Implementation of Intelligent Controller for Single Phase Grid Connected PWM Inverter

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SURENDRA MOHAN GILANI

2K11/C&I/15

Under the Esteemed Guidance of

Dr. NARENDRA KUMAR

Associate Professor

ELECTRICAL ENGINEERING DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

(FORMERLY DELHI COLLEGE OF ENGINEERING)

BAWANA ROAD, DELHI-110042

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DELHI TECHNOLOGICAL UNIVERSITY

DEPARTMENT OF ELECTRICAL ENGINEERING

Certificate

This is to certify that the thesis entitled, “**Implementation of Intelligent Controller for Single Phase Grid Connected PWM Inverter**”, has been submitted in partial fulfilment of the requirements for award of the degree in M.Tech in Control & Instrumentation under my supervision by Surendra Mohan Gilani (2K11/C&I/15), at the Delhi Technological University.

This work has not been submitted earlier in any university or institute for the award of any degree to the best of my knowledge.

Dr. Narendra Kumar
Associate Professor
Department of Electrical Engineering

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SURENDRA MOHAN GILANI

Roll no. 2K11/C&I/15

M.Tech (Control & Instrumentation)

Abstract

Development of distributed generation system has resulted due to the ever growing demand of electrical energy. The keen scarcity of conventional energy sources has resulted in the development of alternate sources of electrical energy. The main abstruse is the harmonization of the DG to the utility grid. PWM based Voltage Source inverters are mostly meant for synchronizing the utility grid to the distributed generation system.

Following objectives are meant to be achieved for a grid connected PWM inverter in order to meet the growing energy demand:

1) To ensure grid stability

2) Active and reactive power control through voltage and frequency control

3) Power quality improvement (i.e. harmonic elimination) etc.

This project will review different control techniques for grid inverters systems. In this Fuzzy logic controller (FLC) is proposed to enhance the power quality by diminishing current error.
An analysis of hysteresis controller is studied for providing control of a grid connected inverter. The hysteresis controller along with PI controller and Fuzzy logic controller is analysed for controlling the harmonic content in current. The studied system is modelled and simulated in the MATLAB/Simulink environment and the results obtained from hysteresis and fuzzy logic controllers are compared with conventional PI Controller.

List of Symbols used

DG	Distributed Generation
VSI	Voltage Source Inverter
K_P	Proportional Gain
K_i	Integral Gain
μ_A	Characteristic function
THD	Total Harmonic Distortion
EPS	Electric Power System
HBCC	Hysteresis Band Current Controller
PLL	Phase Locked Loop
t_s	Sampling Time
i_e^*	Reference Current
i_e	Actual Current
CSBI	Current Source Boost Inverter
HV	High Voltage
VFOC	Virtual Flux Oriented Control
PWM	Pulse Width Modulation
e(t)	Error
K	Scaling Factor
V_{dc}	DC voltage
V_g	Grid voltage
V_o	Rms o/p Voltage
Ti	Integral Time Constant

K_i	Integral Gain
f_s	Switching frequency
L_f	Load inductance
IGBT	Insulated Gate Bipolar Transistor
THD	Total Harmonic Distortion
PI	Proportional Integral
FLC	Fuzzy Logic Controller

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CHAPTER 1
INTRODUCTION

1.1 GENERAL

To meet the future energy demand of electricity Distributed Generations are the viable option as because it can provide a 1) secure and diversified energy options, 2) increase the generation and transmission efficiency, 3) reduce the emissions of greenhouse gases, and 4) improve the power quality and system stability. Inspite of the several advantages, the main technical challenge is the synchronization of the DGs with the utility grid according to the grid code requirements. In most of the cases power electronics converter, especially current controlled PWM-VSI are used for the integration of the DGs with utility grid. The main objectives of the control of grid connected PWM-VSI is to 1)ensure grid stability 2) active and reactive power control through voltage and frequency control 3) power quality improvement (i.e. harmonic elimination) etc. As electric distribution technology steps into the next century, many trends are becoming noticeable that will change the requirements of energy delivery. These modifications are being driven from both the demand side where higher energy availability and efficiency are desired and from the supply side where the integration of distributed generation and peak shaving technologies must be accommodated. A distributed generation (DG) system becomes more prominent in the world electricity market due to the increased demand for electric power generation. The deregulation of the electric power industry and to reduce the greenhouse gas emissions etc. Distributed generation systems and their interconnection should meet certain requirements and specifications when interconnecting with existing electric power systems (EPS). For an inverter-based distributed generator, the power quality largely depends on the inverter controller’s performance. Pulse width modulation (PWM) is the most popular control technique for grid-connected inverters. As compared with the open loop voltage PWM converters, the current-controlled PWM has several advantages such as fast dynamic response, inherent over-current protection, good dc link utilization, peak current protection etc. For quick current controllability, unconditioned stability, good current tracking accuracy and easy implementation, the hysteresis band current control (HBCC) technique has the highest rate among other current control methods such as sinusoidal PWM. However, the bandwidth of the hysteresis current controller determines the allowable current shaping error. By changing the bandwidth, the user can control the average switching frequency of the grid connected inverter and evaluate the performance for different values of hysteresis bandwidth.

1.2 LITERATURE SURVEY

The following section describes the literature survey that is relevant with the work carried out for this thesis work.

Yaosuo Xue, Inverters in DG applications constantly experience a wide range of dc input voltage variations, where the output voltage needs to be boosted up to a level compatible with ac grid. Boost or buck-boost inverters find their niches performing power conversion under variable dc sources as obtained from wind and solar energy. The functions of inverters in distributed power generation (DG) systems include dc–ac conversion, output power quality assurance, various protection mechanisms and system controls. Unique requirements for small distributed power generation systems include low cost, high efficiency and tolerance for an extremely wide range of input voltage variations [10].

