magnitude of output voltage of inverter. To cancel out the disturbances of high frequency and to provide suitable value to output voltage of VSC, the current and voltage controllers are designed. Instantaneous reactive and real power component in d-q frame are defined by measuring output current and voltage.Instantaneous active and reactive power components in dq frame are calculated by measuring output voltage and output current as follows:

$$P = \frac{3}{2}\left[V_d * i_d + V_q i_q\right] \tag{4.1}$$

$$Q = \frac{3}{2}\left[-V_d * i_d + V_q i_q\right] \tag{4.2}$$

Where V_d and V_q are the voltage components of dq-frame of AC system and it cannot be controlled by the VSC system. When PLL in steady state, Vq =0 and equation 1 and equation 2 can be written as equation 3 and equation 4 respectively

$$P = \frac{3}{2} V_d * i_d \tag{4.3}$$

$$Q = \frac{3}{2} - V_d * i_d \tag{4.4}$$

The active reactive power share between Voltage and frequency distribution grid based on drop gain as in

$$w = w_n - m_p P \tag{4.5}$$

$$v* = v_n - n_q Q \tag{4.6}$$

Where w and v* shows the reference output frequency and voltage of inverters, and w_n and v_n are their nominal values respectively. Also mp and nq are the droop coefficients. Where v* and w shows reference output voltage and frequency of inverters, and w_n and v_n are their nominal values respectively. mp and nq are droop coefficients. The droop coefficients can be calculated as

$$m_p = \frac{w_{pccmax} - w_{pccmin}}{P_{max}} \tag{4.7}$$

$$n_q = \frac{V_{max} - V_{dmin}}{Q_{max}} \tag{4.8}$$

The droop control method is based on locally measured data, does not depend on communication signal, accordingly eliminating the difficulties imposed by physical location. The droop method has other advantages such as great flexibility, high reliability, simple structure, easy implementation, free laying, and different power ratings. In power grids, the active power and the reactive power have strong coupling with the frequency and the voltage, respectively. The output of droop controller is given to voltage controller which is shown in the Figure 4.6.

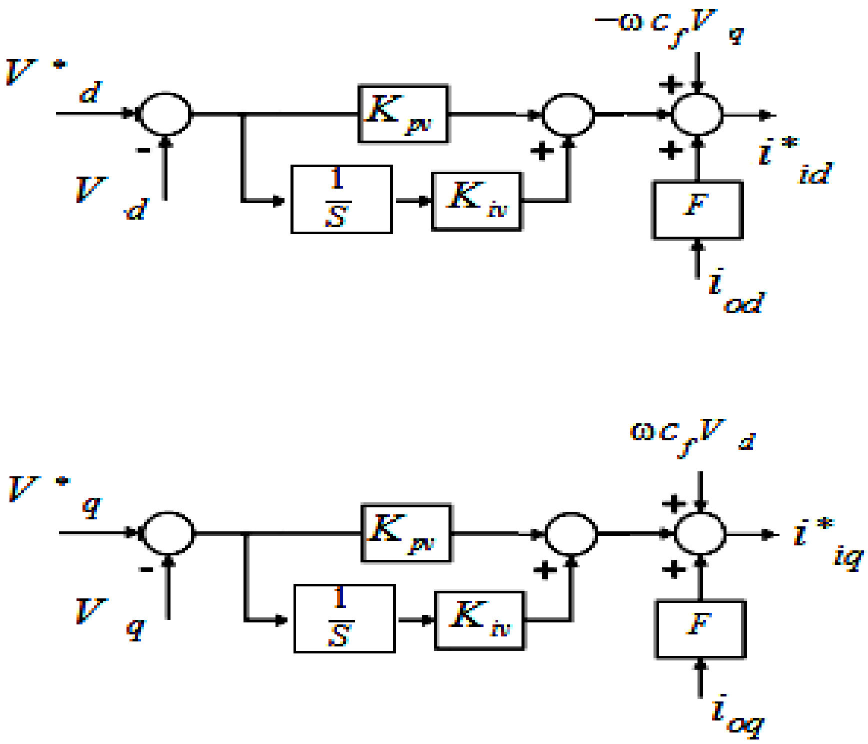

Figure 4.6: Block diagram of voltage controller

Voltage controller equations are

$$v_{id}* = \left(\frac{k_i c}{s}\right)[i_i d * - i_i d] - w_n L_f I_o q \tag{4.9}$$

$$v_{iq}^* = \left(\frac{k_i c}{s}\right)[i_i q * - i_i q] - w_n L_f I_o q \tag{4.10}$$

Where V_{id}^* and V_{iq}^* are the AC system dq-frame common reference frame voltage components. The Figure 4.7 shows block diagram of current controller. Axis DQ is set as common reference frame rotating at frequency w_n. whereas I_{id}^* is the current of reference frame of i^{th} inverters and at D axis and I_{iq}^* is the current of reference frame of i^{th} inverters at Q axis.

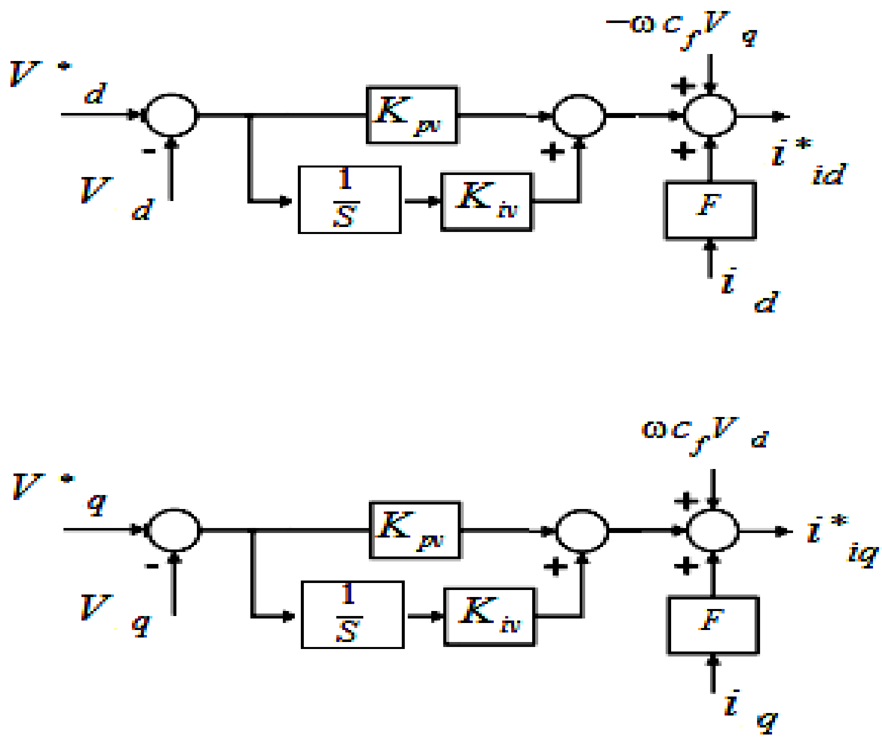

Figure 4.7: Block diagram of current controller.

Current control loop is considered as conventional proportional-integral (PI) controller which is shown the in Fig. 7. The output of the current controller is given to the inverter for switching.

$$I_i d* = \left(K_P V + \frac{k_i v}{s}\right)[V_d * - V_o d] + F i_d - w_n C_f V_q \tag{4.11}$$

$$I_i q* = \left(K_P V + \frac{k_i v}{s}\right)[V_q * - V_o q] + F i_q - w_n C_f V_q \tag{4.12}$$

4.6 Battery charging mode

Figure 4.8 shows the block diagram of operation of Battery charging. The solar panel is connected to the battery through MPPT and dc-dc converter. MPPT gives constant duty cycle to dc-dc converter and dc-dc converter gives constant output to the battery. The battery provides dc supply to the inverter. The gate plues provided through gate circuit. The transformer stepup the voltage level 12V to 230 V. The battery can charge using two ways: throught grid and through solar panel. The Figure 4.8 shows both way battery charging of battery. The battery is charged through grid by using half wave rectifire.

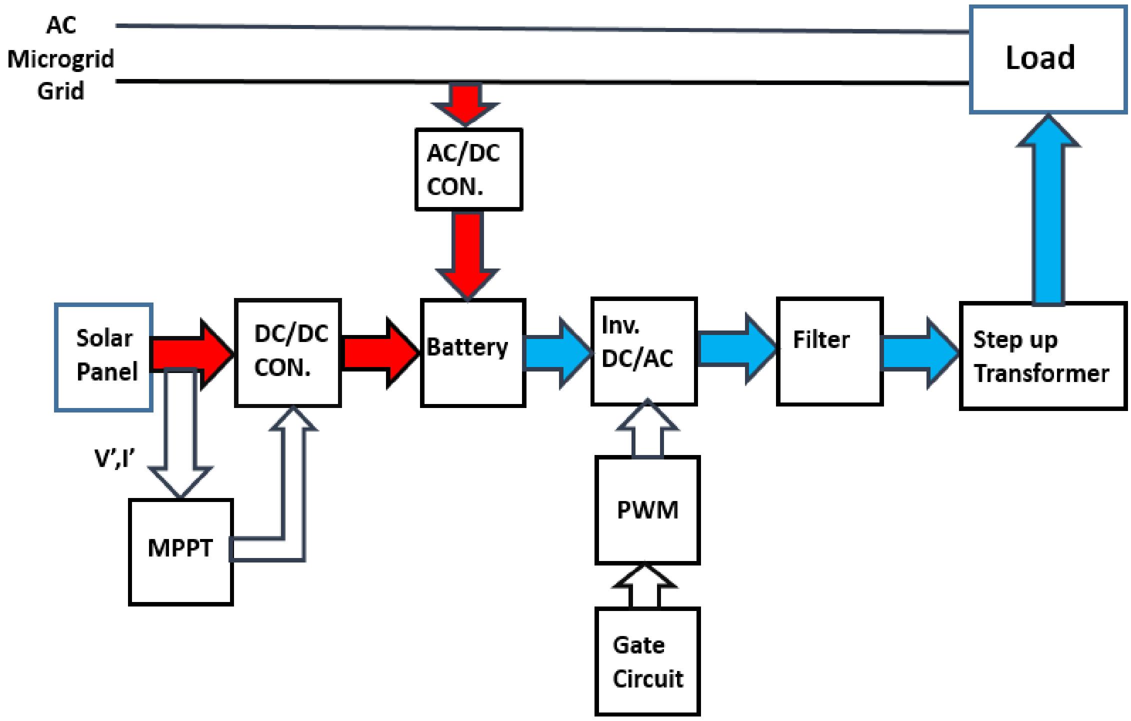

Figure 4.8: Block diagram battery charging and discharging mode

4.6.1 Half wave rectifier

A rectifier is an electronic device that converts AC voltage into DC voltage. In other words, it converts AC to DC. A rectifier is used in almost all electronic devices. Generally, it is used to convert the main voltage into DC voltage in the power section. By using a DC voltage supply, electronic devices work. Depending on the conduction period, the rectifiers are classified into two categories: half-wave rectifier and full-wave rectifier.

