ACTIVE AND REACTIVE POWER CONTROLLER FOR SINGLE PHASE PV GRID CONNECTED INVERTER WITH LCL FILTER

Thesis submitted in partial fulfilment of the requirements for the degree

of

MASTER OF TECHNOLOGY

by

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NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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CERTIFICATE

This is to certify that the thesis entitled ACTIVE AND REACTIVE POWER CONTROLLER FOR SINGLE PHASE PV GRID CONNECTED INVERTER WITH LCL FILTER, submitted by RAHUL AWASTHI to National Institute of Technology, Rourkela, is a record of bona fide research work under our supervision and we consider it worthy of consideration for award of the degree of Master of Technology of the Institute.

Prof. Sanjeeb Mohanty

(Supervisor)

ACKNOWLEDGEMENTS

I express my sincere gratitude to my supervisor, Professor Sanjeeb Mohanty, for his valuable guidance and suggestions without which this thesis would not be in its present form. I also thank them for his consistent encouragements throughout the work.

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My warmest thanks go to my family for their support, love, encouragement and patience.

Rahul Awasthi

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DECLARATION

I certify that

a. The work contained in this thesis is original and has been done by me under the general supervision of my supervisor.

b. The work has not been submitted to any other Institute for any degree or diploma.

c. I have followed the guidelines provided by the Institute in writing the thesis.

d. I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the Institute.

e. Whenever I have used materials (data, theoretical analysis, figures, and text) from other sources, I have given due credit to them in the text of the thesis and giving their details in the references.

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Abstract

This thesis work is concentrated on Photovoltaic system connected with grid by an inverter to control Active Power and Reactive Power independently and reducing THD using LCL filter. Many exciting methods to control power are based on synchronous reference frame transformation, this method requires information on phase angle given by Phase-Locked loop (PLL). At first PV cell characteristics are drawn that help in making the proposed Photovoltaic system. PLL is avoided and a controller is designed for single phase grid connected inverter system connected with a LCL filter in stationary reference frame. To achieve necessary performance with independent control of active and reactive power injected in the grid the decoupling control strategies is adopted. As compared with orthodox control scheme of controlling power for single phase PV grid present scheme is highly reliable, fast in response and active and reactive power is controlled independently.

Present control algorithm is easier and simpler as this scheme is implemented in stationary reference frame. To confine high resonant peak value active damping technique is used in the designed current controller. LCL filter designing has been done in such a way to reduce the net THD and total losses taking place in the inductor of the filter. Switching scheme of the inverter and LCL filter are used to obtain sinusoidal output phase voltage.

Lastly, the proposed control scheme helps in controlling the THD and independent control of active and reactive power are achieved without PLL in the system. Dynamic performance of the system is analysed and various waveforms are studied using MATLAB/Simulink 2014a.

Key words: Volatge source inverter,LCL filter,Controller,PLL,THD

Contents

List of Symbols and Acronyms

List of Symbols

THD	:	Total harmonic distortion
VSI	:	Voltage source inverter
PV	:	Photovoltaic
MPPT	:	Maximum power point transfer
MPP	:	Maximum power point
P and O	:	Perturb and Observe
INC	:	Increamental Conductance
CSI	:	Current source inverter
FACTS	:	Flexible AC transmission system
AC	:	Alternating current
DC	:	Direct current
PWM1cm	:	Pulse width modulation
SPWM	:	Sinusoidal Pulse width modulation
MI	:	Modulation Index

List of Figures

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

With the increase in population the demand for energy is also growing rapidly in todays developing era. Continuous consumption of fossil fuel has led to increase in level of carbon dioxide and other harmful gases in the environment and has created global warming and other problems. Renewable source of energies are growing popularity and interest as a long term sustainable energy source.to meet the future energy crisis there must be a shift towards renewable sources of energy. Wind energy, solar energy and many other non-conventional sources can be used to meet the growing demand of energy with low cost and eco-friendly way. Main forms of renewable energy sources are Hydro, Solar and Wind energy. Hydro energy is seasonal dependent and this is the main reason for inclination of researchers towards solar energy. Availability in abundance and in major places of earth and in most of the seasons across the year solar energy has grown its popularity as compared with other non-conventional sources.

DIFFERENT SOURCES OF ENERGY WIND ENERGY Wind power is the conversion of the energy in wind into a more useful form of energy, like electricity. It is a renewable source of energy that helps to cut down on the pollution of earth's air. As per present scenario wind energy contributes to 336gw of net energy across the world.

GEOTHERMAL ENERGY Geothermal energy is the heat from the Earth. It's clean and sustainable. Resources of geothermal energy range from the shallow ground to hot water and hot rock found a few miles beneath the Earth's surface, and down even deeper to the extremely high temperatures of molten rock called magma.

SOLAR POWER Investment in solar power has been increased worldwide. The photovoltaic systems are used in many ways for generating and supplying energy to various systems. There are many applications of photovoltaic system such as stand-alone or grid connected configuration. A PV system consist of various components including solar panels used to absorb and covert solar energy into electrical form. An solar inverter used to convert electric current from DC to AC, as well as mounting and cables and other electrical accessories as required to set up a working system. Gathering of solar energy is easy due to its availability in abundance. Photovoltaic system can be used in either of stand-alone or grid connected system depending on availability of grid. Stand-alone system is very useful in rural areas due to low availability of grid system. Stand-alone system along with battery storage is also growing popularity in rural areas. PV system can vary from few kilowatts to tens of kilowatts and are built up in small range to large integrated system. These days most PV systems are grid connected and only a few contribute to stand alone or off grid systems. PV system with grid connection is popular in distributed generation system. Synchronism with grid is another issue which need to be taken care. For boosting of output voltage and generating power at maximum power point and interfacing the system with grid by help of an inverter various methods and topologies are available. With constant increase in development in solar cell manufacturing the cost of solar panels are also coming down drastically. The major problem in photovoltaic system is to track maximum power although the year under various changing circumstances .there are various algorithms which are used to increase the efficiency of operation of solar cells and help in tracking maximum power from it.

1.2 LITRATURE REVIEW

This paper suggests that many existing control methods includes PLL in the system which makes the system complicated. In this paper power control is done by stationary reference frame with a LCL filter to control a single phase grid connected inverter. As operations are done on stationary reference frame controller is simple, reliable, faster and easy to implement. THD of current is reduced by using LCL filter to appropriate value as given by IEEE.[9]

Solar power is coming as the best alternate for petroleum and other fossil fuel a compared with other renewable sources. Major problem of solar panel is its high installation cost and poor conversion efficiency.as per researches solar panel can only convert 30-45 percentage of solar energy into electrical form. We need to utilize maximum of it at lower cost and increased efficiency. Solar energy resources are inconsistent and to ensure maximum utilization photovoltaic system must be operated at maximum power point.[3]

To obtain true nature of photovoltaic system stochastic models and other mathematical models are not appropriate. General requirement for MPPT is low cost and fast tracking of varying conditions. Without an effective MPPT controller major power generated will be wasted and to compensate more solar panels are connected which will increase the overall cost of the system.[10]

Generally, for proper synchronism between DG and grid current controlled PWM-VSI is used. PWM-VSI plays a predominant role in high quality power injection in the grid as well as in active and reactive power control through voltage and frequency control strategies and harmonic minimization.[14]

Methods such as P and O, INC are commonly used for working around MPP and these algorithms are known as hill-climbing methods. Distributed generation are good solution for the growing energy demand. To increase its utilization DGs must be connected with utility grid.[13]

There are large variations in DC input voltages and output voltage need to be boosted up to match with the grid and maintained constant. Harmonic content in the current must be reduced and power quality must be improve and this is achieved by help of controllers. There are mainly two types of controllers

i) PID controller

ii) Hysteresis controller

Using these controllers for VSI mode of operation an PV system is being connected with single phase grid.

VSI connected with grid requires high quality of current and power in the system. Deadbeat control strategies of Photovoltaic system with LCL filter is proposed in this paper. Quality of power largely depends on the applied current control strategy. Deadbeat digital controller with minimum number of sensor is used to get optimized power quality.[7]

This paper proposes single phase single stage grid current source inverter based Photovoltaic system for grid connection without use of transformer. Double tuned parallel resonant circuit is used to attenuate harmonics at input side of inverter. Current source Inverter has longer life time than Voltage source Inverter. CSI has become more reliable than VSI as it have continuous DC side current.[11]

PV system consist of single conversion unit to track maximum power point (MPPT) and interface system with the grid. A LC filter is used for getting smooth edges of waveform. For softening of harmonic on DC side a double tuned resonant filter is used [1].due to pulsating power harmonics are present on the DC side and these can affect the MPPT and also reduces PV lifetime. PV inverter with various control strategies are available as CSI mode and VSI mode. Power delivered by PV inverter to the grid is the maximum available power under different conditions [1]. To synchronize DG with grid PLL is used by which frequency matching of the two system is done.

1.3 MOTIVATION

Solar energy is a source totally different from general conventional sources of energy and one of a kind which is present with such a richness. Main problem in drawing power from solar energy source is its low transformation efficiency and its high installation cost. Researchers are developing new techniques and methods to overcome the problems associated with it. New control techniques and methods are being developed so we can use this infinite available energy.

1.4 OBJECTIVES

The objective of our work is to extract maximum power from the PV system and to synchronize PV system with single phase grid with minimization of harmonics using controllers.