Adel M. Sharaf, A Novel FACTS based Scheme with a Smart Dynamic Control Strategy and Modulated Filter Compensator is designed to stabilize the common DC Collection Bus output voltage for the Photovoltaic, Fuel Cell, wind turbine and Diesel Gen set sources in the Village/Island/resort Micro Grid Utilization system [32].

Yujia Shang and Aiguo Wu discuss the problem of harmonic detection delay by the instantaneous reactive power method, a TS fuzzy logic along with synthetic sinusoid generation technique based shunt active power filter is proposed. The VSI gate switching signals are derived from adaptive-hysteresis current controller so that the modulation frequency remains nearly constant, which will improve the PWM performances and APF substantially. The experimental data shows that the dynamic and steady behaviour of the active power filter is perfect [27].

Marian P. Kazmierkowski, used current control techniques for three-phase voltage source pulse width modulated converters. Use of linear predictive and on-line optimized Current Controller is growing fast in medium- and high-performance systems, especially for traction and high power units. Hysteresis Current Controller, in their improved versions, are well suited to fast, accurate conversion systems (e.g., power filters and UPS's) [4].

Krismadinata, Nasrudin Abd Rahim describes a control method for single phase grid-connected inverter system for distributed generation application. Single-band Hysteresis Current Controller is applied as the control method. The current produced by this inverter is in phase with grid voltage and also achieve unity power factor .This method also reduces the number of components such as Phase Lock Loop (PLL) circuits and cost significantly [19].

Sharad W.Mohod, he proposed using wind power into an electric grid affects the power quality. The performance of the wind turbine and their power quality are determined on the basis of measurements, The paper simulates the scheme in MATLAB/SIMULINK for maintaining the power quality in such a way that it can cancel out the reactive and harmonic parts of the load current and maintain the source voltage and current in-phase at the point of common coupling in the grid system [21].

A. Ebrahimi, discuss a novel topology for justifying PV Module output voltage with a single-stage current source boost inverter (CSBI) has been proposed. This topology is proposed with consideration of changes in radiation intensity and temperature. The proposed circuit topology is based on the concept of current source inverters (CSIs), the output voltage about to constant even with changes in radiation intensity and temperature [31].

Satyaranjan Jena, he described the performance of adaptive hysteresis current controller for single-phase grid connected inverter system. Using adaptive hysteresis current controller current error of single phase grid is reduced thus in turn it reduces the THD and it provides constant switching frequency of operation. In addition to that it takes less computation time for real time implementation using digital processor. Further, the results obtained for proposed controller is compared with conventional hysteresis controller and it ensures good dc-bus voltage utilization, constant frequency of operation, less current error (i.e.) Lower THD [35].

Satyaranjan Jena, B. Chitti Babu S.R.Samantaray and Mohamayee Mohapatra they describe the comparative study between adaptive hysteresis and SVPWM current controllers for grid connected inverter system, they concluded that adaptive hysteresis current controller provides good dynamic response over SVPWM current controller during transient conditions But the SVPWM current controller provides better utilization of Dc-link voltage along with lesser THD of grid current [25].

Chen Xiaoju, Based on the analysis of the hysteresis SVPWM control algorithm, a new segmentation control strategy of three-phase PV inverter is proposed by him which reduces the Total harmonic distortion as well lower switching frequency and improve dynamic response [26].

A.Faruk Bakan proposed steady state response, dynamic response, and power quality performance are comparatively analyzed for SVPWM (Space Vector Pulse Width Modulation) and HCC (Hysteresis Current Control) control techniques in three phase voltage source grid connected inverters. It is observed that HCC technique has lower THD value if SVPWM switching frequency and HCC average switching frequency are equal. It is concluded that the use of SVPWM technique is more appropriate than HCC, when maximum switching frequency of HCC is restricted to the SVPWM switching frequency [34].

Guo Xiaoqiang, he proposed a single-phase grid-connected inverter system with the quasi-PR control scheme, the proposed grid-connected inverter system is to achieve high performance in both the sinusoidal reference tracking and the disturbance rejection. Theoretical analysis and experimental results of a 300W experimental prototype verified the high performance of the proposed grid connected inverter system [13].

B.Chitti Babu proposed Hysteresis+PI current controller can enable to reduce switching frequency even if the band width increased without any significant increase in the current error. Hence it provides considerably less THD at higher band width as compared to conventional hysteresis current controller [28]

1.3 OBJECTIVE OF THE PRESENT WORK

The objective of the present work is to implement an intelligent controller for a single phase grid connected PWM Inverter. The improvement in power quality is to be achieved by reducing the harmonic content in the current and compared by implementing two control schemes.

i) PI controller

ii) Fuzzy Logic Controller

The above two control scheme has been tested for performance. The work is implemented in MATLAB/Simulink.

CHAPTER 2
MODELING OF GRID

2.1 INTRODUCTION

The number of distributed generation (DG) units, including both renewable and non-renewable sources, for small rural communities not connected to the grid and for small power resources (up to 1000 kW) connected to the utility network has grown in the last years. There has been an increase in the number of sources that are natural DC sources, for instance fuel cells and photovoltaic arrays, or whose AC frequency is either not constant or is much higher than the grid frequency, for instance micro gas-turbines. These generators necessarily require a DC/AC converter to be connected to the grid. Although some generators can be connected directly to the electric power grid, such as wind power driven asynchronous induction generators, there is a trend to adopt power electronics based interfaces which convert the power firstly to DC and then use an inverter to deliver the power to the 50Hz AC grid.

It is well-known that for systems efficiency increasing, the inverter is the answer of the problem. By its control, the inverter can ensure the efficient operation and the accomplishment of the energy quality requirements related to the harmonics level.