Working principle:

During the positive half cycle, the diode is under direct bias condition and conducts the current per load. Voltage is developed across the load, which is identical to the input AC signal of the positive half-cycle. Alternatively, during the negative half-cycle, the diode is in a reverse bias condition and no current flows in the diode. Only the AC input voltage appears on the load and it is the net result that is possible during the positive half-cycle. The output voltage pulses on the DC voltage. During the positive half-cycle, when the secondary winding of the

upper end is positive with respect to the lower end, the diode is in the direct bias condition and conducts the current. During positive half-periods, the input voltage is applied directly to the load resistor when the direct resistance of the diode is assumed to be zero. The waveforms of the output voltage and the output current are identical to those of the AC input voltage. During the negative half-cycle, when the secondary winding of the lower end is positive with respect to the upper end, the diode is in a reverse bias condition and it does not conduct current. During the negative half-cycle, the voltage and the current across the load remain zero. The magnitude of the reverse current is very small and neglected. Thus, no power supply is delivered during the negative half-cycle. A series of positive half-cycles corresponds to the output voltage developed in the load resistor. The output is a pulsed continuous wave and to use the smooth output wave filters, which should be placed across the load, are used. If the input wave is half cycle, then it is called half-wave rectifier.
PN junction diode conducts only during the forward bias condition. Half wave rectifier uses the same principle as PN junction diode and thus converts AC to DC. In a half-wave rectifier circuit, a load resistance is connected in series with the PN junction diode. Alternating current is the input of the half wave rectifier. A step down transformer takes input voltage and the resulting output of the transformer is given to the load resistor and to the diode. During the positive half cycle, the diode is under forward bias condition. During the negative half cycle, the diode is under reverse bias condition. The voltage output is measured across the load resistance. During the positive half cycles the output is positive and significant. And during the negative half cycle the output is zero or insignificant. This is known as half wave rectification.

Advantages

- It is Cheaper than full wave rectifier.
- Simple to implementation.
- Few components are used for implementation.

4.7 Experimental Setup

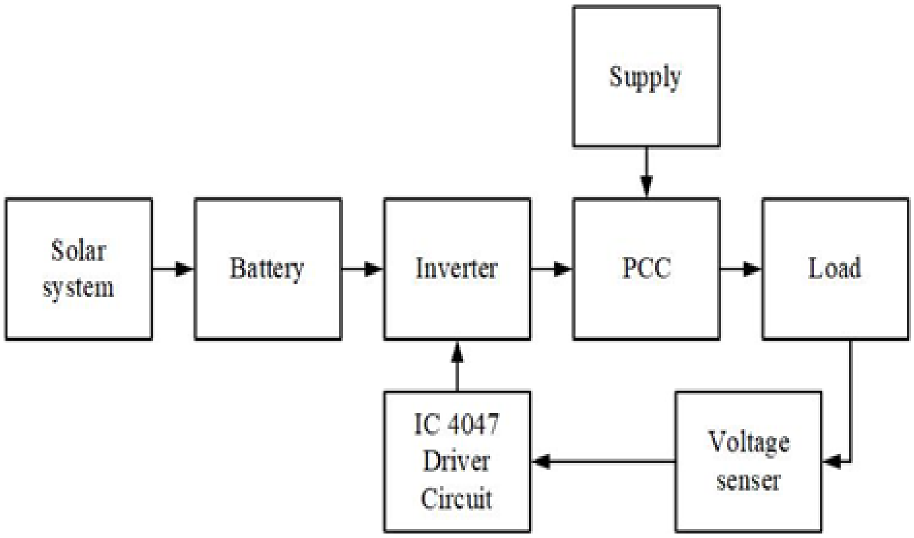

Figure 4.9: Block Diagram of Prototype Hardware

For hardware the single phase system considered. Figure 4.9 shows the block Diagram of Prototype Hardware. Proposed prototype Experimental Setup is shown in Figure 4.10. It consists of the single-phase supply system which is connected to grid and load. The hardware implementation is for a single-phase system. For each phase, different transformers are used. Inverter having separate driver circuit which is designed by using IC 4047. The prototype hardware having 60W solar panel and 3 lead-acid battery. For PV-STATCOM mode one 12V 7Ah battery is used and for islanding mode of operation two 12V 7Ah batteries connected in series which is used to provide 24V supply to inverter. Battery supply 12V and 24V are provided to driver circuit of inverter.

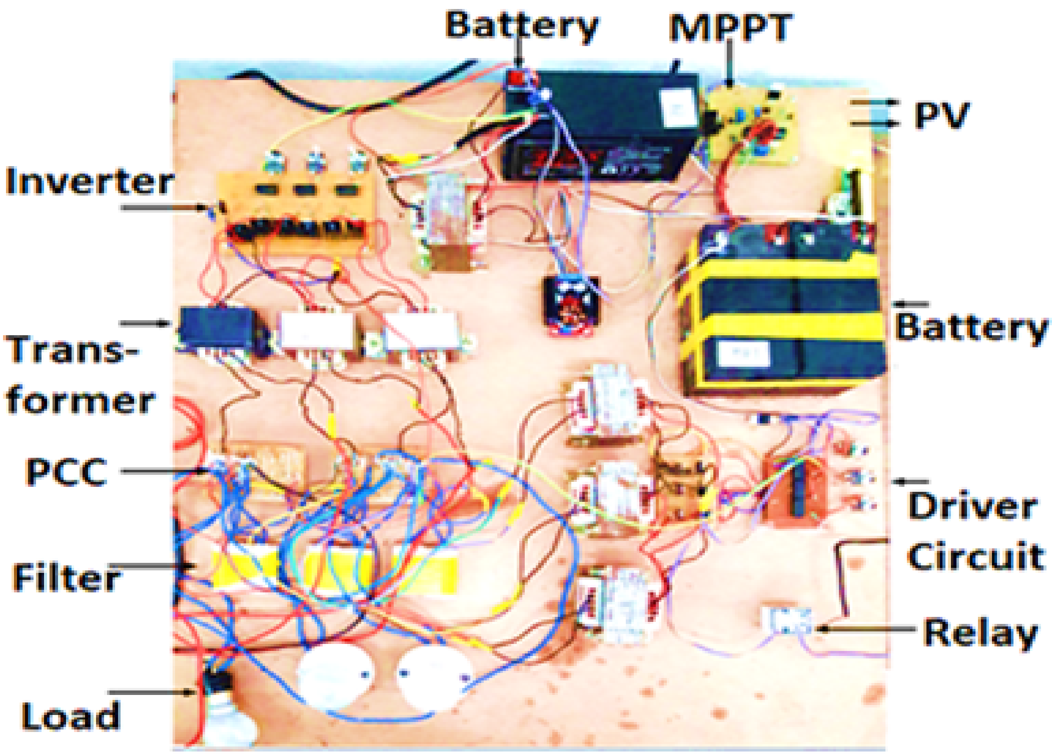

Figure 4.10: Experimental Setup

4.8 Specifications of components

4.8.1 PV Modules

PV modules having 60W rated power. This is polycrystalline solar module. The output voltage of this module is 12V with open circuit voltage is 22V and short circuit current is 5A. It having Efficiency 22% and Moderate efficiency in cloudy condition. Figure 4.11 shows the PV module.

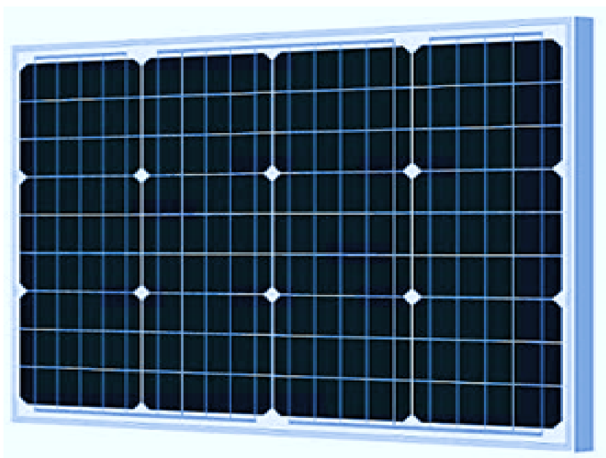

Figure 4.11: PV module

4.8.2 Charge Controller

The charge controller is the key element of a Solar Home System. It cuts off the power supply to and from the battery beyond certain preset levels thus ensuring the proper band of charge level. Under the condition of charging, if the voltage of battery increases above the some pre-set value or limit then this system stops charging battery afterwards. Likewise, when the battery discharging process reaches to the some pre-set value then after that point it stops discharging the battery by disconnected from the load. This optimizes the performance and life of a battery.

4.8.3 Driver circuit

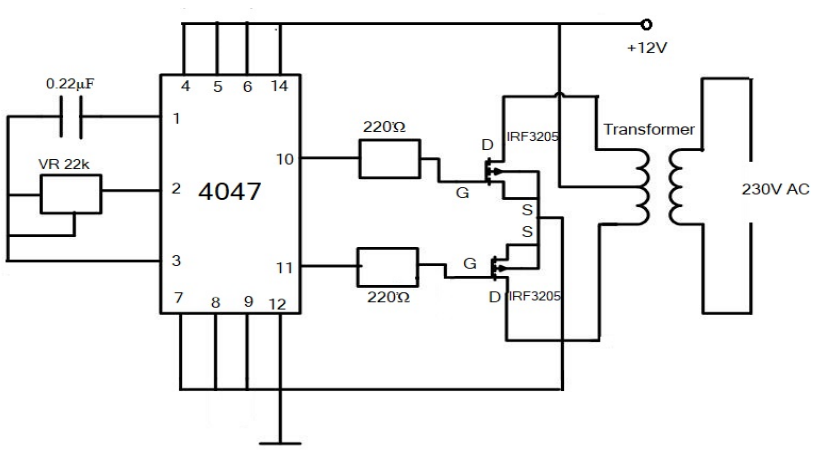

Figure 4.12: Inverter using IC CD4047

An inverter is a device which converts DC power into AC. This is the main part of PV inverter. Basically there are three types of inverters are used

- Square wave inverter
- Quasi square wave or modified square wave inverter
- Quasi square wave or modified square wave inverter
- Sine wave inverter

Generally, sinusoidal inverters are used because of it having low cost, simple to implement. For driving the inductive loads, the sine wave inverters with IC 4047 are preferred. This system does not requires extra battery charging circuit. This

type of driving circuit is used up to 1000W power applications. IC 4047 requires low power for operation and it is able to operate under to modes astable and monostable. This system constructed to operate as astsble multivibrator mode. Its working depends on the capacitor and varying resistor. In astable mode capacitor is charged through variable resistor for every mode of operation. The use of variable resistor RV1 in this circuit is to adjust the output frequency 50Hz. For calculation of oscillation time period, the following relation is used.
The detailed working of IC CD4047 is obtained from its datasheet. The driver IC DC4047 has two output pins (pin 10 and pin 11): these two pins are complementary to each other. The generated sine wave pules from IC DC 4047 are pre-amplified using the MOSFET. The current of an amplifier circuit is used for driving the transformer. The circuit consists of two IRF 3205 MOSFET is parallel combination for improving current carrying capacity. The IC required 9V voltage which is provided by using capacitor. When the output pin 10 is low i.e 0 and the output pin 11 is high i.e 1, therefore the MOSFET 1 and 2 are turn on and the current will flow through upper winding of transformer. It generates positive half cycle of output. When the output pin 10 is high i.e. 0 and the pin 11 is high i.e. 1, therefore the MOSFET 3 and 4 are turn on and the current will flow through lower winding of transformer.
This is a fairly straightforward inverter that provides 220V AC when a 12V DC source is provided. It can be used to power very light loads such as night lights and cordless phones, but can be converted into a high-performance inverter by adding more MOSFETs. It uses 2 power IRF3205 MOSFETs to drive the output power and the 4047 IC as a stable multivibrator operating at a frequency of about 50 Hz.The 10- and 11-pin outputs of the IC direct-acting MOSFETs used in a push-pull configuration. The output transformer has 9V-0-9V, 2A on the secondary and 230V on the primary. Use appropriate radios for MOSFETs. It generates negative half cycle of output. Its output is pure sinusoidal wave. The proposed circuit is applicable for the resistive loads and inductive loads. For this proposed inverter, 12 V 8Ah lead-acid battery supply is used. The transformer rating is 12-0-12 V.