ORGANIZATION OF THESIS

The thesis has been organised as follows:

CHAPTER 2: this describes modelling of PV cell and its equivalent circuit diagram.

CHAPTER 3: provides overview of various MPPT techniques and working of DC-DC BOOST converters.

CHAPTER 4: provides description of inverter and also gives its control strategies along with description of PLL for grid connection.

CHAPTER 5: it gives details of LCL filter used.

CHAPTER 6:Discusses results

CHAPTER 7: conclusion AND FURTURE WORK

CHAPTER 2

MODELLING OF PV CELL

2.1 Introduction

A PV module consist of number of solar cells arranged in series and parallel to give needed voltage and current. A single solar cell can be modelled using a current source, diode and two resistors connected as shown in figure. There are two kinds of modelling of a solar cell two diode model and single diode model. We have discussed on single diode model.

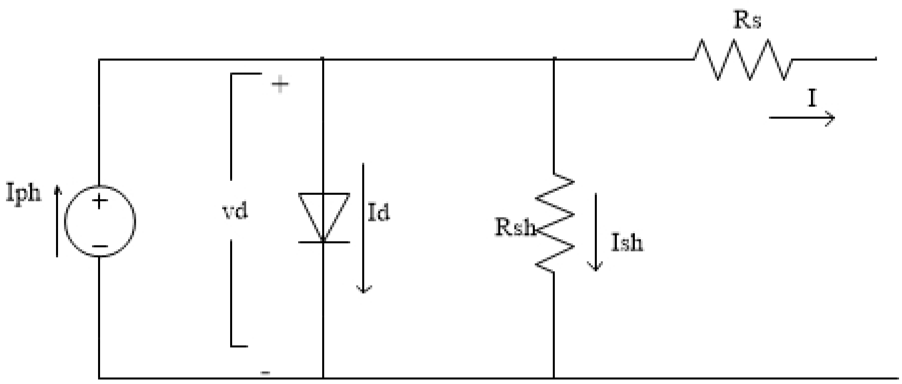

Figure 2.1: SINGLE DIODE MODEL OF SOLAR CELL

Characteristic equation of solar cell are specified as [5]

Where,

$$I = I_{ph} - I_o(e^{\frac{q*(V+IR_s)}{A*K*T}} - 1) - \frac{V + IR_s}{R_{sh}} \tag{2.1}$$

$$I_o = I_{or} * \left(\frac{T}{T_r}\right)^3 * [e^{q*E_{go}*\frac{\frac{1}{T_r}-\frac{1}{T}}{A*K}}] \tag{2.2}$$

V and I: cell output voltage and current

I_o : reverse saturation current at T_r

I_{or} : Cell reverse saturation current

T: cell temperature in C^o

K: Boltzmann constant

q : Electron charge,$1.6 * 10^{-23}C$

A: ideality factor

T_r : Reference temperature

E_{go} : band gap energy for silicon

I_{ph} : current generated by light

R_s : Series resistance

R_{sh} : Shunt resistance

The value of current also depends on the number of parallel and series cells. It has also been witnessed experimentally that current depends more on series resistance with respect to parallel resistance.

$$I = N_p * I_{ph} - N_p * I_o * (e^{q*\left(\frac{\frac{V}{N_s}+I\frac{R_s}{N_p}}{A*K*T}\right)} - 1) - \frac{V * \left(\frac{N_p}{N_s}\right) + IR_s}{R_{sh}} \tag{2.3}$$

Where,

N_p : Number of cells in parallel

N_s : Number of cells in series

Working of PV cell is basically based on photoelectric effect. When sunlight of certain wavelength strikes the PV cell energy is absorbed by the electron and it comes out of conduction band and flow of electrons start. During striking of light at the surface of material some part of the light energy is absorbed by it and rest is converted in heat or electrical energy form. Electrons absorbed energy in conduction band are now free to move and by electric field created in PV cell electrons are directed towards a fixed direction. These flow of electrons constitutes current in the cell. Metal plates are connected to both side of PV cell which directs the flow of current outside the cell.

The P-V and I-V curves of PV cell is being drawn below. It can be observed that at low voltage it works as a constant current source and at low current as a constant voltage source.

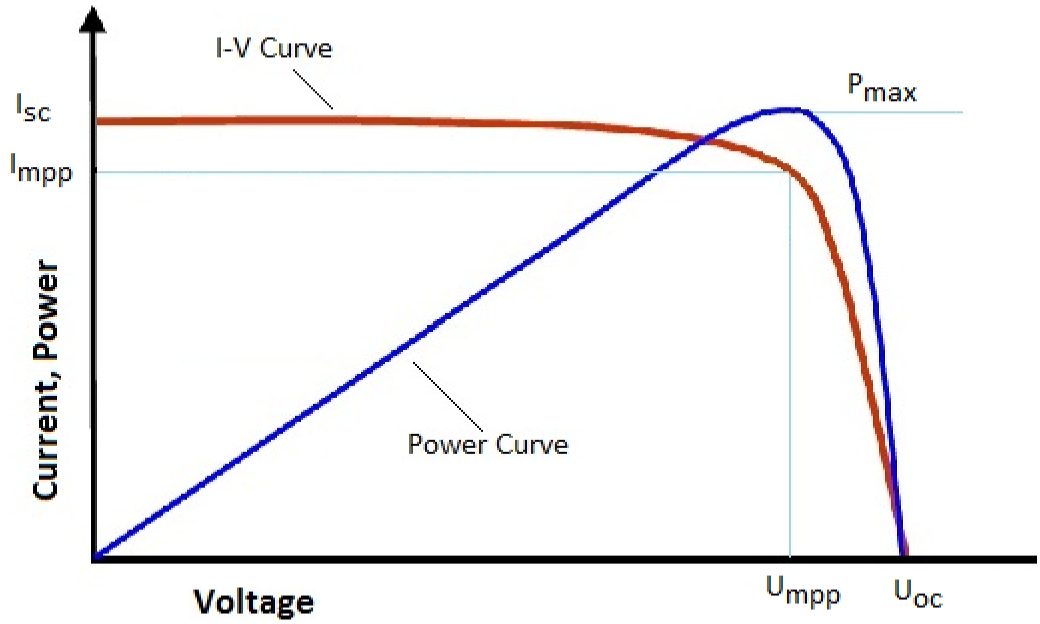

Figure 2.2: PV and IV curve of a solar cell at given temperature and solar irradiation

2.2 Effext of Variable Irradiance

The variation in PV cell characteristics are effects of change in irradiance values. Solar irradiance changes with variation in environment regularly and there is a mechanism that can track this change and work accordingly to meet load demand. More irradiance results in more energy to the cell and more power can be delivered for same amount of voltage.

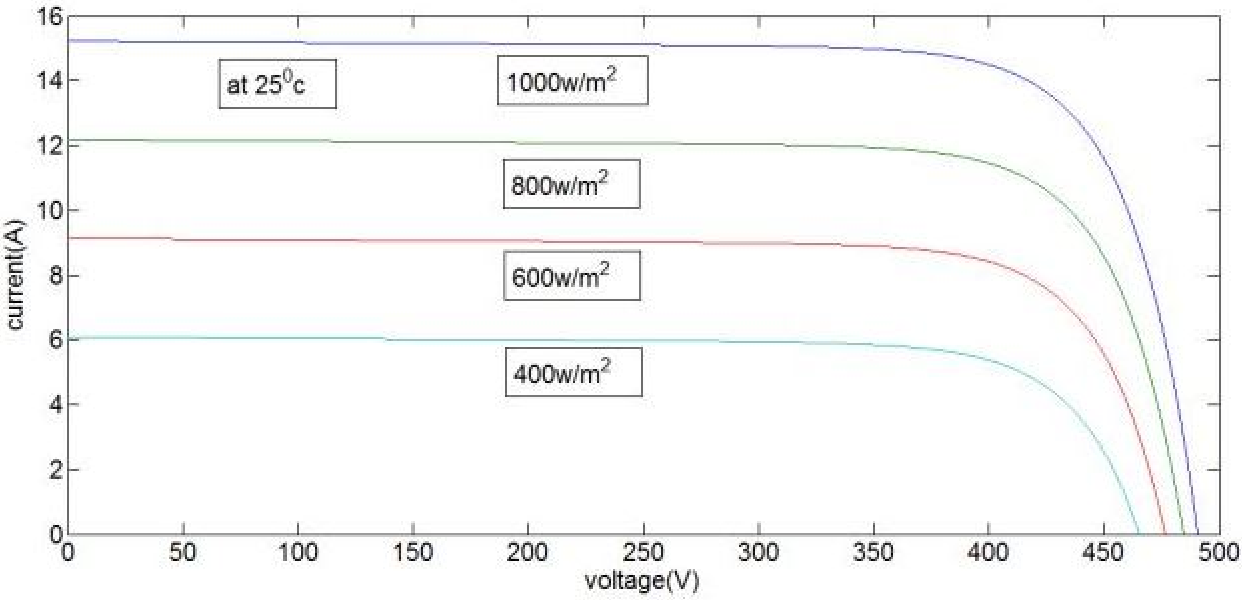

Figure 2.3: Variation of IV curve with solar radiation

2.3 Effect of Variation of Temperature

With increase in temperature nearby the cell band gap of the material also increases.due to increase in band gap of material the open circuit voltage of cell reduces and overall efficiency of the cell becomes poor