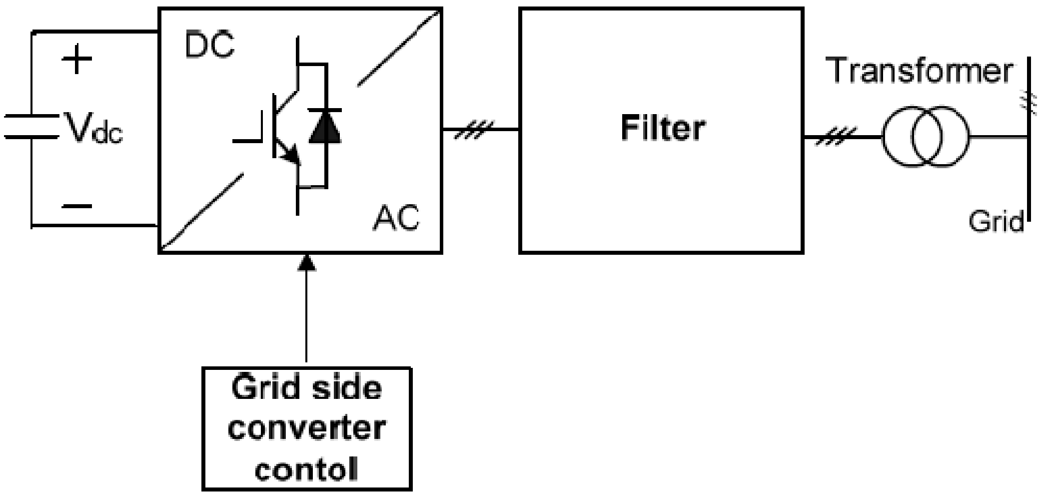


Fig.2.1 Layout of the model system

Power quality is important because many electric devices and appliances are designed to function at a specific voltage and frequency. In North America, AC (alternating current) power is delivered at 120 and 240 Volts and 60 Hz (cycles/second). If power is not delivered properly, it may result in appliance malfunction or damage. In the worst situation, fire hazard is a possibility.

2.2 POWER GENERATION SYSTEM

Electric power systems are real-time energy delivery systems. Real time means that power is generated, transported, and supplied the moment you turn on the light switch. Electric power systems are not storage systems like water systems and gas systems. Instead, generators produce the energy as the demand calls for it.

The system starts with generation, by which electrical energy is produced in the power plant and then transformed in the power station to high-voltage electrical energy that is more suitable for efficient long-distance transportation. The power plants transform other sources of energy in the process of producing electrical energy. For example, heat, mechanical, hydraulic, chemical, solar, wind, geothermal, nuclear, and other energy sources are used in the production of electrical energy. High-voltage (HV) power lines in the transmission portion of the electric power system efficiently transport electrical energy over long distances to the consumption locations. Finally, substations transform this HV electrical energy into lower-voltage energy that is transmitted over distribution power lines that are more suitable for the distribution of electrical energy to its destination, where it is again transformed for residential, commercial, and industrial consumption.

Raising the voltage to reduce current reduces conductor size and increases insulation requirements. The cost due to losses decreases dramatically when the current is lowered.

The power losses in conductors are calculated by the formula I^2R. If the current (I) is doubled, the power losses quadruple for the same amount of conductor resistance (R). Again, it is much more cost effective to transport large quantities of electrical power over long distances using high-voltage transmission lines because the current is less and the losses are much less.

2.2.1 Distributed Generation System

Distributed generation (or DG) generally refers to small-scale (typically 1 kW – 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. Distributed generators include, but are not limited to synchronous generators, induction generators, reciprocating engines, micro turbines (combustion turbines that run on high-energy fossil fuels such as oil, propane, natural gas, gasoline or diesel), combustion gas turbines, fuel cells, solar photo voltaic, and wind turbines.

2.2.1.1 Applications of Distributed Generating Systems

There are many reasons a customer may choose to install a distributed generator. DG can be used to generate a customer's entire electricity supply; for peak shaving (generating a portion of a customer's electricity onsite to reduce the amount of electricity purchased during peak price periods); for standby or emergency generation (as a backup to Wires Owner's power supply); as a green power source (using renewable technology); or for increased reliability. In some remote locations, DG can be less costly as it eliminates the need for expensive construction of distribution and/or transmission lines.

2.2.1.2 Benefits of Distributed Generating Systems

Distributed Generation:

- Has a lower capital cost because of the small size of the DG (although the investment cost per kVA of a DG can be much higher than that of a large power plant).
- May reduce the need for large infrastructure construction or upgrades because the DG can be constructed at the load location.
- If the DG provides power for local use, it may reduce pressure on distribution and transmission lines.
- With some technologies, produces zero or near-zero pollutant emissions over its useful life (not taking into consideration pollutant emissions over the entire product lifecycle i.e. pollution produced during the manufacturing, or after decommissioning of the DG system).
- With some technologies such as solar or wind, it is a form of renewable energy.

- Can increase power reliability as back-up or stand-by power to customers.
- Offers customers a choice in meeting their energy needs.

2.2.1.3 Challenges associated with Distributed Generating Systems

- There are no uniform national interconnection standards addressing safety, power quality and reliability for small distributed generation systems.
- The current process for interconnection is not standardized among provinces.
- Interconnection may involve communication with several different organizations.
- The environmental regulations and permit process that have been developed for larger distributed generation projects make some DG projects uneconomical.
- Contractual barriers exist such as liability insurance requirements, fees and charges, and extensive paper work.

2.2.1.4 Integration of DG system with the grid

For reasons of reliability, distributed generation resources would be interconnected to the same transmission grid as central stations. Various technical and economic issues occur in the integration of these resources into a grid. Technical problems arise in the areas of power quality, voltage stability, harmonics, reliability, protection, and control. Behaviour of protective devices on the grid must be examined for all combinations of distributed and central station generation. A large scale deployment of distributed generation may affect grid-wide functions such as frequency control and allocation of reserves.

2.2.2 Electrical Grid

An electrical grid is an interconnected network for delivering electricity from suppliers to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers.

Power stations may be located near a fuel source, at a dam site, or to take advantage of renewable energy sources, and are often located away from heavily populated areas. They are usually quite large to take advantage of the economies of scale. The electric power which is generated is stepped up to a higher voltage-at which it connects to the transmission network.