Driver circuit flip flop IC 4047

This the main component of the driver circuit this consists of one IC. It consist of simple low power PWM inverter. This is the low power IC which is adapted to operates in Astable and Monostable Multivibrator State. In the proposed system, it is used as Astable mode.

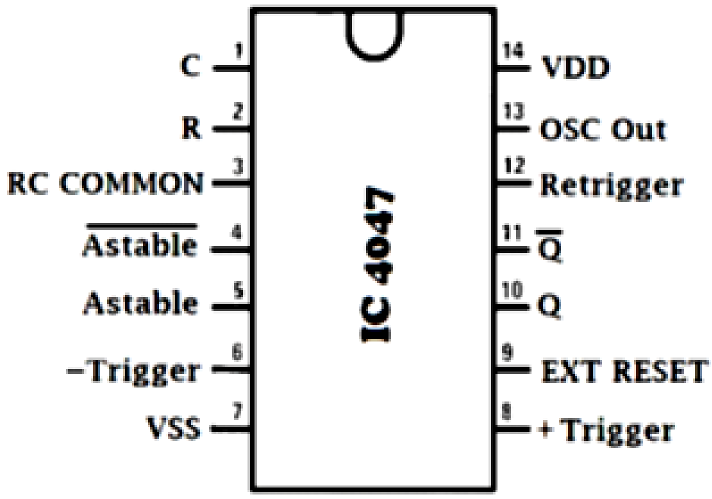

Figure 4.13: pin description of IC 4047

Features of Driver circuit flip flop IC 4047.

- High Voltage Type (20V rating)
- Power consumption is low
- Monostable or Astable operation
- True and complimented buffered outputs
- It requireds only one external R and C
- It have buffered inputs
- Standardized, symmetrical output characteristics
- 5 V, 10 V, 15 V parametric ratings

Astable multivibrator features

- Free running or gatable operating modes
- 50% duty cycle
- Oscillator output available
- Astable frequency stability is good

Applications

- Digital equipment where low power dissipation or high noise immunity are primary design requirement
- Envelope Detection
- Frequency Multiplication
- Frequency Division
- Frequency Discriminators
- Timing Circuits
- Time Delay Applications

4.8.4 Transformer

The main purpose of the transformer is to change the value of voltage level. The transformer used in this project is the step-down transformer. In the step-up transformer, the secondary side of the transformer has less turns than the primary turns. Hence the voltage at secondary side is less than primary side. The voltage is stepped up from 12V to 230V. The voltage sag is formed by using step-down transformer. The secondary winding turns are 86 with 1.02mm wire and primary winding has 1648 turns with 0.142mm wire.

4.8.5 Diode (IN4007)

Diode is the device which just allows the unidirectional flow of current if it operates on rated voltage. Diode simply blocks the reverse flow of current. The IN4007 series diodes are the general purpose silicon rectifier diodes of 5A rating. It is generally used in AC adapters for all household appliance. Blocking voltage of this diode contrasts from 50V to 1000V. **Features**

- Defused junction
- High current capability and low forward voltage drop
- Surge overload rating to 30A peak
- Low reverse leakage current

4.8.6 MOSFET (IRF3205)

This MOSFET connected to the primary of transformer and it provides 12 V AC. The circuit consist of four MOSFETs. Based on the output pin polarity of IC 4047 the MOSFET con get on and off. At the time only two MOSFET in on condition.
Features

- Dynamic dV/dt rating
- 1750C Operating temperature
- Fast switching

4.8.7 Voltage regulator

The main objective of the designing of voltage regulator is to maintain constant output voltage. Voltage regulator is require where need to change the voltage level as per requirement of circuit and voltage is unstable. The voltage regulator is used for two purpose:

- For regulating and vary output voltage across the circuit
- To maintain the constant voltage at output under different voltage supply or load current.

The driver circuit consist of one voltage regulator to regulate 12 v voltage output and this12 V output pin is directly connected to the middle tapping of the transformer.
Features

- Excess Output current 5A is sustain
- External thermal overload protection
- No external components required to regulate voltage
- Internal short circuit current is limit
- Available in the aluminum TO-3 package

4.8.8 Transistor (C828)

This transistor is NPN Silicon Epitaxial Planar Transistor used for switching and MPPT. These transistors are split into three groups Q, R and S based on their DC current gain. Figure 4.18 shows the pins of the transistor C828.

4.8.9 Liquid crystal display (LCD)

Liquid crystal display is one of the electronic modules of a display screen and has much more application. The basic module of LCD is 16x2 LCD display and it is used for various circuits and devices. Seven segments are preferred over this module. A 16x2 LCD stands for characters are 16 per line and 2 lines are present. The character in the LCD displayed is 5x7 pixel matrix. The two registers in this LCD are data and command. Storage of data is done by data register. The instructions to be given for LCD is stored by the command register. One of the instructions given is the command in which it performs various tasks like controlling the display, the setting of cursor position, clearing of the screen also initializing the history. The data which is to be displayed on the screen is stored by data register. This Liquid crystal display used for showing solar panel voltage, battery voltage, ON and OFF charging state of battery.

4.8.10 Boost converter

The boost converter is cost-efficient; no any external components are required. The regulation of output voltage is maintained by a boost converter. If the input voltage is less as compared to output voltage then the boost converter maintains the voltage.. To obtain easy control in this converter, low side boosts MOSFET and high side boost MOSFET is included.

4.9 Closure

The detailed overview of the proposed system is described in this chapter. The overview of solar panel and its solar charge controller is described in this chapter. The block diagram, prototype hardware model and its components with features are described.

Chapter 5

Results and Discussion

5.1 Introduction

In this chapter, the proposed system is implemented in MATLAB Simulink and simulation results are presented. Also, the proposed improved EMS is checked experimentally. The experimental results are presented in section.

5.2 Three Phase System

The three phase 100W system is simulated in two modes: PV-STATCOM mode and islanding mode. The system consist solar panel, MPPT, battery, inverter, transformer, filter, microgrid.

5.2.1 Simulation

PV-STATCOM Mode

The Solar panel having 60W 12V rating.L is the inverter side filter with i3.2mH rating. C is the inverter side filter with 0.04mF rating. Fundamental frequency of System is 50HZ and Switching Frequency is 4kHZ. The Line Voltage (RMS) is 440V. The Figure 5.1 shows simulation of PV-STATCOM Mode.

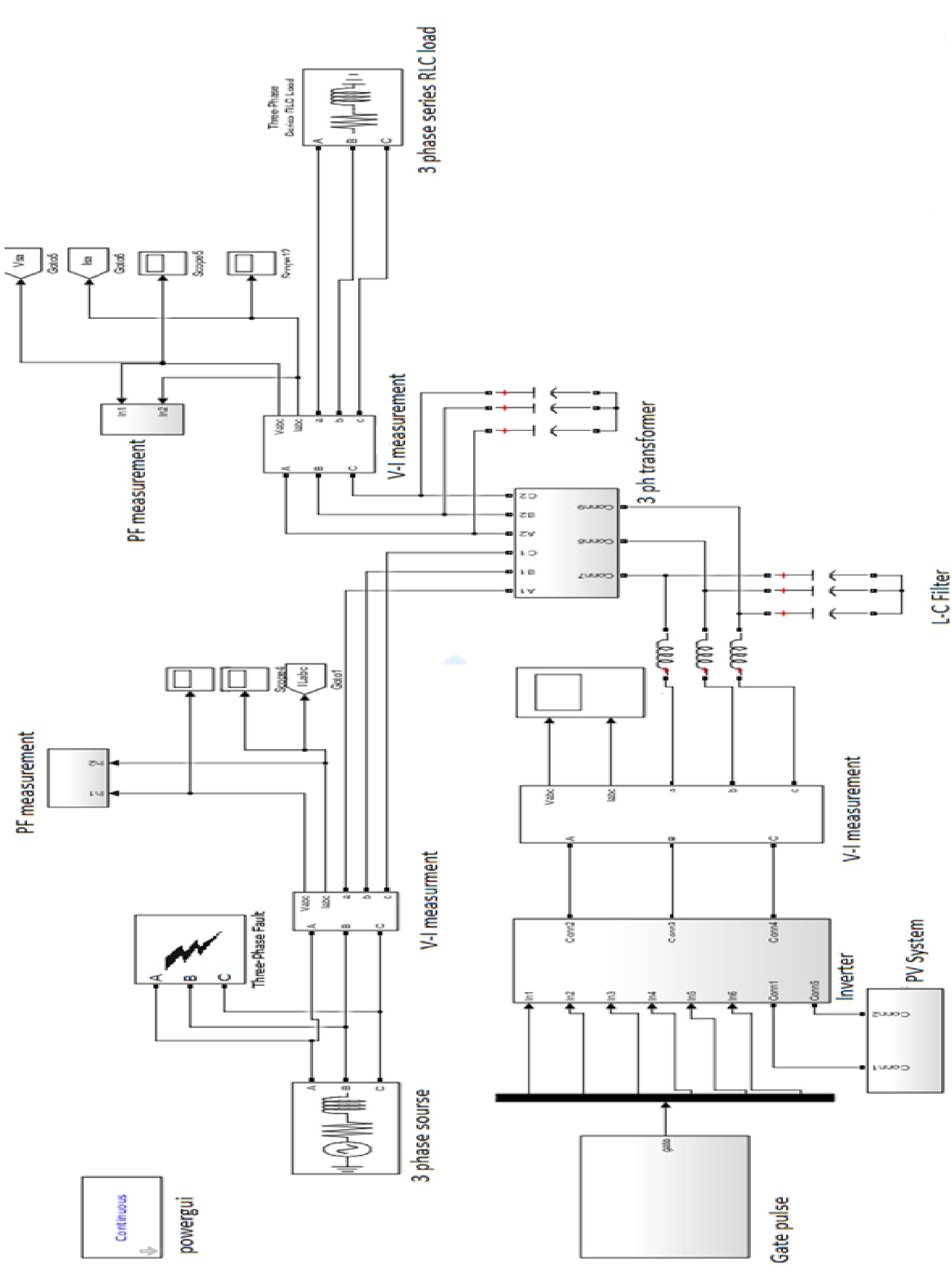

Figure 5.1: Simulation of PV-STATCOM Mode

Figure 5.1 show the simulation of PV-STATCOM mode. Consider the three-phase transmission line. The fault occurs on the transmission line during 1-1.3 sec. In faulty condition, there is voltage drop in transmission line and current is much higher. Voltage is dropped over the length of the line leaving less voltage during fault. V=I*R Therefore there power is loss in transmission line. At this condition system needs reactive power.