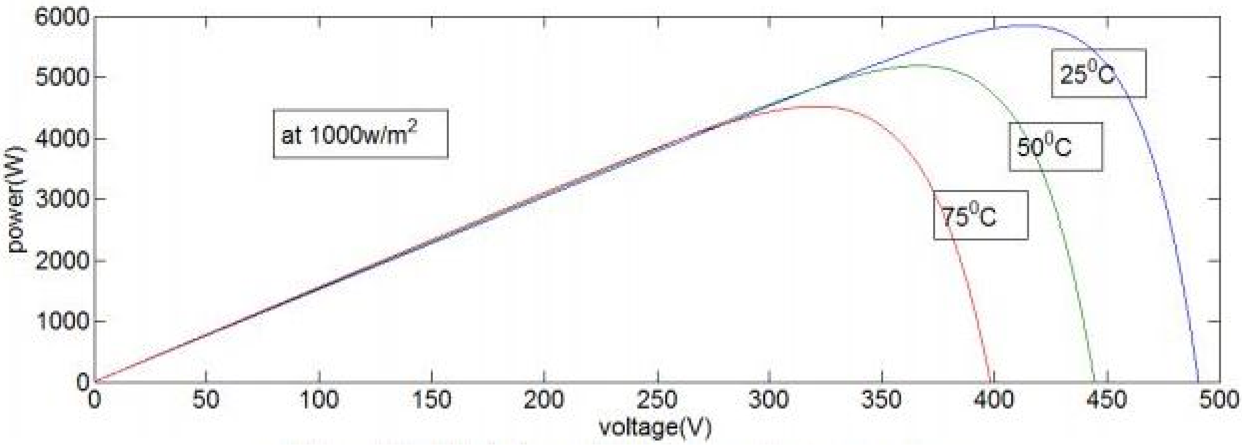

Figure 2.4: Variation of PV curve with temperature

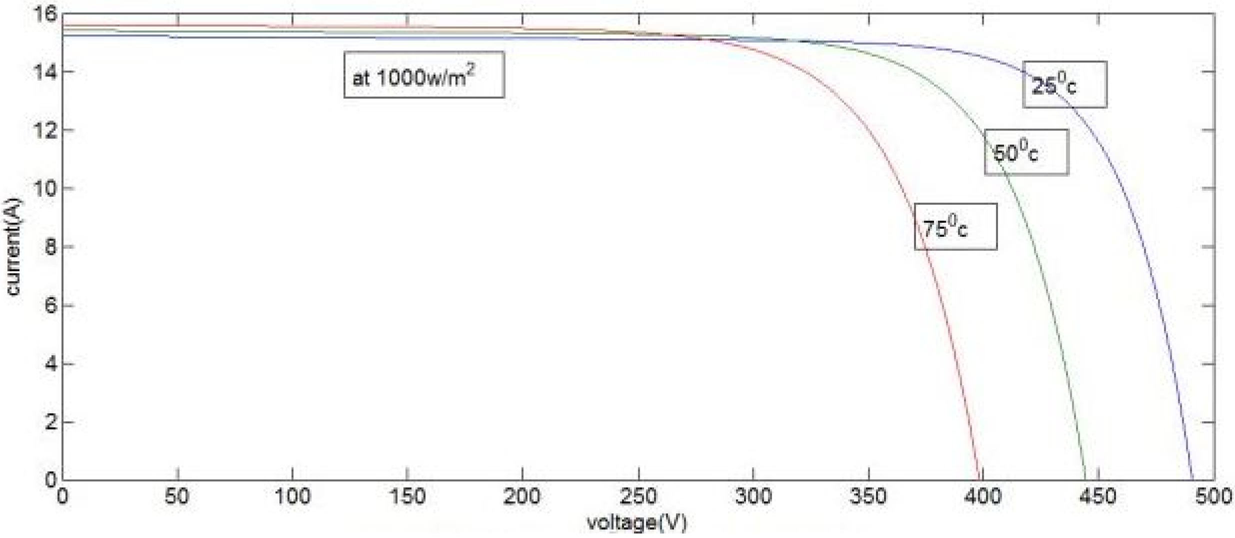

Figure 2.5: Variation of IV curve with temperature

2.4 MPPT Techniques

We know that efficiency of solar module is very low and to extract majority of the power the module should work at maximum power point. In order to fulfil need of MPP various techniques are used. Every method have its own advantage and disadvantage over other be it tracking speed, simplicity, price and other conditions.

Some of the methods are:

Fractional open circuit voltage

Fractional short circuit current

Perturb and observe

Incremental convergence

Of these P and O and Incremental conductance are mostly used methods.

2.4.1 Perturb and Observation

It is one of the simplest and most used method for getting maximum power point. This method is uses voltage and current sensing to track MPP.in this method voltage is disturbed in one direction and changes in power is considered if power increases then voltage is increased in the same direction. If power starts to decrease during perturb then voltages is reduced as MPP must be on the other direction.as soon as MPP is reached working point oscillates around MPP.

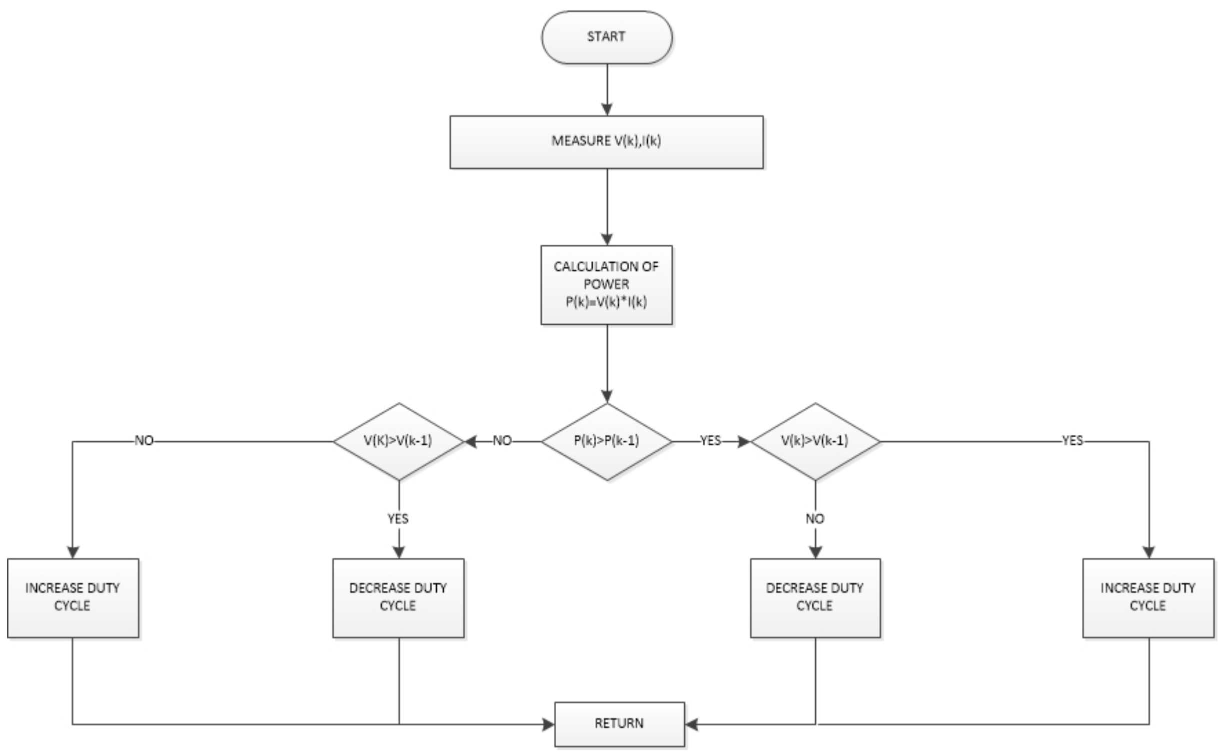

Figure 2.6: Flow chart of Perturb and Observe Lgorithm

2.4.2 Increamental conductance

In this method current and voltage are incremented and change in power is detected. This method is speedier as compared with PandO but requires more calculations. PandO can calculate wrong MPP if there is sudden and frequent change in irradiance but by using INC method this problem is nullified.INC uses two sample of each voltage and current to get MPP. However, INC is very complicated with respect to PandO. Efficiency of INC is varied with step size which is the biggest advantage of INC over PandO.