The transmission network will move the power long distances, sometimes across international boundaries, until it reaches its wholesale customer (usually the company that owns the local distribution network).On arrival at a substation, the power will be stepped down from a transmission level voltage to a distribution level voltage. As it exits the substation, it enters the distribution wiring. Finally, upon arrival at the service location, the power is stepped down again from the distribution voltage to the required service voltage(s).

2.2.3 Power System Efficiency

The efficiency of a power system is maximized when the total combined load is purely resistive. Therefore, when the total load on the system approaches purely resistive, the total current requirements and losses are minimum. The total power that has to be produced is minimized when the load is purely resistive.

The total power becomes “real” power (i.e., watt power) only. When the system efficiency is maximized (i.e., minimum power required to serve all loads), two significant benefits are realized:

1. Power losses are minimized

2. Extra capacity is made available in the transmission lines, distribution lines, and substation equipment because this equipment is rated on the amount of current carrying capability. If the current flow is less, the equipment has more capacity available to serve additional load.

2.2.4 Reliable Grid Operations

Factors that contribute to reliable grid operations are discussed in this section for both normal and emergency operating conditions.

2.2.4.1 Normal Operations

Normal operations occur when all loads are being served with stable frequency, proper transmission line flows, ample reserve margins, and little known activity that could suddenly grab the attention of the system operator to take remedial action. In today’s environment, normal means operating several generation units and transmission lines at or near full capacity, trying to schedule equipment out of service for maintenance, and responding to daily events such as planned outages, switching lines and equipment for maintenance, coordinating new construction projects, and so on.

2.2.4.2 Frequency Deviation

Generators are limited to a very narrow operating bandwidth around the 60/50 Hz frequency. Frequency deviation within an electric system outside these tight parameters will cause generation to trip. Since transmission systems are interconnected to various generation sources, frequency deviation may also trip transmission lines in order to protect other sources of supply.

Frequency deviation must be carefully monitored and corrected immediately. The system operator is watching for the common causes of frequency deviation conditions, such as:

2.2.4.3 Sudden Supply/Demand Imbalance

Loss of supply can reduce frequency. Loss of load can increase frequency. Either way, frequency deviation is not tolerable and the operator or the automatic generation control system is required to make changes immediately if any event occurs on the system that could jeopardize frequency.

2.3 CONTROL STRATEGY FOR GRID SIDE INVERTER

2.3.1 Bidirectional Back-To-Back Two-Level Power Converter

This topology is state-of-the-art. The back-to-back PWM-VSI is a bi-directional power converter consisting of two conventional PWM-VSCs. The topology is shown in Fig 2.2

To achieve full control of the grid current, the DC-link voltage must be boosted to a level higher than the amplitude of the grid line-line voltage. The power flow of the grid side converter is controlled in order to keep the DC-link voltage constant, while the control of the generator side is set to suit the magnetization demand and the reference speed.

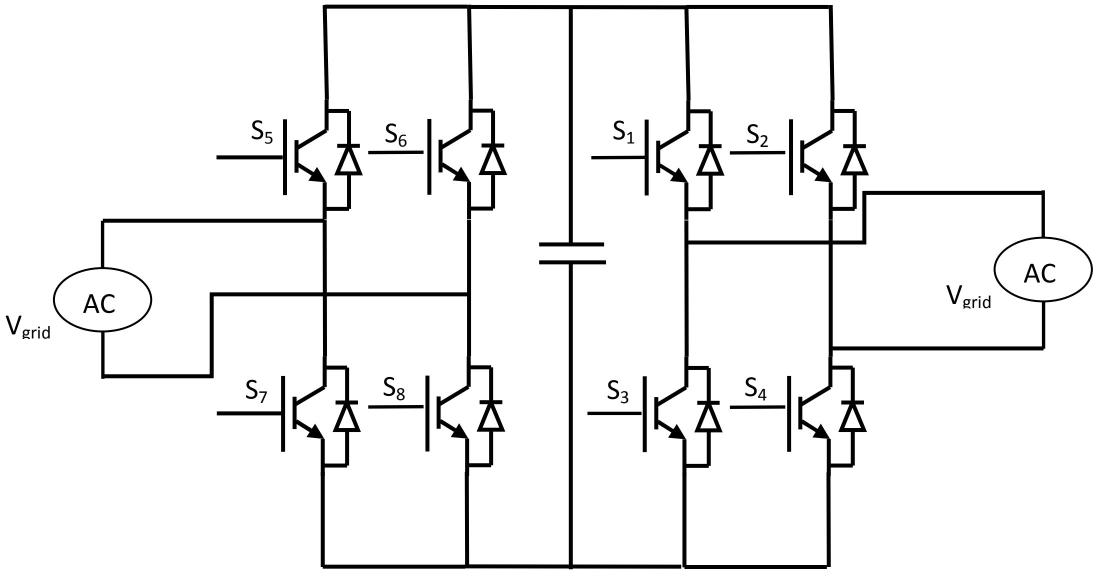


Fig.2.2 Structure of the back-to-back Voltage Source Converter

An advantage of the PWM-VSC is the capacitor decoupling between the grid inverter and the generator inverter. Besides affording some protection, this decoupling offers also separate control of the two inverters, allowing compensation of asymmetry both on the generator side and on the grid side, independently. The inclusion of a boost inductance in the DC-link circuit increases the component count, but a positive effect is that the boost inductance reduces the demands on the performance of the grid side harmonic filter, and offers some protection of the converter against abnormal conditions on the grid.

On the other hand, in several papers concerning adjustable speed drives, the presence of the DC-link capacitor is mentioned as a drawback, since it is heavy and bulky, it increases the costs and maybe of most importance, - it reduces the overall lifetime of the system. Another important drawback of the back-to-back PWM-VSI is the switching losses. Every commutation in both the grid inverter and the generator inverter between the upper and lower DC link branch is associated with a hard switching and a natural commutation. Since the back-to-back PWM-VSI consists of two inverters, the switching losses might be even more pronounced. The high switching speed to the grid may also require extra EMI-filters.