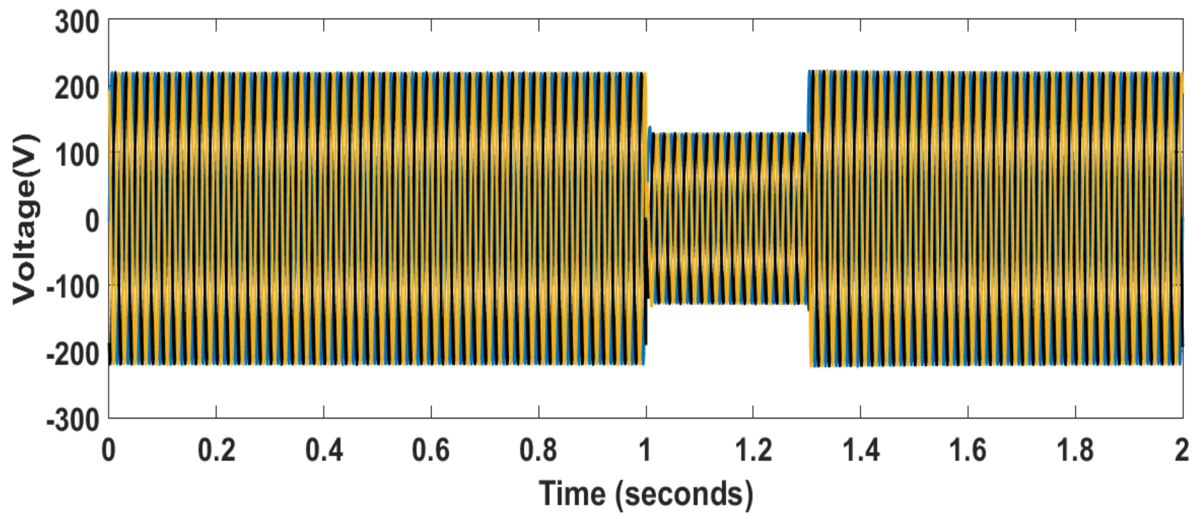

Figure 5.2: Voltage during fault condition

The Figure 5.2 shows voltage verses time characteristics. When three phase fault occur on the transmission line (short circuit fault). The current suddenly go on increasing (infinity) and voltage drops. Also, these results show some power loss in transmission line.

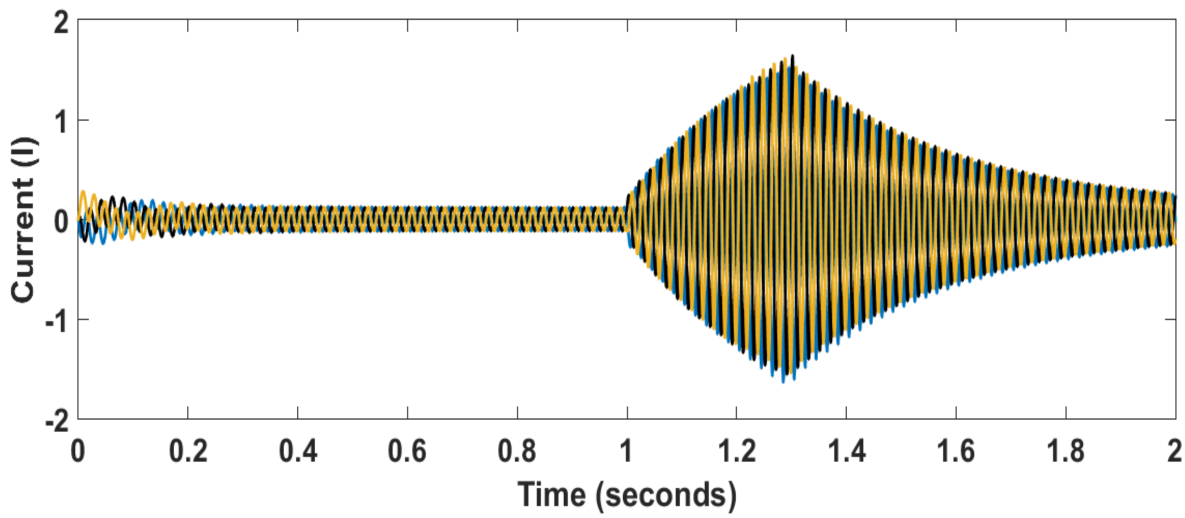

Figure 5.3: Current during fault condition

Figure 5.3 shows the current waveform during fault. Current suddenly goes on increases during fault condition.

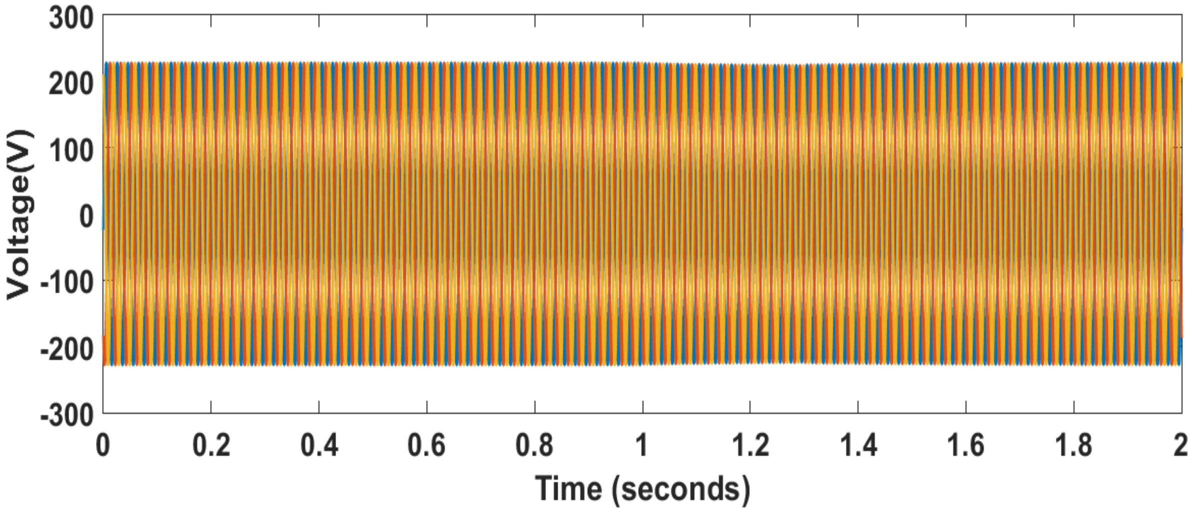

Figure 5.4: Voltage after reactive power injection

After injection of reactive power, the voltage of line is increased. The Figure 5.4 shows the voltage waveform after injection of reactive power. The voltage drop during the fault condition is nullified

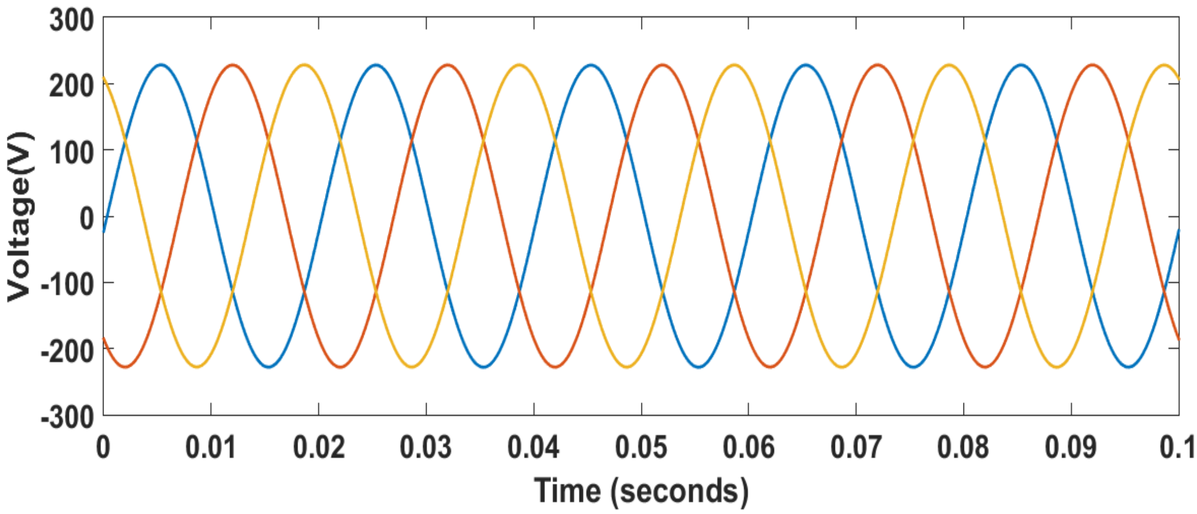

Figure 5.5: Voltage waveform after fault clearing

Figure 5.5 shows zoomed view of voltage waveform after fault clearing.

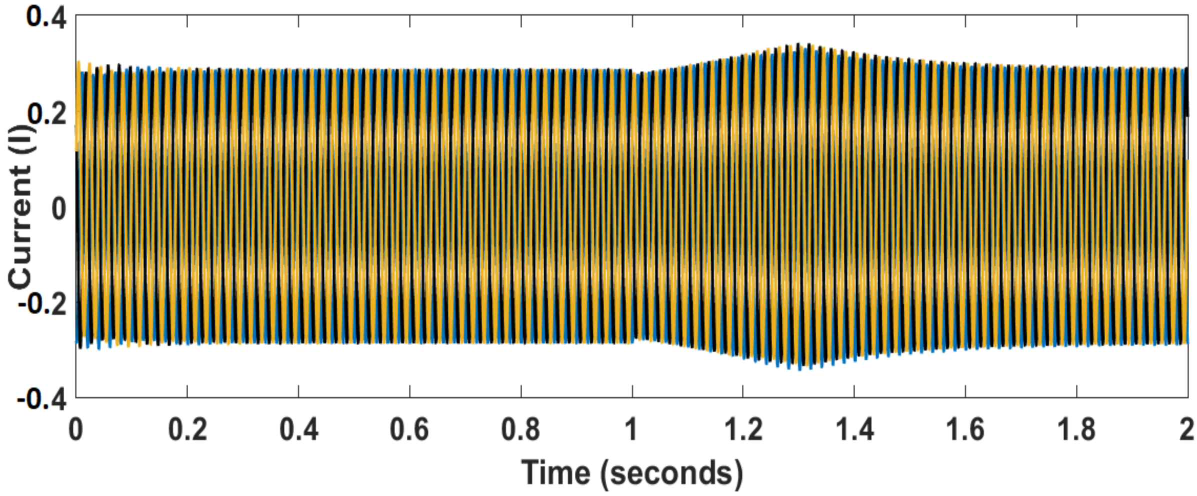

Figure 5.6: Current after reactive power injection

Current waveform after reactive power injection is shown in the Figure 5.6 the current is in proper limit after reactive power injection. The reactive power of the line before injection of reactive power is 144VAR. After reactive power injection by PV inverter the total reactive power is 220VA.