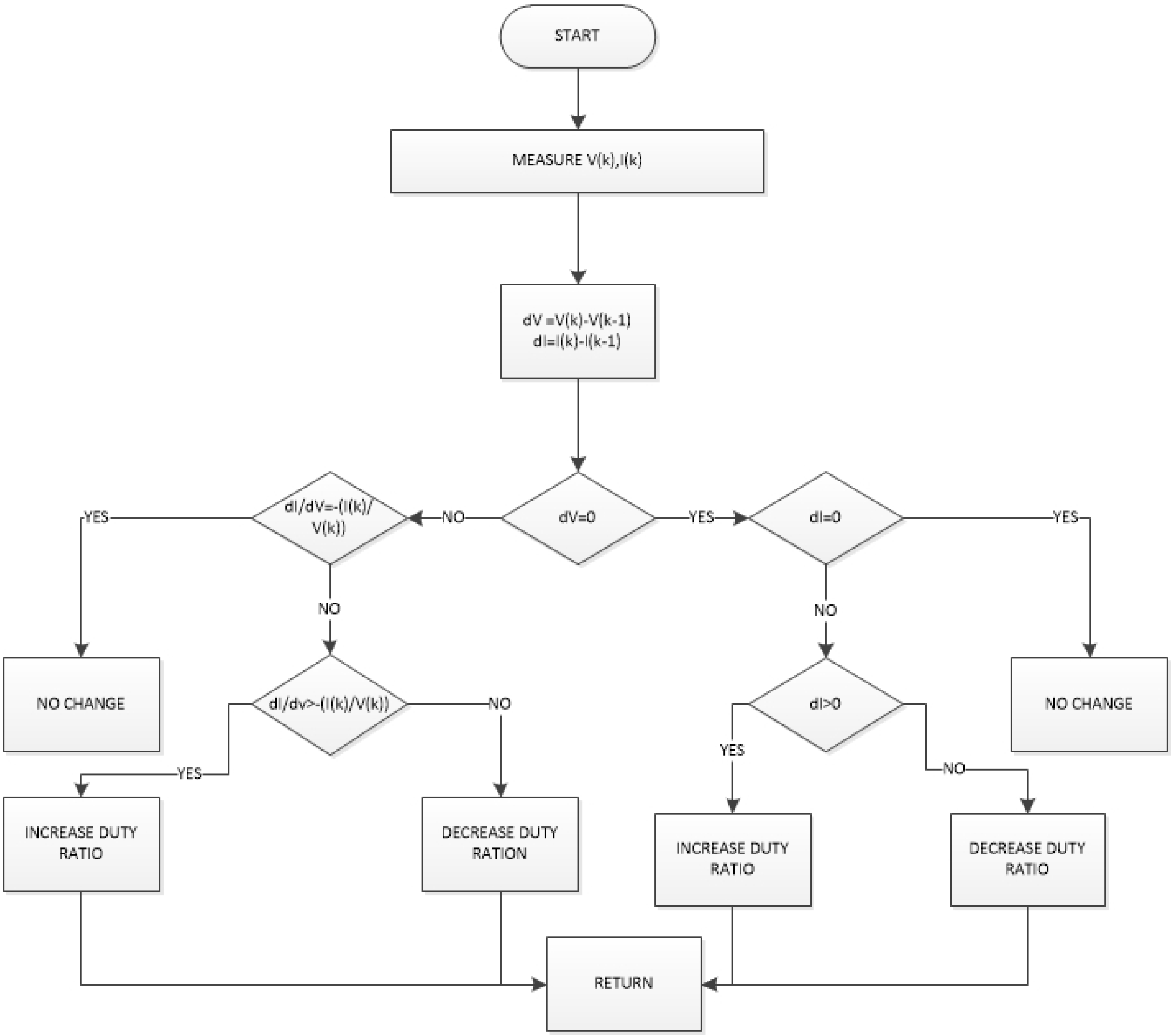

Figure 2.7: Flow chart of Increamental conductance

CHAPTER 3

BOOST CONVERTER

Choppers are also called as dc transformers as they are used to step up and step down the dc voltages. Boost converter is used to step up the dc voltage. Main component of dc converter are diode, a high frequency switch and an inductor. This converter is used for stepping up the voltage by varying the duty cycle. Various control strategies are present to control the duty cycle of the converter.[7]

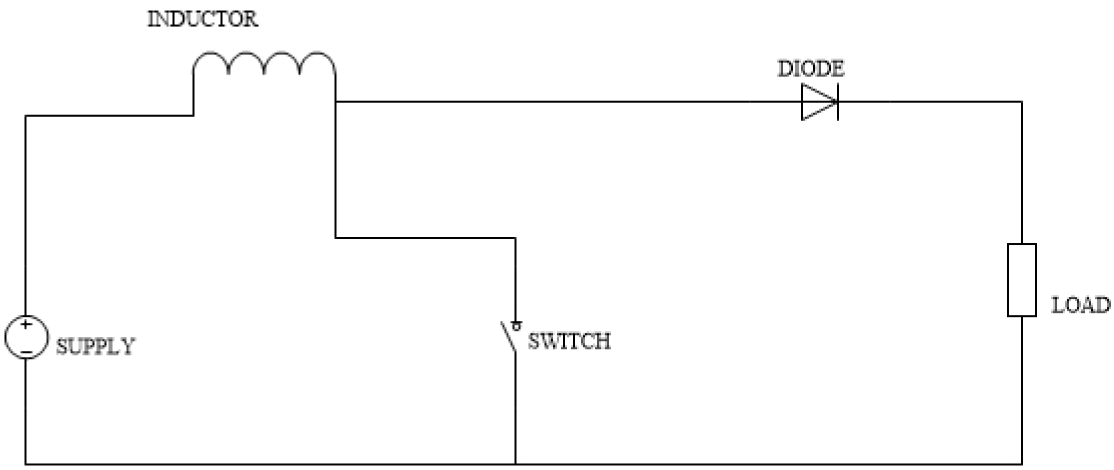

Figure 3.1: boost converter circuit

3.1 Charging Mode

In this mode switch is closed and inductor is charged exponentially but for simplicity it assumed to be linear. During charging of inductor load is supplied by the load end connected capacitor. This capacitor ensures the flow of current through the load when switch is on. Diode restricts the flow of current to the load end during charging mode.

3.2 Discharging Mode

Switch is closed in this mode and diode is forward biased. Load is supplied by the source and inductor also releases its energy. During this mode capacitor is charged and load demand is also met. Variation in load current is very small and so generally it is taken as constant.

3.3 Control of Coverter

The voltage output of DC-DC converter is controlled by varying duty cycle of the switch.The circuit is ideally considered as 100 percent efficient for ideal operation and to get input and output power as equal

3.4 Waveforms

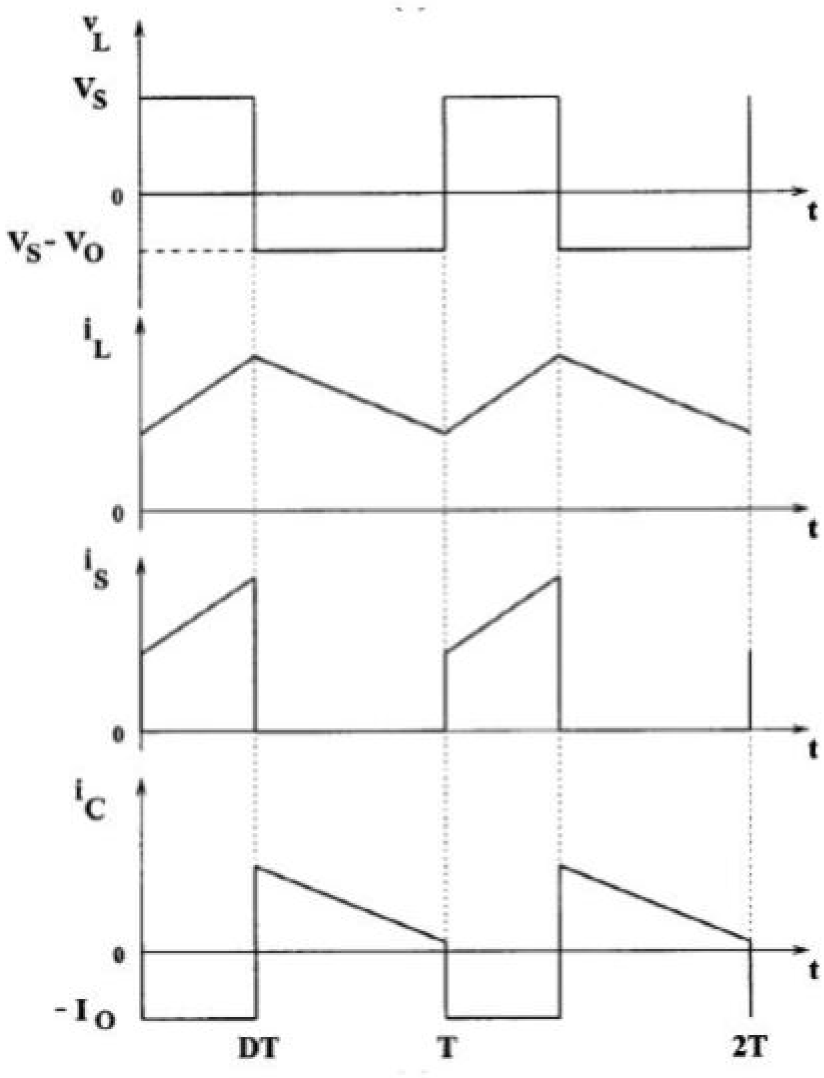

Figure 3.2: boost converter waveforms

CHAPTER 4

INVERTER DESIGNING

4.1 Introduction

Many designs are available for inverters used to connect a photovoltaic grid connected system. Many factors are considered for designing an inverter for PV system such as circuit topology, harmonic, conversion efficiency, maximum power point etc. These considerations are important for a single phase PV grid connected system.[6]

Decision of inverter topology must be first made by the designer out of available topologies. The PV array voltage and grid condition is considered for choosing proper inverter topology. Input side DC voltage can have wide variation depending on environmental condition and array power and this is needed to be considered.

Conversion efficiency of inverter is the most important aspect needed to be considered for various DC powers. Losses of inverter must be as minimum as possible and majority of the power should be delivered to utility grid. Primary process of improving inverter efficiency is done by choosing of inverter components depending on their effectiveness.[5]

Key function of the integrated system is maximum power point tracking. Inverter along with converter must be so chosen so that there should not be any conciliation with the MPP. Algorithms are described in chapter 2 are to be implemented under variable temperature and radiation. Characteristics of PV module is non-linear and every MPP condition must satisfy before connecting inverter.