2.3.2 Unidirectional Power Converter

The diode rectifier is the most common used topology in power electronic applications. For a three-phase system it consists of six diodes. The diode rectifier can only be used in one quadrant, it is simple and it is not possible to control it. It could be used in some applications with a dc-bus.

The variable speed operation of the wind turbine is achieved by using an extra power converter which fed the excitation winding.

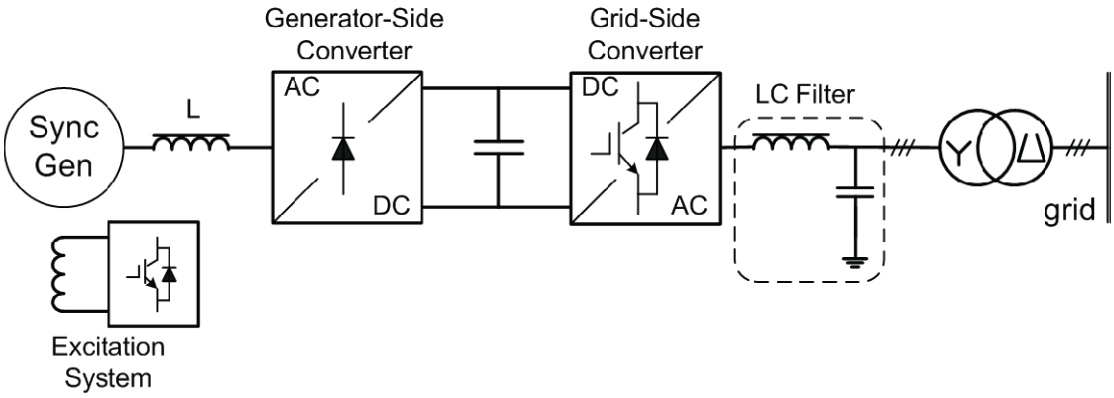


Fig.2.3 Full scale power converter

The grid side converter will offer a decoupled control of the active and reactive power delivered to the grid and also all the grid support features.

The optimum control strategy for the grid inverter control must be chosen based on the characteristics of known control methods. The control methods to be investigated should be as a minimum Voltage Oriented Control (VOC), Virtual Flux Oriented Control (VFOC) and Direct Power Control (DPC).

2.4 VOLTAGE SOURCE INVERTERS

A converter is a term coined in general for a rectifier or an inverter. A rectifier converts AC voltage into DC voltage while as an inverter converts DC voltage into AC voltage. The word ‘inverter’ in the context of power-electronics denotes a class of power conversion (or power conditioning) circuits that operates from a dc voltage source or a dc current source and converts it into ac voltage or current. The ‘inverter’ does reverse of what ac-to-dc ‘converter’ does (refer to ac to dc converters). Even though input to an inverter circuit is a dc source, it is not uncommon to have this dc derived from an ac source such as utility ac supply. Thus, for example, the primary source of input power may be utility ac voltage supply that is ‘converted’ to dc by an ac to dc converter and then ‘inverted’ back to ac using an inverter. Here, the final ac output may be of a different frequency and magnitude than the input ac of the utility supply.

Voltage Source Inverter (VSI) is a type of inverter where the independently controlled ac output is a voltage waveform. The output voltage waveform is mostly remaining unaffected by the load. Due to this property, the VSI have many industrial applications such as adjustable speed drives (ASD) and also in Power system for FACTS (Flexible AC Transmission).Thus if the input dc is a voltage source, the inverter is called a voltage source inverter (VSI).

The single-phase grid connected inverter shown in Fig.2.4.Which is composed of a dc voltage source (VDC), four switches (S1-S4), a filter inductor (Lf) and utility grid (Vg). In inverter-based DG, the produced voltage from inverter must be higher than the Vg in order to assure power flow to grid. Since Vg is uncontrollable, the only way of controlling the operation of the system is by controlling the current that is following into the grid.

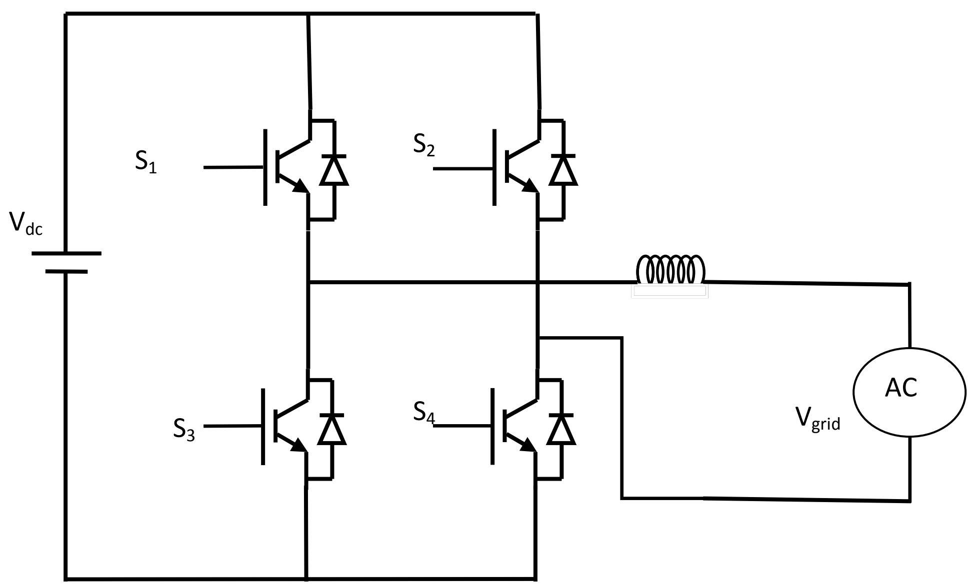


Fig.2.4 Single phase inverter connected to utility grid

2.4.1 General Structure of Voltage Source Inverters

Fig.2.5 shows the typical power-circuit topology of a single-phase voltage source inverter. This topology requires only a single dc source and for medium output power applications the preferred devices are n-channel IGBTs. ‘Edc’ is the input dc supply and a large dc link capacitor (Cdc) is put across the supply terminals. Capacitors and switches are connected to dc bus using short leads to minimize the stray inductance between the capacitor and the inverter switches. Needless to say that physical layout of positive and negative bus lines is also important to limit stray inductances. Q1, Q2, Q3 etc. are fast and controllable switches. D1, D2, D3 etc. are fast recovery diodes connected in anti-parallel with the switches. ‘A’ and ‘B’ are output terminals of the inverter that get connected to the ac load. A single-phase inverter has only one pair of load terminals. The VSI consists of single phase IGBT bridge inverter.