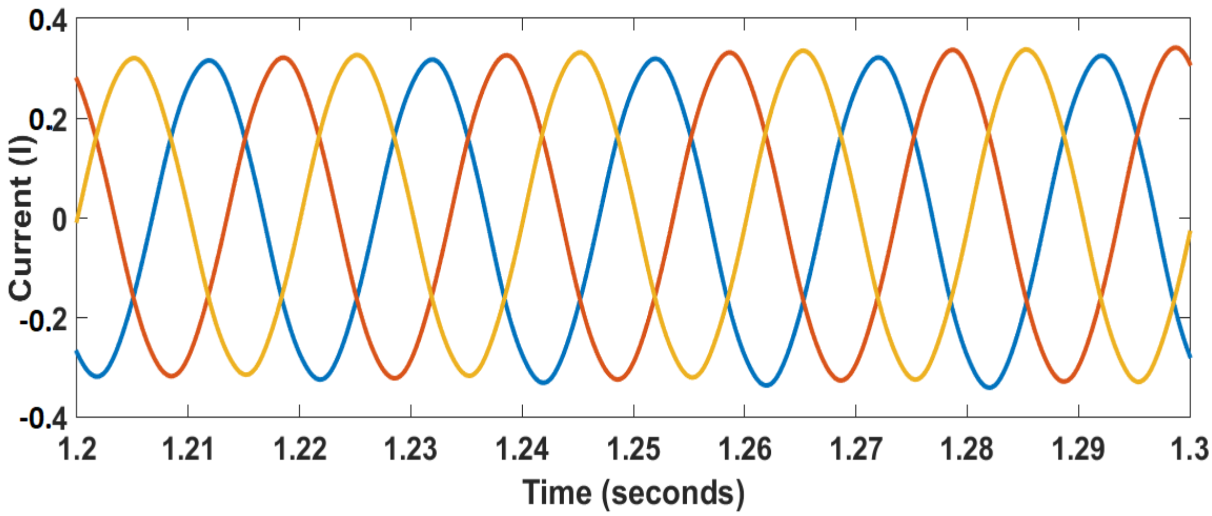

Figure 5.7: Current waveform after fault clearing

Figure 5.7 shows view of current waveform after fault clearing.

Islanding Mode

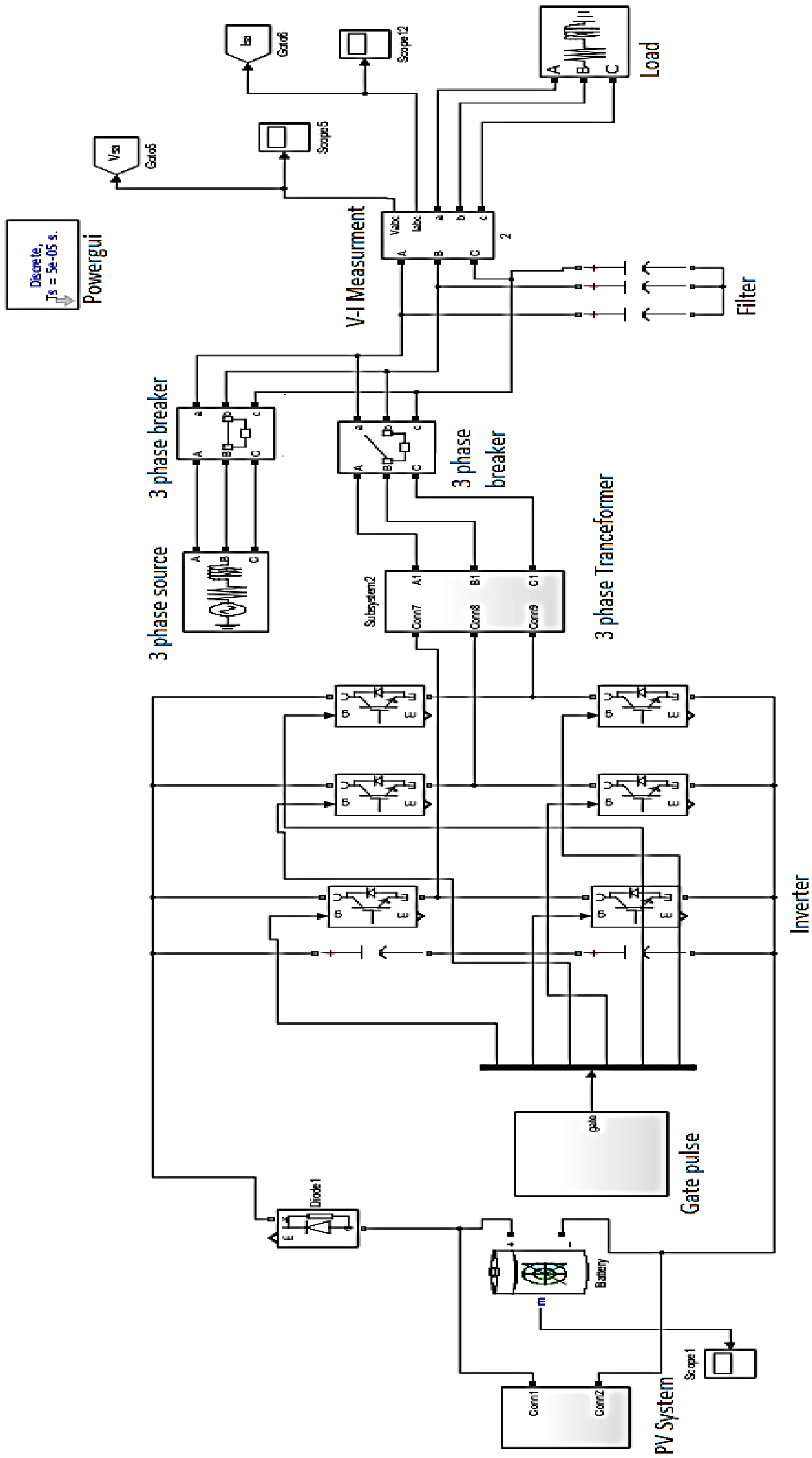

Figure 5.8: Simulation of Islanding Mode

Figure 5.8 show the simulation of islanding mode. Here the islanding mode is simulated using the breakers. This system has two breakers. First breaker is connected after the three-phase source. Initially this breaker is closed. At 1 to 2 sec. the breaker is open. Supply to the load is cutoff during time instant 1 to 2 sec. At this condition islanding condition is occur. After the time 2 sec. again breaker is close and grid is able to provide supply to load. The second breaker is connected to the PV system after the injection transformer. This breaker is initially open. At time instant 1 to 2 sec. the breaker is closed and able to provide supply to load during islanding mode. After the time 2 sec. breaker goes on original open position. After time 2 sec. the grid is available to provide supply to load. The inverter is designed for 700W load. The output voltage of inverter is 13.45 volts. The transformer is used to step up voltage of inverter. The inverter output voltage is steped up upto 440 V.

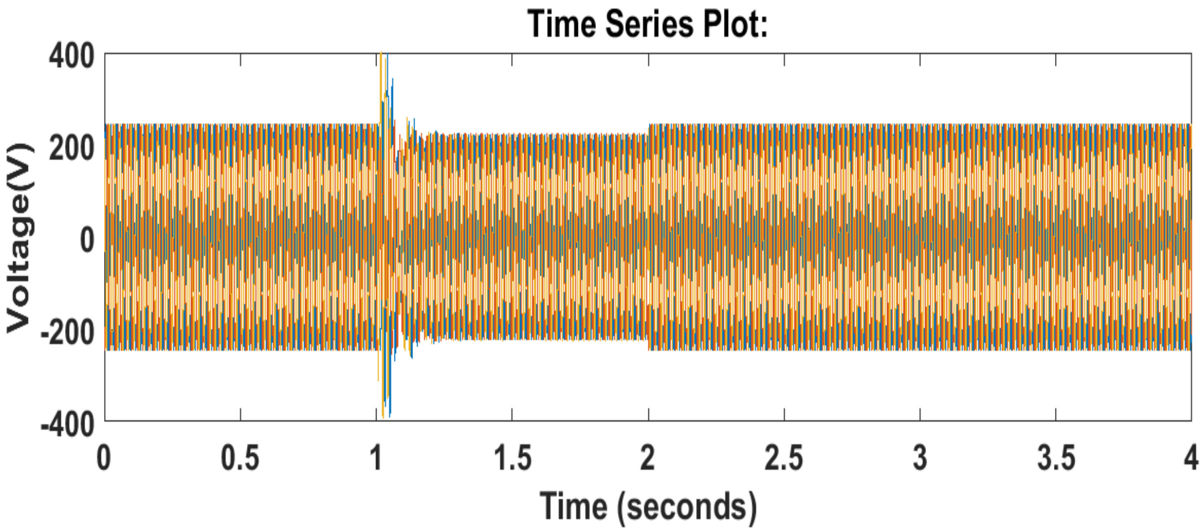

Figure 5.9: Voltage waveform of islanding mode

Figure 5.9 shows voltage Waveform of islanding mode. Time 0 to 1 sec. instant grid is present. Time 1 to 2 grid supply is absent and supply provide to the by PV inverter. During the switching of the breaker some harmonies are produce. Before the 2 sec. grid is available to provide supply and PV inverter supply is cutoff.

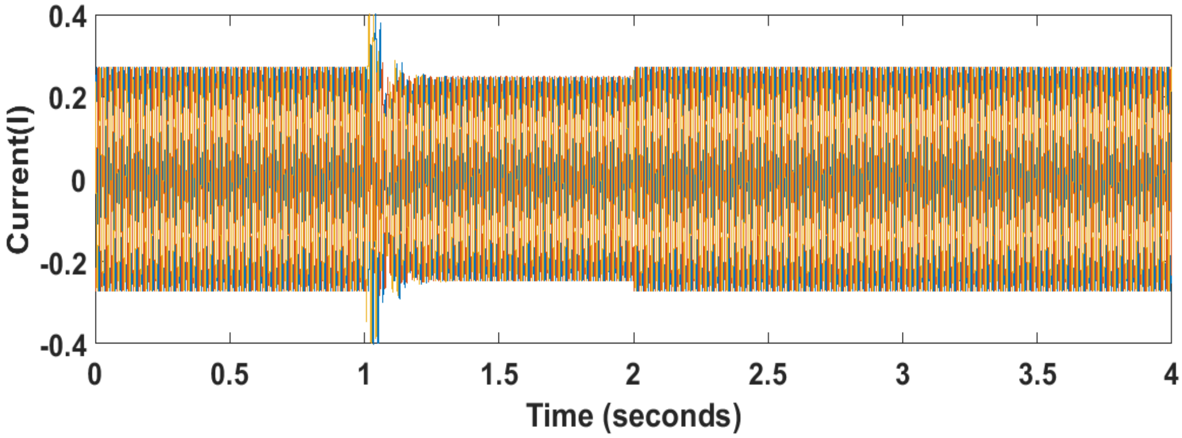

Figure 5.10: Current waveform of islanding mode

The Figure 5.10 shows the current waveforms during islanding mode. During the switching some harmonics create on the system.