Inverters is a power electronic circuit device which operates from dc current source or voltage source and gives ac voltage or current as output. Depending on the input side source inverter is classified as voltage source VSI or current source CSI. If voltage source is applied on dc side then it is a VSI and if current source is present we get a CSI. By VSI direct control over output voltage is possible and by CSI output current is controlled.

A photovoltaic module is used here as a source of power in the input side. All inverters assume stiff voltage supply at input end. Stiff voltage is referred as the voltage which remains constant and inverter always maintain constant input side voltage irrespective of load. Ideally inverter should give pure sinusoidal voltage but practically inverter cannot give pure sine wave and output obtained is quasi sine wave along with harmonics control. Quasi sine wave is acceptable for low and medium power application.

Inverter is used to get variable voltage at output AC side. Variable voltage can be obtained either by varying the input DC voltage and maintaining inverter gain constant or by varying the inverter gain and maintaining input voltage constant. This can be achieved by various inverter control strategies.

Another aspect of PV system is grid utility. The power injected into the grid must meet utility power requirement as specified by IEEE 929-2000. Quality of the power induced into the grid must be quality power. To get high quality power high frequency devices must be employed as measured by total harmonic distortion factor. To reduce harmonics appropriate filter must be chosen as power to be transferred must be of high quality with less harmonic losses.

4.2 Full Bridge Invereter

We are using a single phase full bridge inverter here. This is an DC-AC converter with desired frequency and output AC power. A full bridge inverter can produce twice the voltage as produced by half wave. This is the distinct feature for using full bridge inverter in high power devices instead of parallel half bridge.

The single phase bridge inverter circuit is shown in fig. The topology comprises of two legs with four switches, two in each of the leg. Single-phase converters are utilised where conversion between DC and AC voltage is needed. Further precisely where converters transfer power back and forth between DC and AC. Unfiltered output voltage is created by switching the full-bridge in an appropriate sequence. Output voltage of inverter can vary as +V, 0 or V and is dependent on control of switches.

Input side voltage is maintained fixed by help of a capacitor connected in parallel and output voltage is varied with its polarity as well as magnitude as needed. Similarly the magnitude and direction of the output current can be controlled. So a full bridge converter can have all quadrant operation and flow of power through it can be in any direction.

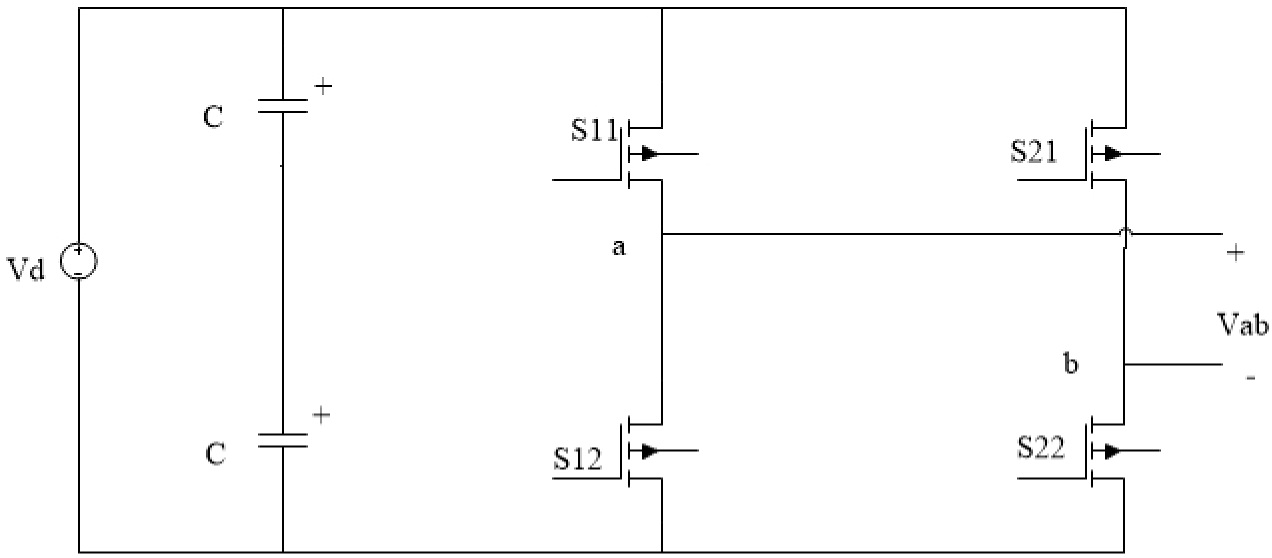

Figure 4.1: full bridge inverter

Switches from S11-S22 are controlled by pulse width modulation technique to generate unfiltered output. There are many PWM switching schemes used for improving the output waveform of inverter. The switches in the legs are fired in such a way so that no two switches in the same leg are open at a time which can result in short circuiting.

Simultaneous switching of switches can destroy the capacitor and the source in the DC side of the inverter. Switching is done crosswise ,S11 and S22 pair togather to get +V as output and S12 and S21 to get V as the output volage. This combination gives unfiltered output voltage. Freewheeling action is required to get 0 as output voltage with current being continuous. Antiparallel diodes are connected across switches for continuous conduction.

4.2.1 voltage and current source inverter

Inverters can broadly be classified into two types voltage source inverter (VSI) and current source inverter (CSI) based on their operation.

The type of inverter of which output voltage waveform is controlled is a voltage source inverter. VSI has property of maintaining output voltage unaffected by load variation. VSI is used in many industries as FACTS devices or as a variable speed adjuster.

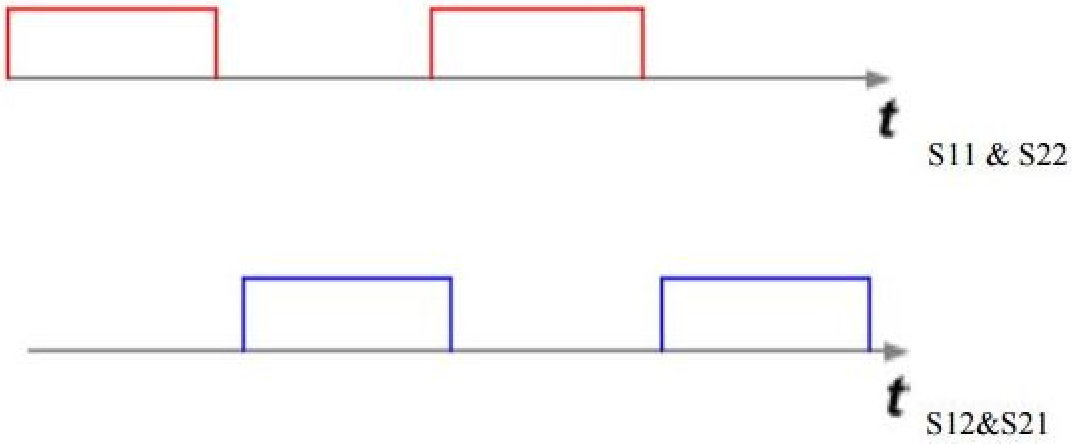

Figure 4.2: switching scheme of full bridge inverter

In current source inverter (CSI) output current waveform is controlled independently. CSI has unaffected output current by load variation. This type of inverter is used in medium voltage type of industry where high quality waveform is needed.

VSI has rigid voltage source at input terminal whereas CSI has adjustable current with high impedance on the input side. In CSI output current is not affected by load as it is fed by rigid current source.

This thesis focuses on VSI topology of inverter along with a dc-dc converter. This kind of topology is commonly used for dual stage PV system with inverter. If in the input side voltage amplification takes place at input capacitor DC-AC converter used is a voltage source inverter (VSI). This inverter handles DC bus regulation and variation of output current.

4.3 Control Strategies of Inverter

Different control strategies are presented here to control VSI. Generally there are three main technique to control the voltage source inverter that is hysteresis control, predictive, and sinusoidal pulse width modulation technique (SPWM). In present thesis we will discuss all PWM techniques and concentrate on the best possible one.