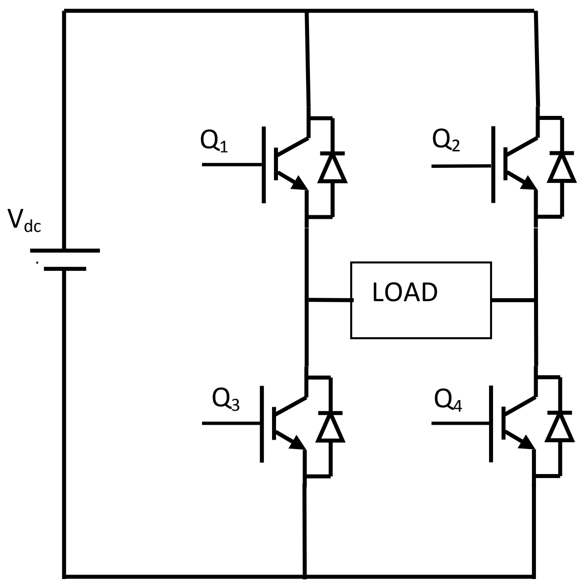


Fig.2.5 Topology of a 1-phase VSI

In the VSI, IGBT semiconductor switches are used. IGBT offers advantages over other semiconductor switches. The IGBT is suitable for many applications in power electronics, especially in current regulated PWM voltage-source inverters requiring high dynamic range control and low noise to improve power quality by minimising harmonic distortion of grid current. IGBT improves dynamic performance and efficiency and reduced the level of audible noise. It is equally suitable in resonant-mode converter circuits. Optimized IGBT is available for both low conduction loss and low switching loss. It has a very low on-state voltage drop. It can be easily controlled in high voltage and high current applications.

2.4.2 Classification of Voltage Source Inverters

Voltage source inverters can be classified according to different criterions. They can be classified according to number of phases they output. Accordingly there are single-phase or three-phase inverters depending on whether they output single or three-phase voltages. It is also possible to have inverters with two or five or any other number of output phases. Inverters can also be classified according to their ability in controlling the magnitude of output parameters like, frequency, voltage, harmonic content etc. Some inverters can output only fixed magnitude (though variable frequency) voltages whereas some others are capable of both variable voltage, variable frequency (VVVF) output. Output of some voltage source inverters is corrupted by significant amount of many low order harmonics like 3rd, 5th, 7th, 11th, 13th order of the desired (fundamental) frequency voltage. Some other inverters may be free from low order harmonics but may still be corrupted by some high order harmonics. Inverters used for ac motor drive applications are expected to have less of low order harmonics in the output voltage wave form, even if it is at the cost of increased high order harmonics. Higher order harmonic voltage distortions are, in most ac motor loads, filtered away by the inductive nature of the load itself.

CHAPTER 3
CONTROL STRATEGIES DESIGN

3.1INTRODUCTION

This chapter presents the study of the grid control strategy. First part will describe the main requirements for the strategy chosen for the design and implementation. The chosen strategy is PI Controller and Fuzzy logic controller with PLL and the functionality together with the mathematical model is presented in this section. One of the goals of this project is to control the grid currents by using a convenient strategy which can highlight the behaviour of the grid in different operating modes.

In this chapter will be described one method for controlling the grid currents, PI controller with PLL. The control strategy should meet the following demands

- The bandwidth of the controllers should be sufficiently high to inject 5th and 7th harmonic currents into a 50Hz grid.
- Frequency change rate up to 5Hz/sec.
- Power factor cosϕ range from 0.9 inductive to 0.9 capacitive at full load. Reactive power up to 0.85 time rated power when no active power is produced.
- Ease of implementation and controller tuning.

3.2 CONTROL METHOD

The current controllers used in the scheme are PI controller and Fuzzy Logic Controller (FLC). The two controllers are individually used to control the current of the grid and the results so obtained from them will be matched to check the performance of the two controllers.

3.2.1 PI Controller

In control engineering, a PI Controller (proportional-integral controller) is a feedback controller which drives the plant to be controlled by a weighted sum of the error (difference between the output and desired set-point) and the integral of that value. It is a special case of the PID controller in which the derivative (D) part of the error is not used.

The PI controller is mathematically denoted as:

$$\boldsymbol{P_{out} - P_O = K_P\left(e(t) + \frac{1}{T_i}\int e\,dt\right)} \tag{3.1}$$

The transfer function of a PI controller is:

$$H(s) = K_P(1 + \frac{1}{T_i s}) \tag{3.2}$$

Where K_P the high frequency is gain of the controller and T_I is the integral time constant.

Integral control action added to the proportional controller converts the original system into high order. Hence the control system may become unstable for a large value of K_p since roots of the characteristic eqn. may have positive real part. In this control, proportional control action tends to stabilize the system, while the integral control action tends to eliminate or reduce steady-state error in response to various inputs. As the value of T_i is increased,

- Overshoot tends to be smaller
- Speed of the response tends to be slower.