Battery Charging Mode

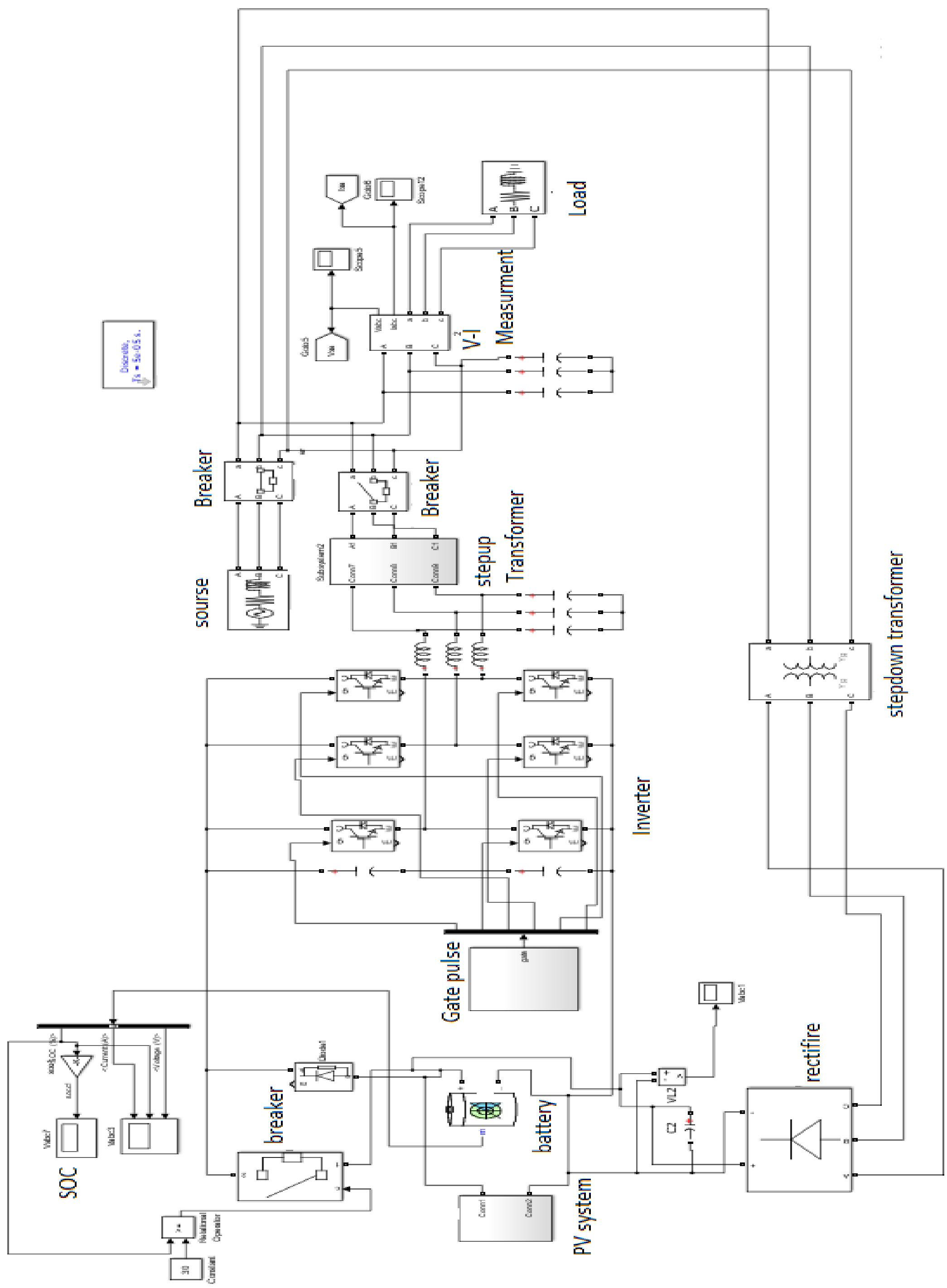

Figure 5.11: Simulation of Battery Charging Mode

Figure 5.1 show the simulation of battery charging mode.

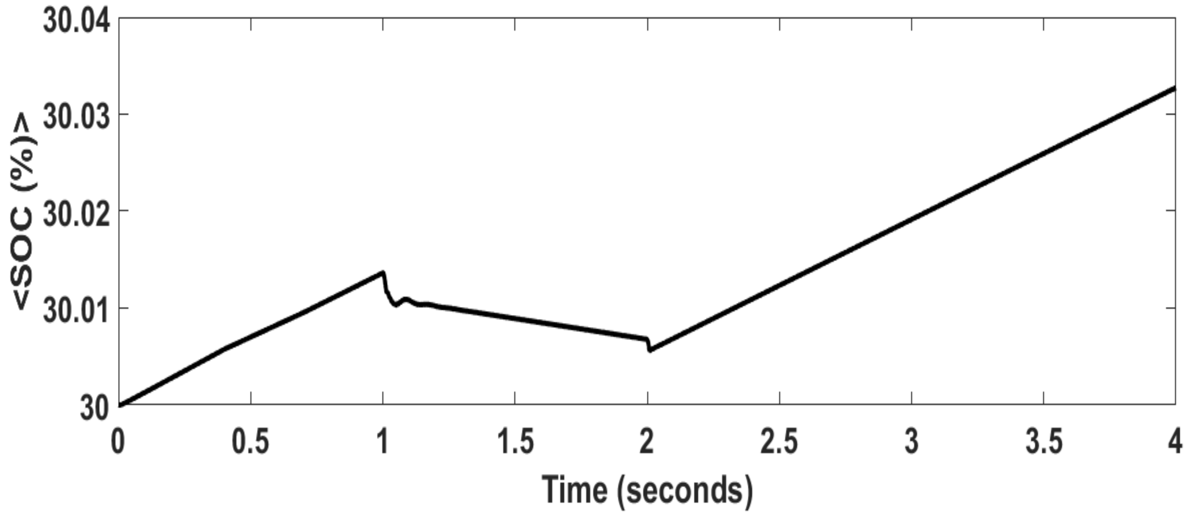

Figure 5.12: SOC of Battery

Figure 5.12 shows the SOC of Battery. 0-1 sec. and 2-4 sec micro grid supply is available, so that battery is charged through grid as well as solar panel. In cloudy condition, PV solar panel is unable to provide sufficient voltage to battery, during this period micro grid provides the supply for battery charging. 1-2 sec. grid supply is unviable (islanding mode), so that during this period battery start to discharge due to VSI provides supply to the micro grid system.

5.3 Single Phase System

The single phase 100W system is simulated in two modes: PV-STATCOM mode and islanding mode

5.3.1 Simulation results

PV-STATCOM Mode

During Faulty conditions, the voltage of supply system is less than standard grid voltage. The PV inverter injects the reactive power to the grid voltage through PCC. The 46W Load is connected to the supply system. The supply voltage is less than standard voltage. It enables to fulfill load demand. Figure 5.13 shows the input voltage PV-STATCOM Mode.

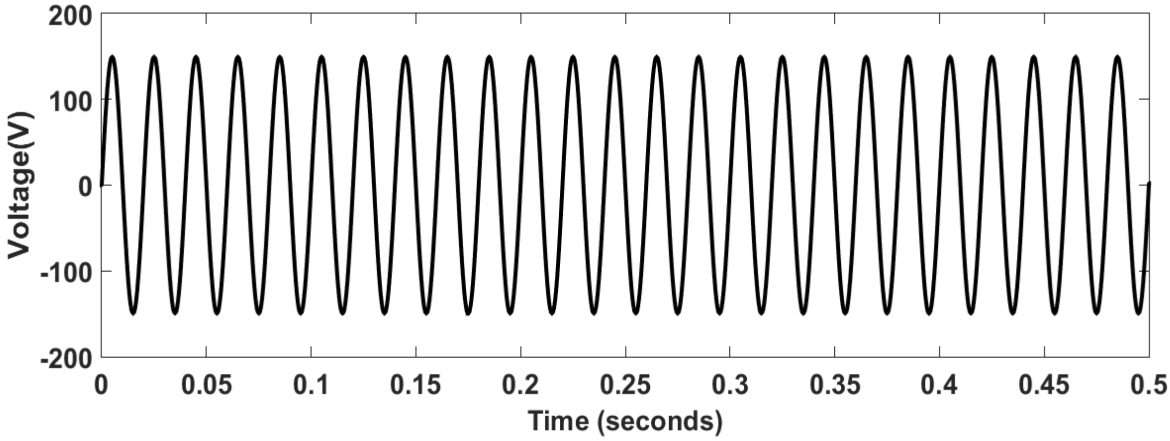

Figure 5.13: Input grid voltage

Figure 5.13 shows supply voltage at fault condition is 150V. Load requires 46W power but supply system is unable to fulfill this demand. At that instant, PV inverter supplies reactive power to fulfill this load demand. After injection of reactive power, the supply voltage is increased up to standard grid voltage.

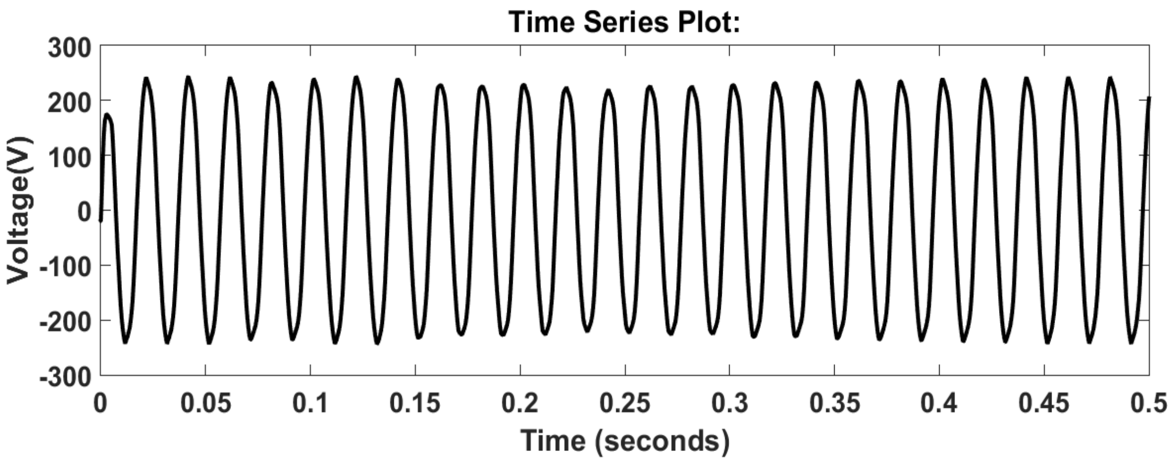

Figure 5.14: Voltage across load

Figure 5.14 shows the increase in voltage after injection of power. Voltage is recovered after injection of power. Also, oscillations in voltage are damped out by using damping oscillator.

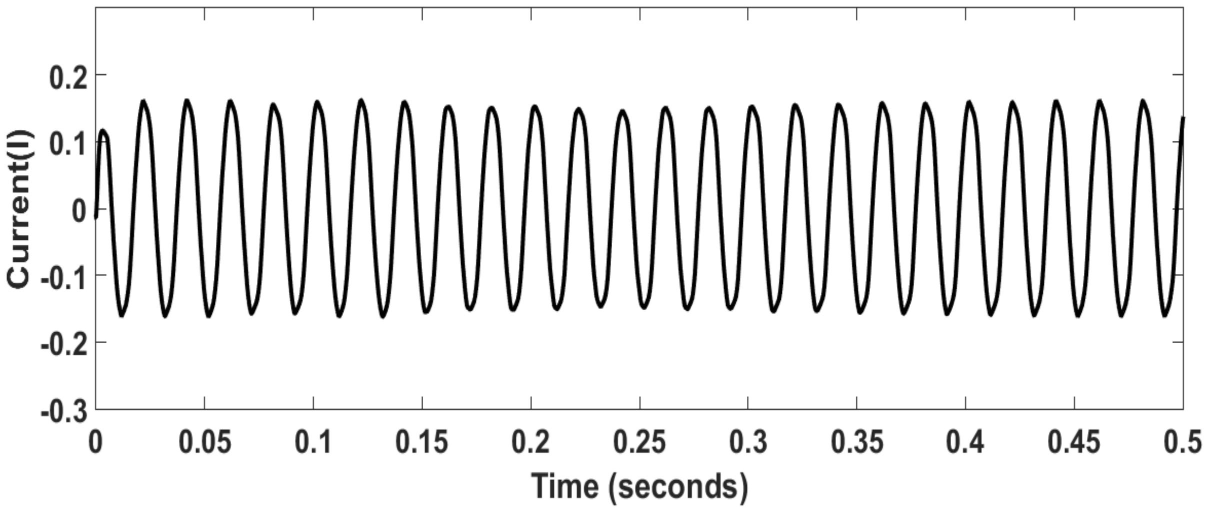

Figure 5.15: Current at load terminal

Figure 5.15 shows the current waveform after the recovering the voltage after fault clearing.