Inverters are generally controlled by PWM techniques. In PWM techniques width of gate pulses are varied by various mechanisms. PWM inverter maintains rated output voltage irrespective of variation in load. Inverters with PWM control switch between different circuit

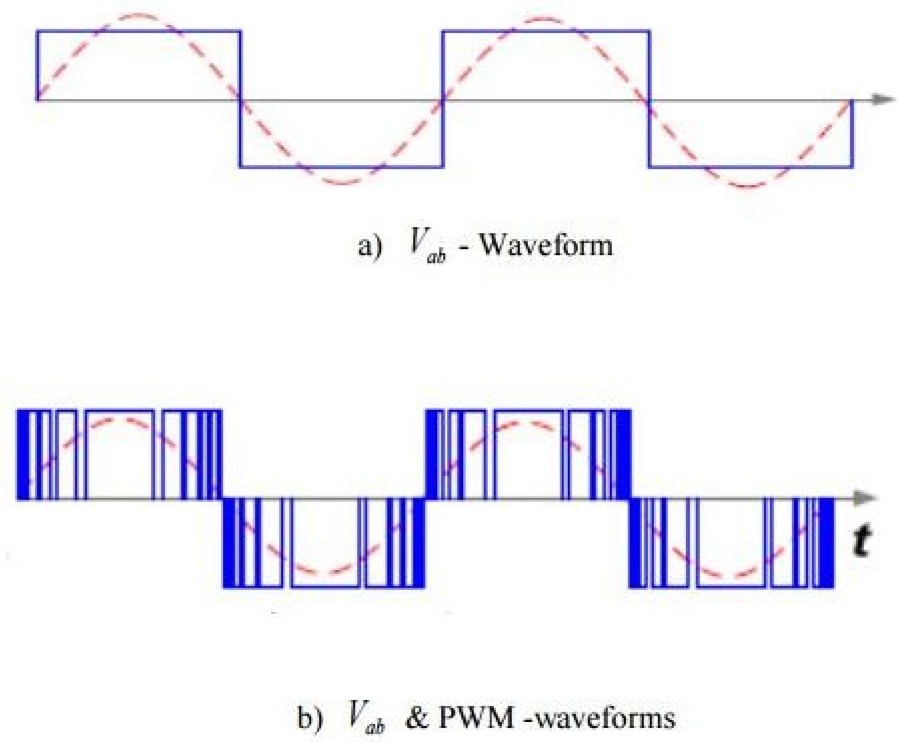

Figure 4.3: output voltage of single phase bridge

topology which means that inverter is non-linear and only piece worthy smooth.

Control strategies of inverter is also similar with DC-DC converter. Both current mode control and voltage mode control are employed in this. By pulse width modulation technique a constant amplitude wave is generated by pulse duration by modulation of duty cycle.

Analog based PWM technique requires a reference and a carrier signal which are compared and based on some logical output, final output signal is generated. Reference signal may be sinusoid or square wave depending on preferred signal and carrier is saw tooth or triangular signal with slightly increased frequency with respect to reference signal.

Inverters generally take constant input voltage and by PWM control strategy they convert DC to AC voltage wave with controlled magnitude and frequency. PWM can be implemented in many ways to control the inverter output. Different kinds of PWM techniques are Single pulse width modulation, multiple pulse width modulation and Sinusoidal pulse width modulation.

Advantage of using SPWM is low power consumption, highly efficient energy, large power quality capability, minimum temperature variation degradation in linearity and SPWM is

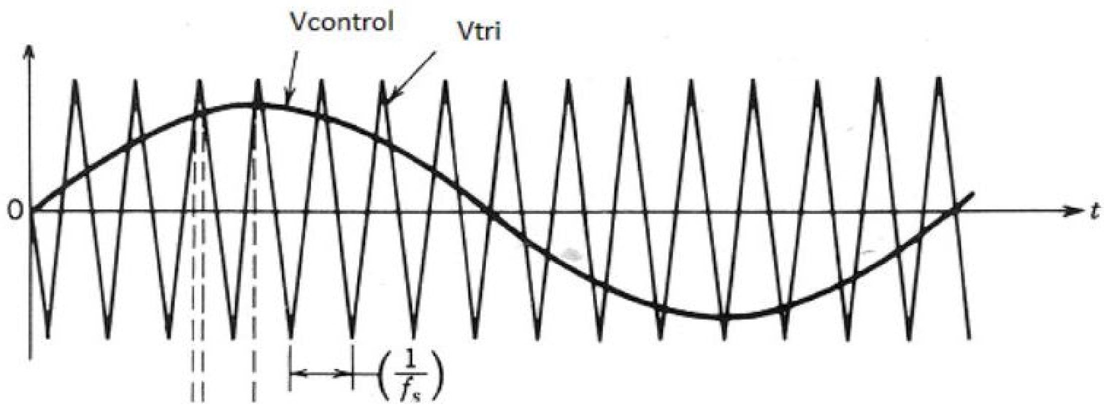

Figure 4.4: comparison of dsired freq and triangular wave

simple to implement and control. SPWM has constant amplitude pulse with different duty cycle ratio.

4.4 Sinusoidal Pulse Width Modulation

SPWM technique uses several pulses in a half cycle and of different width. The width is proportional with amplitude of sine wave estimated at centre of the same pulse. To generate gating signal reference wave signal is compared with triangular wave signal. Frequency of inverter output is determined by frequency of reference signal.

Consider a Carrier waveform V_{tr} with frequency f_s .This carrier wave frequency control the switch speed of the inverter at which it is to be turned on and off. The reference signal $V_{control}$ is used to modulate duty ratio of the switch having frequency off_1 . Frequencyf_1 is the fundamental frequency of the inverter output voltage. Output of inverter will contain harmonics at switching frequency as it is controlled by switching frequency. SPWM signal is produced by all these operation.

Modulation ratio is the ratio of amplitudes of reference voltage and carrier voltage. Output voltage amplitude is controlled by modulation index. Large MI can cause high magnitude of output voltage although spectral content of voltage becomes poor. Over modulation may also result in more harmonic content.

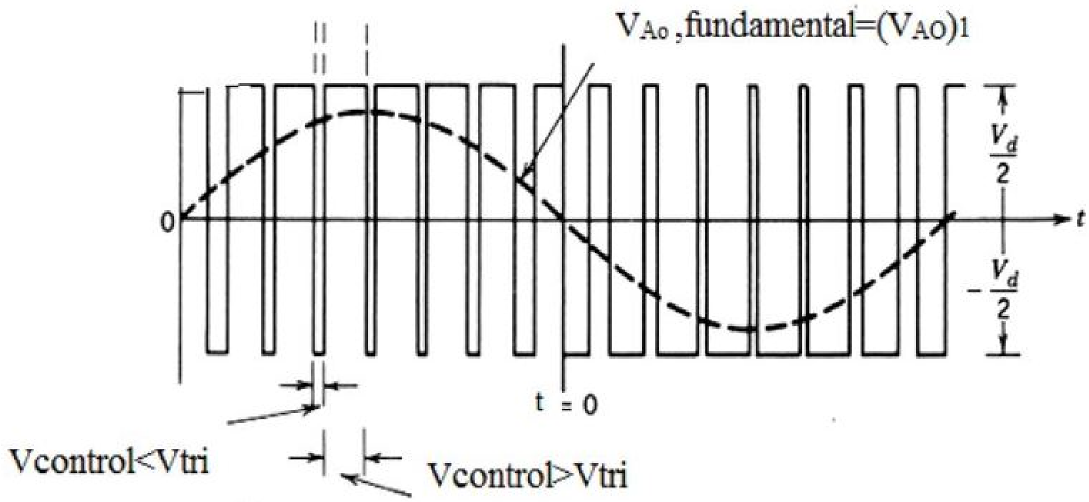

Figure 4.5: pulse widh modulation

4.4.1 SPWM with bipolar Switching

In this type of switching switches are treated as wo switch pairs. Switches are Simultaneously triggering on and off. A comparator is used to compare reference signal and carrier signal and finally a bipolar switch signal is produced. The signal applied to switches of inverter are equal with reversed polarity.

Output voltage of inverter is determined by comparing carrier signal and control signal as shown in fig. to obtain switching pulses for switching devices. The resultant wave is obtained as shown in fig. Output of switching signal carries the fundamental frequency of output voltage. Analysis of harmonics are also being done.

The output voltage switches between +V and V voltage levels. This is the reason of calling this type of switching a bipolar switching. This type of switching causes high harmonic content in the DC side current of inverter. The harmonic content result in ripple in capacitor voltage.

CHAPTER 5

GRID CONNECTION WITH LCL FILTER

To supply harmonic distortion free sinusoidal line current to the grid we need to install a filter between inverter and grid. Every semiconductor converter uses filter as an essential part of the circuit.to reduce the effect of harmonics created by continuous switching of semiconductor device on other parts of the system filter is essential.

Various parameters such as efficiency, weight, and cost has to be consider for choosing a proper optimal filter topology. Losses in filter are not large but still topologies with minimum losses are to be chosen. Weight and volume of filter are also important parameters to cure the difficulties taking place while installation and transportation of inverters.[11]

Cost of the filter is also an important parameter and it depends on type of components and quality of material used. Independence of filter over grid parameter is important and should work identical within a limit of variation of parameters, like resonance susceptibility and dynamic performance are of major importance.[12]

There are different kinds of topologies of filters as L-filter, LC-filter and LCL filter as shown in the fig. various advantages and disadvantages of all these topologies based on their design and performance are discussed in details. Attenuating the harmonics, quality of decoupling between filter and grid impedance are various performance parameters to be analysed.