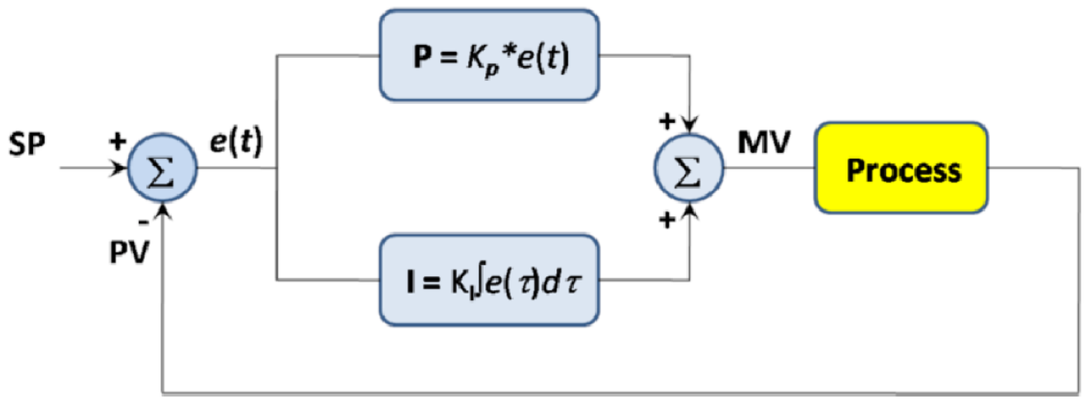


Fig. 3.1 Proportional Integral Controller

3.2.1.1 Operation with PI

PI controller is a conventional control technique used in most of the control process applications. The PI controller is used as a current controller in this scheme. The input of the PI controller is the difference between the reference current i_e* and the actual measured current i_e. The PI controller is designed in the MATLAB shown in Fig.3.2 Saturation control link is meant to limit the output amplitude.

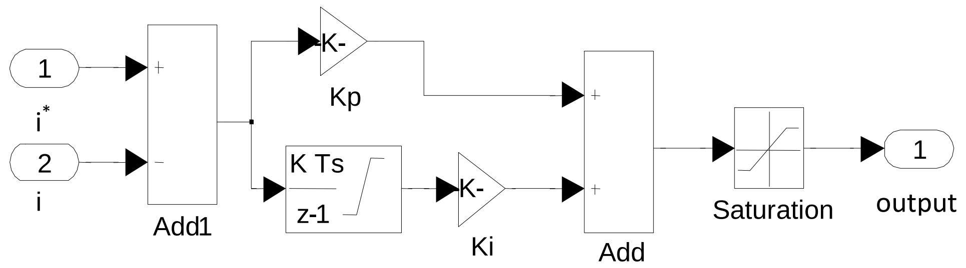


Fig.3.2 Proportional Integral Controller block diagram

3.2.1.2 Tuning of PI

The PI controller can be tuned using any method available to find out the best possible values of K_p & K_i. There are tuning methods like Ziegler-Nichols method etc. used for tuning PI controller.

3.2.2 Fuzzy Logic Controller

The second control method used for current control of the grid is Fuzzy Logic Controller. The current of grid and total harmonic distortion (THD) obtained using PI controller is compared with the grid current and THD obtain with Fuzzy Logic Controller +PI controller. This control method will be discussed in the next chapter.

3.3 PULSE WIDTH MODULATION (PWM)

The Pulse Width Modulation (PWM) is a technique which is characterized by the generation of constant amplitude pulse by modulating the pulse duration and modulating the duty cycle. Analog PWM control requires the generation of both reference and carrier signals that are feed into the comparator and based on some logical output, the final output is generated. The reference signal is the desired signal output maybe sinusoidal or square wave, while the carrier signal is either a saw tooth or triangular wave at a frequency significantly greater than the reference.

In this type of drive, a diode bridge rectifier provides the intermediate DC circuit voltage. In the intermediate DC circuit, the DC voltage is filtered in a LC low-pass filter. Output frequency and voltage is controlled electronically by controlling the width of the pulses of voltage to the motor. Essentially, these techniques require switching the inverter power devices (transistors or IGBTs) on and off many times in order to generate the proper RMS voltage levels.

There are various types of PWM techniques and so we get different output and the choice of the inverter depends on cost, noise and efficiency.

3.3.1 Basic PWM Techniques

There are three basic PWM techniques:

1. Single Pulse Width Modulation
2. Multiple Pulse Width Modulation
3. Sinusoidal Pulse Width Modulation

For present work, Sinusoidal Pulse Width Modulation Technique is used for the generation of constant amplitude pulse. In this modulation technique, multiple numbers of output pulse per half cycle and pulses are of different width are generated. The width of each pulse is varying in proportion to the amplitude of a sine wave evaluated at the centre of the same pulse. The gating signals are generated by comparing a sinusoidal reference with a high frequency triangular signal.

The rms ac output voltage,

$$V_O = V_S \sqrt{\frac{P\delta}{\pi}} \tag{3.3}$$

3.4 HYSTERESIS CURRENT CONTROLLER

In this circuit single phase load is connected to the PWM voltage source inverter. The load currents *ia*, *is* compared with the reference currents *ia** and error signals are passed through hysteresis band to generate the firing pulses, which are operated to produce output voltage in manner to reduce the current error.