Islanding Mode Mode

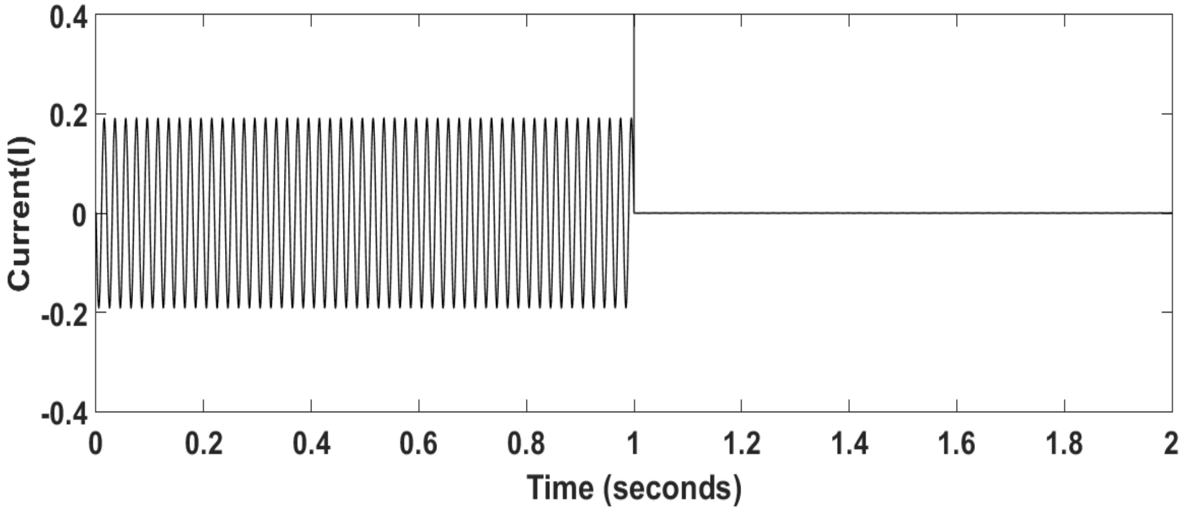

Figure 5.16: Current at supply terminal (grid side)

Above Figure 5.16 shows current waveform of grid islanding mode of operation. In above mode, from 0-1 sec the grid is ON. From 1-2 sec., there is no supply grid fails. During this time, power is supplied through solar generation. As the grid is the present during 0-1 sec. solar generation is absent for this duration.

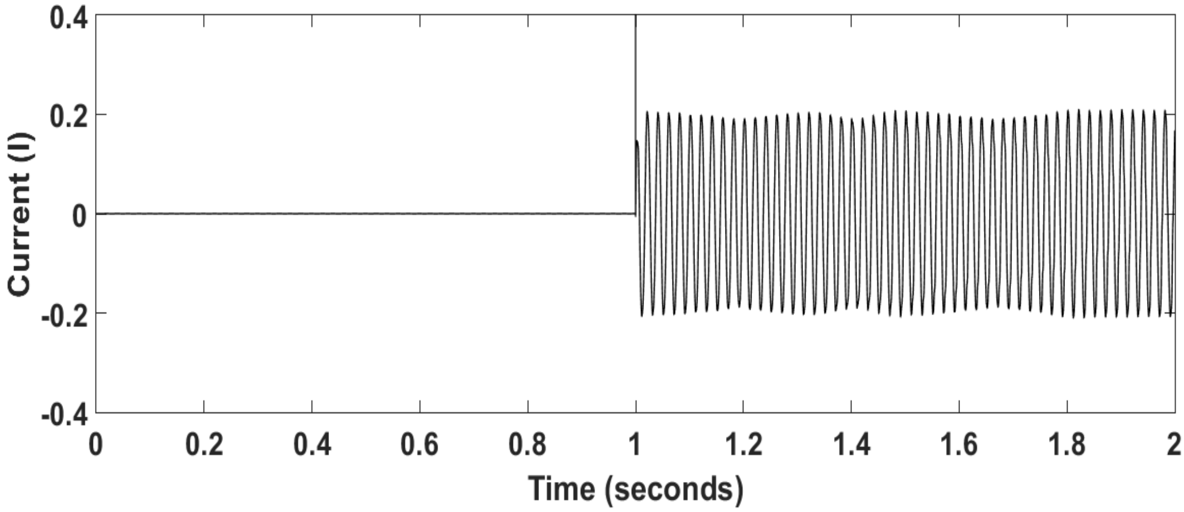

Figure 5.17: Current at solar generation side.

Figure 5.17 shows the current waveform of solar generation side. Solar system injects the power for time period 1-2 sec. When the grid is in off state.

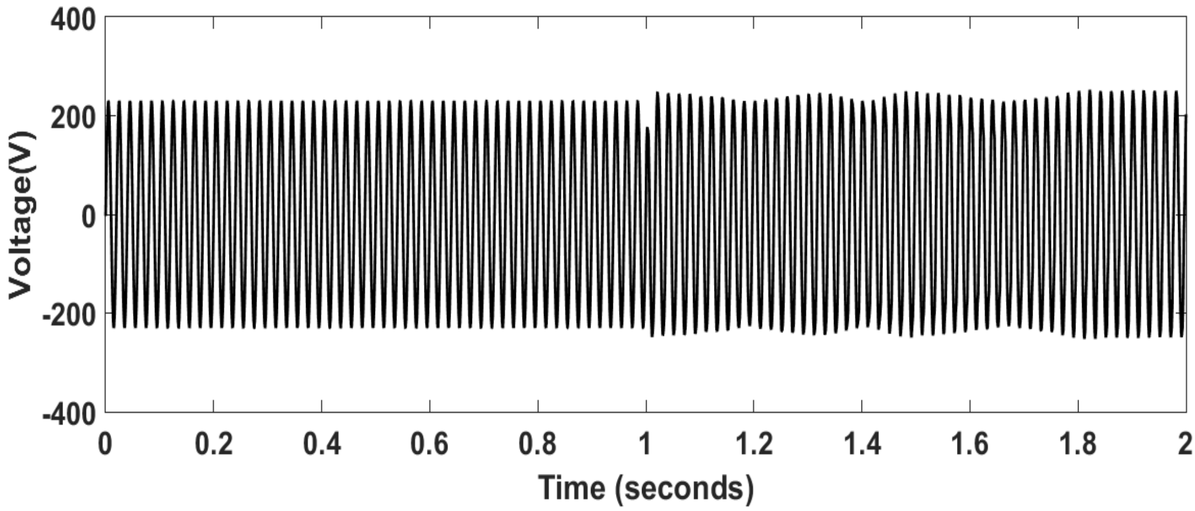

Figure 5.18: Voltage across load.

Figure 5.18 shows the islanding mode of voltage waveforms across the load. For 0-1 sec. the voltage waveform is of grid whereas for 0-1 sec. the voltage waveform is of solar power injection. From the Fig 14, it is clear that the voltages of grid and solar power generation are approximately same and thus the supply to the load is maintained continuously. the power for time period 1-2 sec. When the grid is in off state.

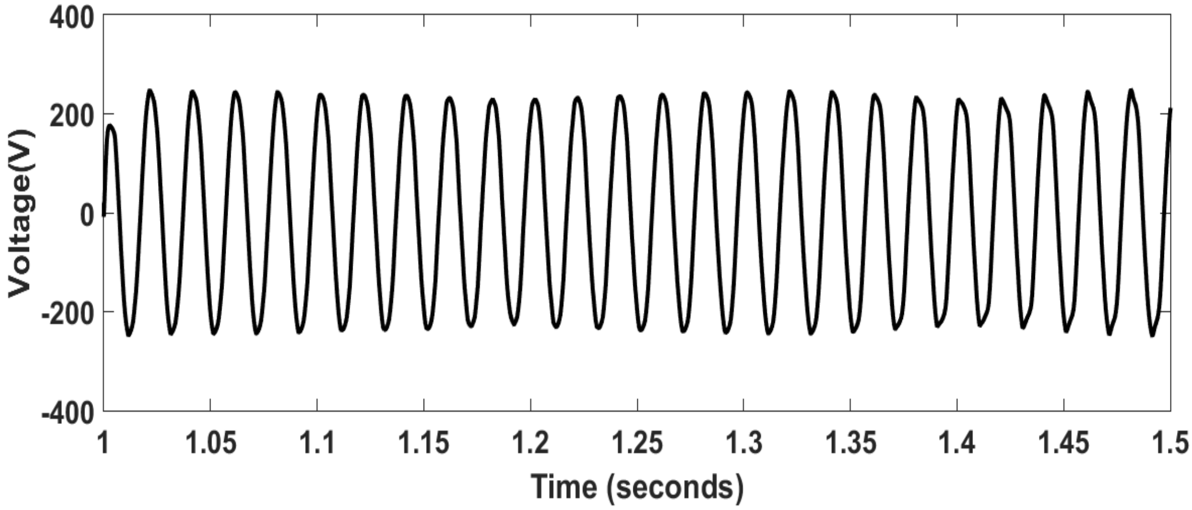

Figure 5.19: Voltage after solar power injection to load

Figure 5.19 shows the voltage waveform solar power injection and it shows the sinusoidal voltage supply to the load.

Battery Charging Mode

For charging the battery, PV and grid are used. In cloudy condition, PV solar panel is unable to provide sufficient voltage to battery. Battery discharging level is set to 30% to avoid damage and improve its life. Below 25% charging of battery directly affects life of battery. The combination of islanding mode and battery charging mode is possible. For battery charging, the grid voltage is step down up to 12 V by step down transformer and the AC voltage is converted into DC voltage by using rectifier. The output voltage of rectifier is given to battery terminals for charging. The initial charge of battery is set to 30 %. The charging of battery begins when battery charge is 30%. Percent.

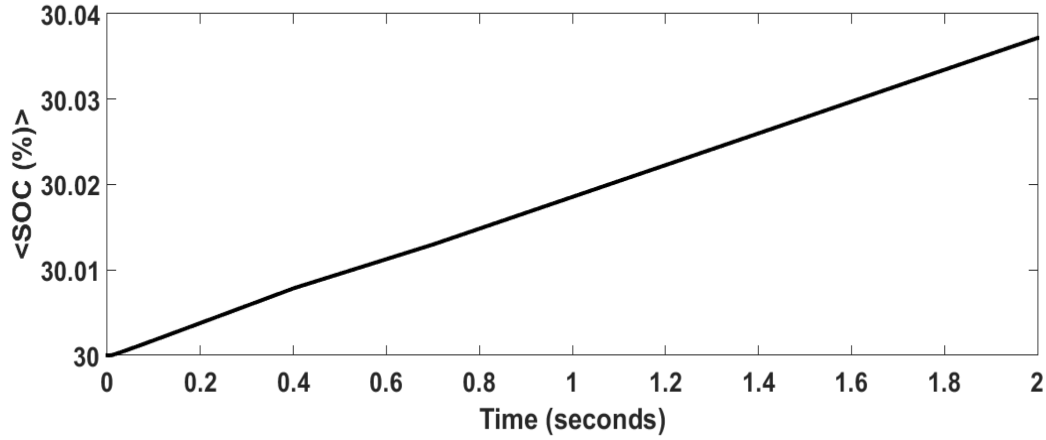

Figure 5.20: SOC of battery

Figure 5.20 shows the state of charge of battery. It shows battery charging is start from 30%.