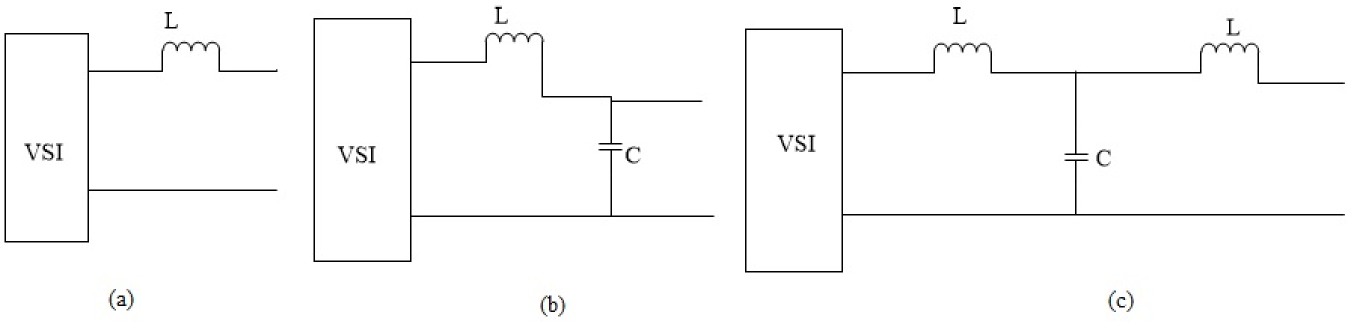

Figure 5.1: Filter Toplogies a) L-Filter b) LC-Filter c)LCL filter

5.1 LCL Filter

Filter performs many main functions one to convert voltages from switch device to current, other to reduce noises from high frequency switching and to protect switching devices from transients. L-filter and LC filter both also have excellent performance in converting voltage into current but the damping of HF noise is poor. Biggest disadvantage of L and LC filter is capacitors direct exposure to line grid voltage and if high current comes capacitor may get damaged. LCL filter gives good current attenuation in order to protect the capacitor from getting damaged by high magnitude of line current.

LCL filter damps the HF noise by its extra inductance along with good voltage-current conversion. The capacitor of LCL filter does not exposes directly with line voltage distortion unlikely with L and LC filters. LCL filter also have other advantages as low grid current distortion and reactive power production and it also uses relative low switching frequency for given harmonic attenuation. Above resonant frequency gives attenuation of -60dB/dec as LCL filter is a third order frequency.

Sometimes LCL filter may cost more as compared with other topologies of filter and also a bit complicated. Above all it has biggest advantage of independence over grid parameters and helps in giving stable power quality level in high frequency application. Further, it gives better attenuation of current as compared with other filters of same size and also limits the current inrush problem.

At resonance LCL may cause both dynamic and steady state input current distortions and may led to unstabilty.to reduce oscillation and chances of instability in LCL filter damping resistors are added. These addition of damping resistor in the circuit of filter is called passive damping.

Damping technique described above is reliable and easy but it reduces the efficiency and raises the losses of the system. Damping resistor may be connected in four possible ways it can be placed series or parallel to inductor of inverter side or may be in series/parallel with capacitor.

Use of LCL filter has many advantages over other filter topologies. Extra capacitor used in LCL filter gives many benefits to compensate its cost.to damp the system a resistor is connected with capacitor. The designing of LCL filter is also discussed further.

5.2 Filter Design Parameter

There may be either passive type of active damping possible in a LCL circuit. Here we are including a resistor in series with capacitor. The type of damping adopted in the topology is passive type.

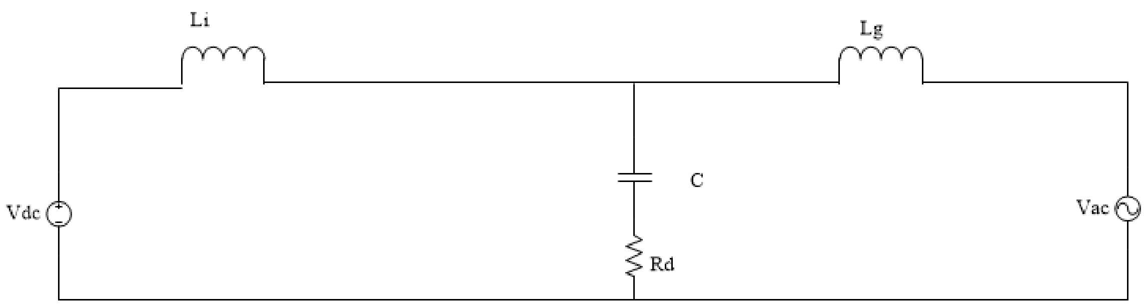

Figure 5.2: LCL Filter and Components

V_l - line to line RMS voltage

C_{ws} - inverter output voltage

P_n - rated active power

V_{dc} - DC line voltage

f_n - grid frequency

f_{sw} - switching frequency

f_{res} - resonance frequency

5.2.1 Parameter calculation

First we need to calculate all the required base values

$$Z_b = \frac{V^2{}_l}{S_n} \tag{5.1}$$

$$C_b = \frac{1}{w_n * z_b} \tag{5.2}$$

Calculation of input side inductor

Input side inductor can limit output current ripple by 10 percent of nominal value

$$L_i = \frac{V_{dc}}{16 \times f_s \times \Delta \triangleleft i_{l\max}} \tag{5.3}$$

Where, is 10 percent of current ripple Given by

$$\Delta i_{l\max} = \frac{.01 \times P_n \times \sqrt{2}}{V_l}$$

Calculation of filter capacitor value

Maximum power factor variation accepted upto 5 percent and is controlled by capacitor

$C_p = .05 \times C_b$

Calculation of output inductor

where, r is obtained by ratio curve

$L_g = r \times L_i$

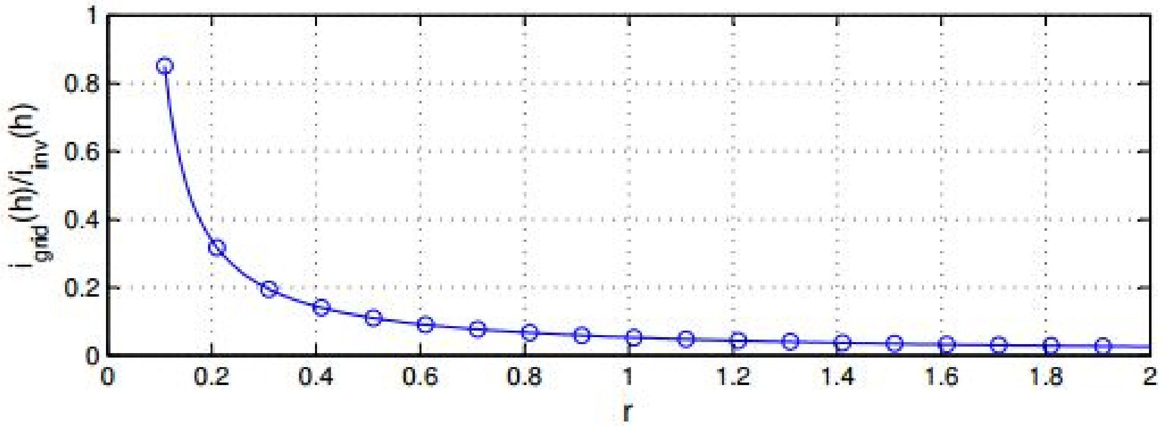

Figure 5.3: Ratio Curve

5.2.2 Design of Filter Frequency

Value of resonating frequency must be away from grid frequency and atleast must be half of switching frequency.

$$f_{res} = \frac{1}{2\pi} \times \sqrt{\frac{L_i + L_g}{L_i \times L_g \times C_f}} \tag{5.4}$$

There must be damping in the system to reduce oscillation and make the system stabilised. For doing this a series resistor is chosen and this type of damping is called passive damping. This damping is very simple and reliable but contribute to system heat loss.[1]

5.3 Grid Connected Inverter Control

The control of grid connected inverter is done by a multi loop composed of output power loop and current inner loop with active damping technique.[2]

By instantaneous power theory real power and reactive power is calculated. Two independent control values I_p and I_q are produced by comparing active and reactive powers by reference values. I_p and I_q are then multiplied by sinusoidal signal to obtain two new signals I_p^1 and I_q^1 will be attained and these signals carry both angle and amplitude information. Power control and inner loop current control both are done by these two newly obtained signals.[4][8]

5.3.1 Current Controller

Cross coupling and feed forward methodology are used in conventional current controllers. In conventional current controller lower order harmonics are predominant and thus power quality has very little improvement even if major modifications are done in PLL structure. In the proposed scheme of current controller, inner loop of the system is current loop.

To improve the dynamic behaviour and to track the current reference with low Total Harmonic Distortion inner current loop is used. To overcome resonance problem introduced by LCL filter capacitor current feedback is added to current loop.

The current reference value can be achieved by equation

$$I_{ref} = I_p^1 + I_q^1 = \frac{I_p V_{g-\alpha} + I_q V_{g-\beta}}{\left|V_g\right|}$$

Infinite gain is obtained at resonance frequency obtained by PR controller applied to serve as grid current loop compensator. Accuracy and acceptable distortion is achieved by dual closed loop current controller with capacitor current inner loop and grid current outer loop.

5.3.2 Power Controller

Active and reactive power control is not possible by using conventional controllers. Feedback from grid current is obtained which is reference current and is used to control reactive and active power. The dynamic VAR control system detects and compensates instantaneously the voltage disturbance by inserting leading or lagging reactive power at vital junctions of transmission grids.[13][15]

PI controller sre ued with K_p and K_i values obtained by hit and trial method for power control. The open loop of power controller is expressed as

$$G_o(s) = \frac{k_P + k_I}{s} * V_g * \frac{kw^2}{s^2 + kws + w^2} * \frac{1}{T_c + 1} \tag{5.5}$$

T_c is the control period of the whole system and is of small magnitude in real implementation. K and w are parameters of SOGI module. Main function of power output loop is to track the power reference value with zero steady state error and high stability of system. SOGI provide high gain at working frequency and at certain frequency range V_g will not affect the system performance.

CHAPTER 6

SIMULATION RESULTS AND DISCUSSION

6.1 INTRODUCTION

This chapter explains the details of simulation diagram of PV connected grid system with inverter. Active and Reactive power curves of PV grid connected system are also presented and explained.The output current and voltage waveforms of inverter circuit are also compared.Total Harmonic Distortion(THD) present in the current of the circuit after connecting LCL Filetr is shown and discussed.

6.2 Simulation Result

Figure 6.1: ACTIVE POWER CURVE

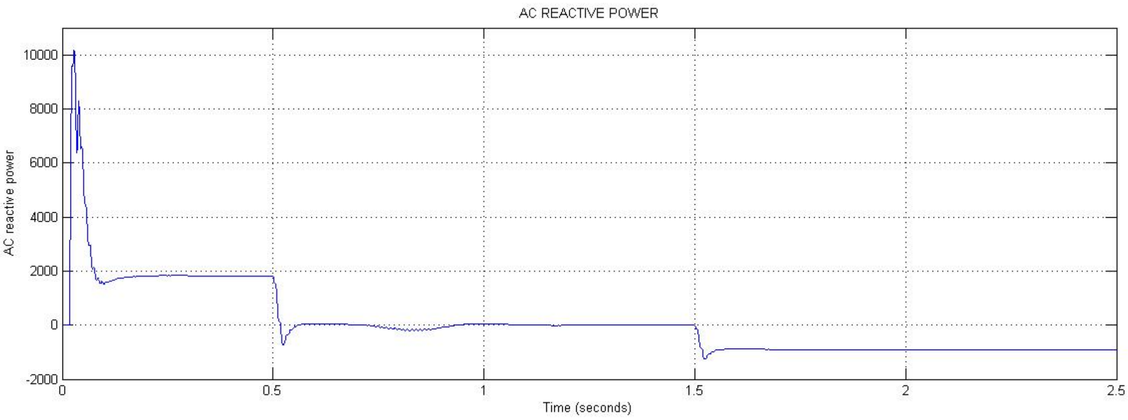

Figure 6.2: REACTIVE POWER CURVE

As reference values of Active Power and Reactive Power changes takes place at various time instants and as the curve shows output performance of the system also varies simultaneously.

Active Power Curve

Reference Active Power changes from 2000KW to 4500KW at .7 sec and to 3500KW at 1.3sec by varying irradiance of the PV system and as we can observe output power follows this.Some transients occurs at .7sec but for very less time and steady state is achieved.Active Power is controlled saperately without affecting other parameters of the system by help of d-axis current.[4]

Reactive Power Curve

Reactive Power is initially leading and changes at .5 sec and 1.5 sec to unity power factor and lagging power factor by setting the reference Power and by help of q-axis current.This control will have no effect on active power as the two current are independent.

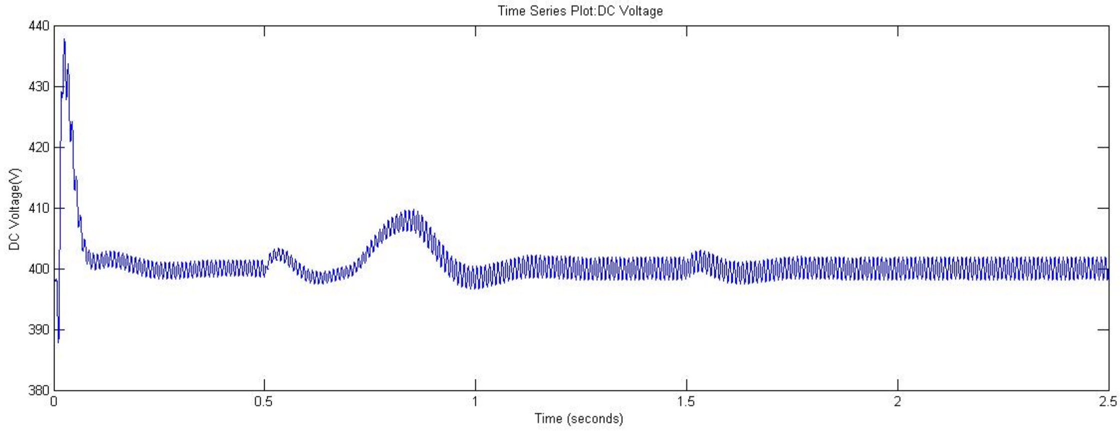

Figure 6.3: DC Input Voltage

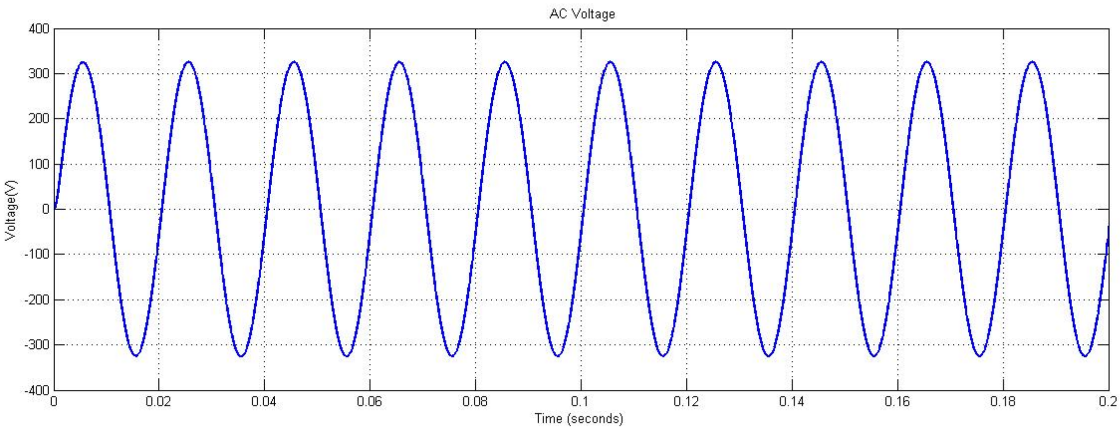

Figure 6.4: AC Output Voltage

Change in current takes place with variance and the reference reactive power.predictive control current method is used in this method we are getting smooth variation in current without big ripples caused due to changes taking place in active and reactive power.

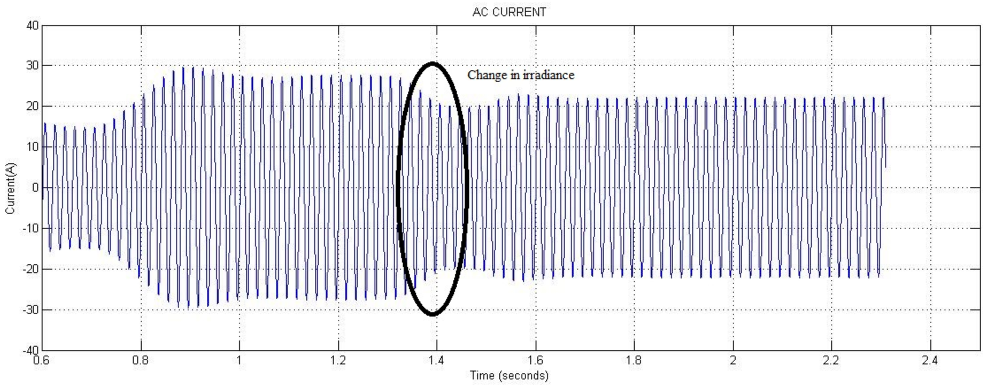

Figure 6.5: Grid current

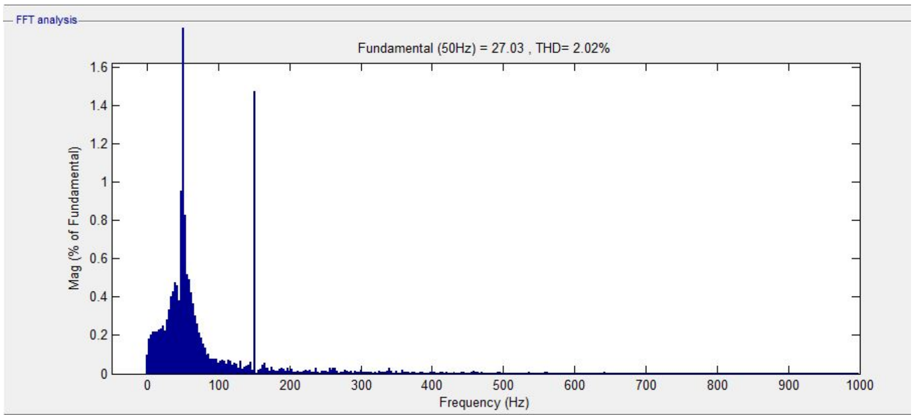

Figure 6.6: Total Harmonic Distortion of current

The THD of the proposed method is as low as 2.02 percent and as we can observe by the above fig that current have predominient 3rd harmonic component along with little other higher order.

CHAPTER 7

CONCLUSION & FUTURE WORK

7.1 Conclusion

P and O MPPT is used along with two stage inverter topology containing Boost Converter to step up Voltage and Inverter used to control the PV Grid system.DC-DC converter decouples direct connection of PV with grid preventing output power ripple to disturb PV voltage so that effieciency of MPPT is high.LCL filter is used to reduce the harmonics generated by switching in the system.Exclusive control of Active and Reactive power can be done as shown in the simulation results under variable irradiance and references.

7.2 Future Work

- Study and simulation of advanced MPPT algorithms
- Hardware implementation of the set-up
- Simulation of effects of PI,PR, controller on transient response for different K p and K i values

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