5.4 HARDWARE RESULTS

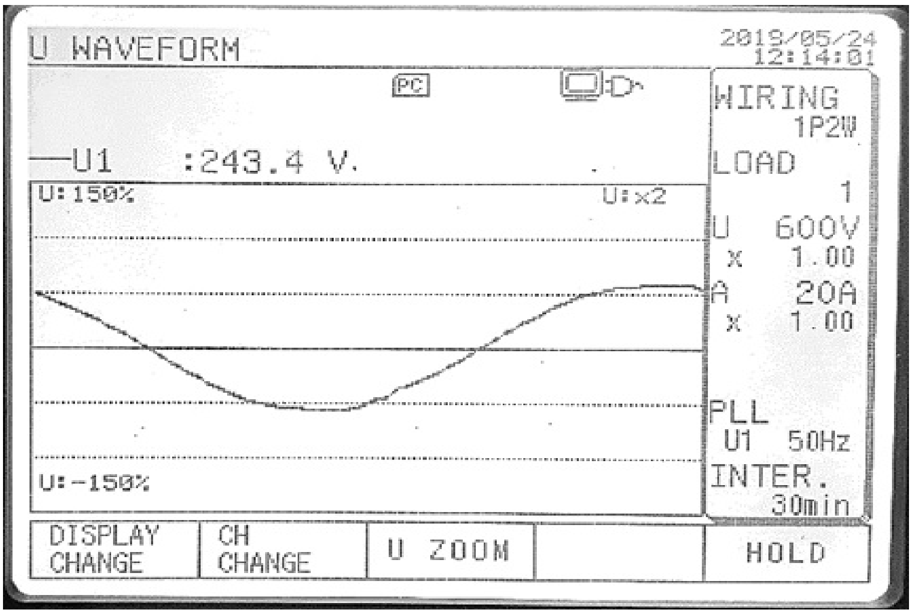

Figure 5.21: Voltage at PCC with PV-STATCOM

Figure 5.21 shows the voltage at point of common coupling when PV-STATCOM is connected to grid. Grid supply provided to the load through PCC. Voltage sag is created in the system through transformer. Load and transformer are interconnected through PCC. When grid supply to load is on, the supply also flows in the transformer. The voltage drop occurs in transformer due to transformer winding (inductor coil). This voltage sag is mitigated and voltage increased to 243V with the help of PV-STATCOM. The output waveform is almost sinusoidal with total harmonic distortion is 2%.

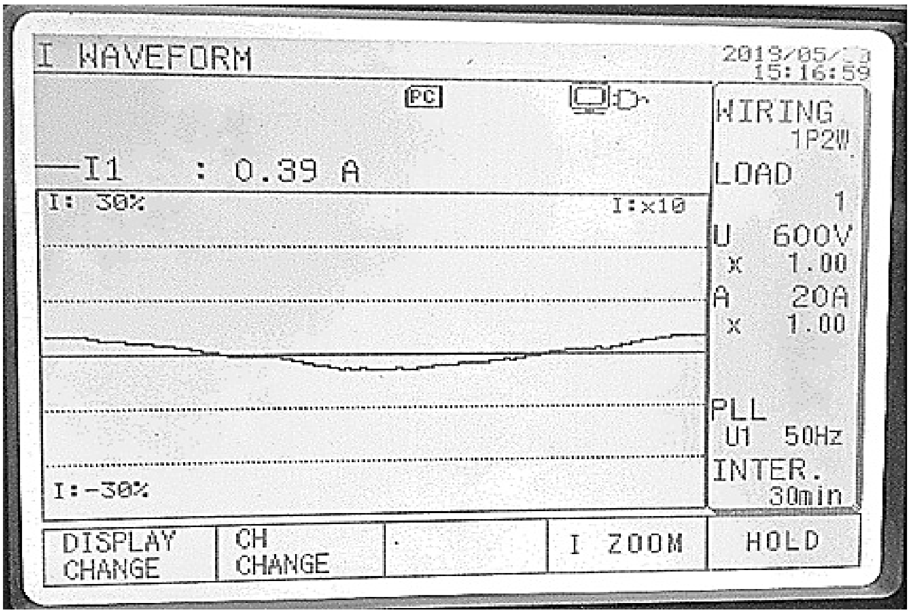

Figure 5.22: Grid power with PV-STATCOM

Figure 5.22 shows the current at point of common coupling (PCC) when PV-STATCOM is connected to grid. After voltage sag condition current is restored to 0.39A.

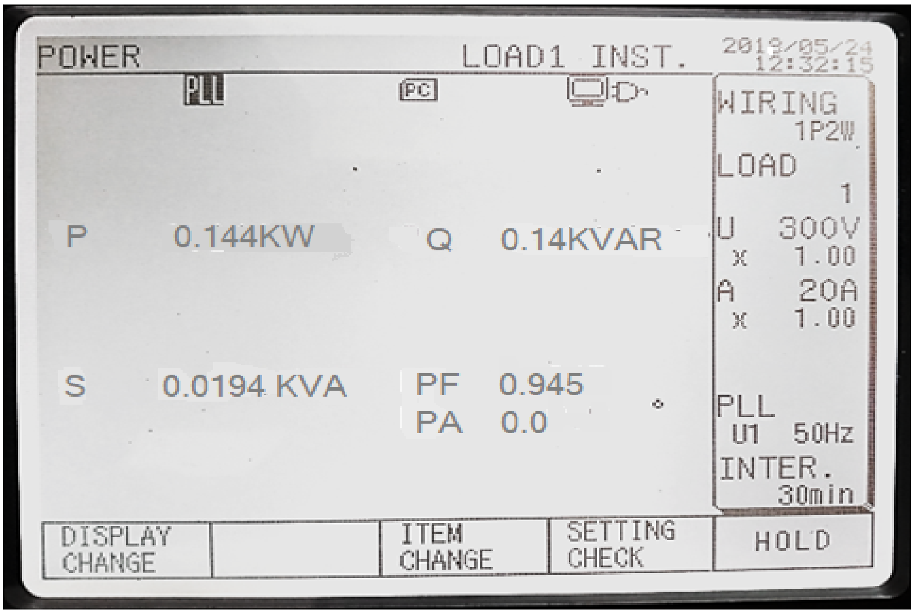

Figure 5.23: Grid power without PV-STATCOM

When 10W load is connected at PCC, the active and reactive power at point of common coupling are shown in Fig.20 Active power without PV-STATCOM at PCC is 14.4W and apparent power is 19.4VA. Power factor is 0.945 which is low for any industrial application.

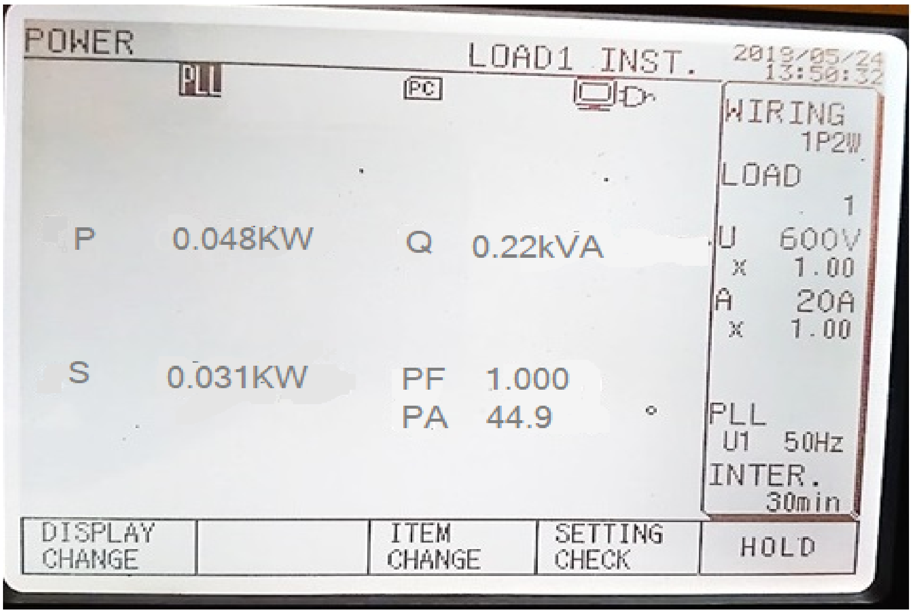

Figure 5.24: Grid power with PV-STATCOM

Figure 5.24 shows the value of output power of proposed system using the PV-STATCOM. From above it is clear that, with the use of PV-STATCOM grid power transfer is increased from 19.4VA to 31VA. Reactive power is supplied by PV-STATCOM to maintain voltage within limit. From these power values, it is clear that by using this proposed system, there is an increase in grid power.

5.5 Closure

The simulation models along with its results are given in this section. Simulation models consists of proposed PV-STSTCOM Mode, Islanding Mode,Battery Charging Mode. This chapter also consists of results of experimental setup of proposed system. Hardware results are tested on power analyzer equipment.

Chapter 6

Conclusion and future scope

6.1 Conclusion

In this desertation PV-STATCOM mode, islanding mode battery charging mode topology is discussed. The PV solar farm is inoperative at night time period. In this proposed topology of utilizing PV inverter as STATCOM during nighttime increases the utilization factor of inverter. Various type of literature on PV-STATCOM is surveyed to study the compatibility of PV inverter as STATCOM. Hence the solar farms are employed as STATCOM for improving the power transfer capacity with utilizing full solar inverter capacity. Also, during day time inverters has capacity remaining after the active power production, this remaining capacity can be employed for increasing the power transfer capability. The results show the improvement of power transfer capability in grid power. Therefore, the proposed control technology helps to reduce need of investment of extra expensive FACTS devices and series/parallel capacitors. During islanding mode proposed the storage provides supply to load. Therefore, continues supply is provided to load. The charging of battery through solar panel as well as grid is done. Therefore, active and reactive power management is done by using proposed control strategies. 0.22kVAr reactive power is supplied by PV-STATCOM, when fault is create. Total harmonic distortion of prototype hardware is 2 %. Hardware results are tested on power analyzer equipment. PV-STATCOM supplies reactive power when voltage drops below 1.1pu. Relays are used for switching of PV-STATCOM with point of common coupling. During islanding condition the inverter is provide supply to microgrid. bhattery is charged using two ways: through grid and through solar panel.

6.2 Future scope

This energy management system, PI control topology used for PV-STATCOM mode and VF control topology used for Islanding mode. The future scope is the hardware implementation of three phase system of proposed system also the different controlling method use for PV inverter to utilize as a STATCOM. The artificial intelligent controllers like fuzzy-PID controller can also be used for controlling grid power. The work can be expanded by using different MPPT methods such as IC algorithm and Artificial Neural Network. Fuzzy logic controller can be used in maximum power point tracking system. Mechanically sun tracking method can also be implemented for MPPT algorithm.

- Fuzzy-PID controller can be used for controlling inverter
- Battery energy management system for inverter DC source
- Artificial intelligence techniques like ANN and fuzzy controller in MPPT technique
- Implementation of transformerless multilevel inverter.
- Mechanically sun tracking can be implemented for PV application.

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LIST OF PUBLICATIONS ON PRESENT WORK

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