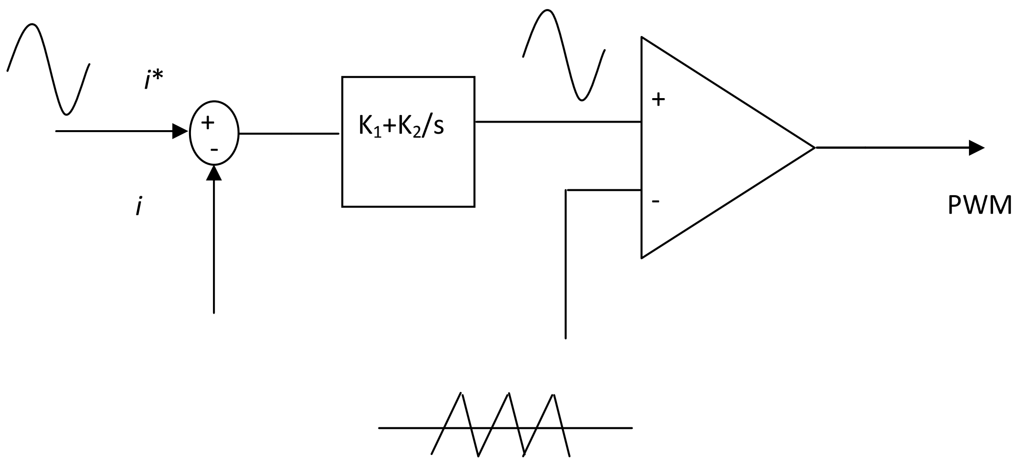


Fig.3.3 PWM obtained from hysteresis current control

The principle of Hysteresis current control is very simple. The purpose of the current controller is to control the load current by forcing it to follow a reference one. It is achieved by the switching action of the inverter to keep the current within the Hysteresis band. The load currents are sensed & compared with respective command currents by independent Hysteresis comparators having a hysteresis band '*h*'. The output signals of the comparators are used to activate the inverter power switches

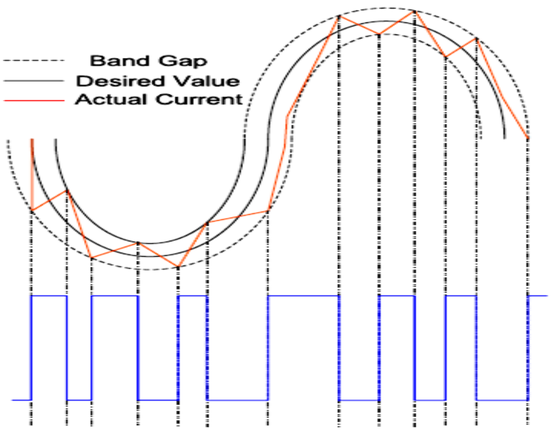


Fig.3.4 Principle of Hysteresis Band Control

In this scheme, the hysteresis bands are fixed throughout the fundamental period. The algorithm for this scheme is given as

$$Iref = I\,max sin\omega t$$

Upper band

$$iup = iref + h$$

Lower band

$$ilow = iref - h$$

Where h = Hysteresis band limit

If $ia > iup,\ \ Vao = -Vdc/2$

If $ia < ilow,\ Vao = +Vdc/2$

3.4.1 Hysteresis Band current controller

The hysteresis band current control is characterized by unconditioned stability, very fast response, and good accuracy. On the other hand, the basic hysteresis technique exhibits also several undesirable features; such as uneven switching frequency that causes acoustic noise and difficulty in designing input filters.

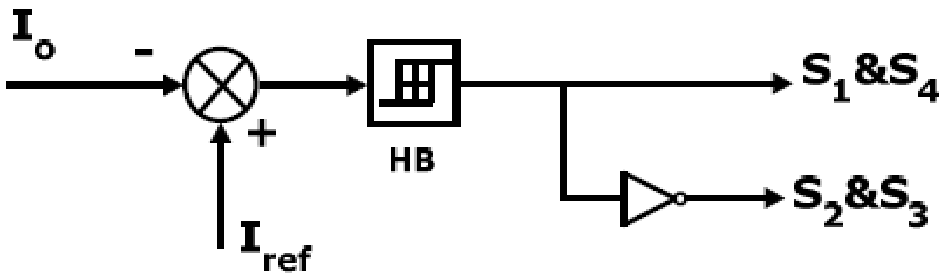


Fig.3.5 Hysteresis –Band Current Controller

In spite of several advantages, some drawbacks of conventional type of hysteresis controller are limit cycle oscillations, overshoot in current error, sub-harmonic generation in the current and uneven switching .In case of hysteresis controller as shown in fig.3.5 the error is directly fed to the hysteresis band. As given by equation (3.4) the reference line current of the grid connected inverter is referred to as i_{ref} and difference between i_o and i_{ref} is referred to as error (e). The hysteresis band current controller assigns the switching pattern of grid connected inverter.

$$e = i_o - i_{ref} \quad (3.4)$$

The switching logic is formulated as follows:

If e >HB then switch S1 and S4 is on

If e <-HB then switch S2 and S3 is on

The average load power is computed as:

$$P_L = \frac{1}{n}\sum_{j=1}^{n} v_s(j) i_l(j) \quad (3.5)$$

Using Torrey and Al- Zalmel methodology, the reference source current is computed as:

$$\mathrm{i_{ref}} = \mathrm{k}v_g \quad (3.6)$$

Where k is the scaling factor and computed as

$$\mathrm{K}{=}2\frac{P_L}{V_m^2} \quad (3.7)$$

The switching frequency of the system can be calculated as

$$V_{dc} = L_f \frac{di_o}{dt} + V_g \quad (3.8)$$

From Equation 3.4

$$i_o = i_{ref} + \mathrm{e} \quad (3.9)$$

By rearranging equation (3.8 and 3.9) we can calculate

$$T_{ON} = 2\frac{L_f HB}{V_{dc} - V_g} \quad (3.10)$$

And

$$T_{OFF} = 2\frac{L_f HB}{V_{dc} + V_g} \quad (3.11)$$

$$\frac{1}{f_s} = T_s = T_{ON} + T_{OFF} \quad (3.12)$$

$$f_s = \frac{({V_{dc}}^2 - {V_g}^2)}{4V_{dc} L_f HB} \quad (3.13)$$

Hence, the switching frequency varies with the dc voltage, grid voltage, load inductance and the hysteresis band.

3.4.2 Fuzzy With Hysteresis Current Controller

The main drawback of hysteresis current controller is uneven switching frequency which causes acoustic noise and difficulty in designing input filters during load changes. The switching frequency can be reduced by reducing the band width of the hysteresis band but at the same time the current error will increase which produce more distortion in the output current. To eliminate drawback upto certain extent fuzzy is used along with hysteresis current controller as shown in fig.3.6

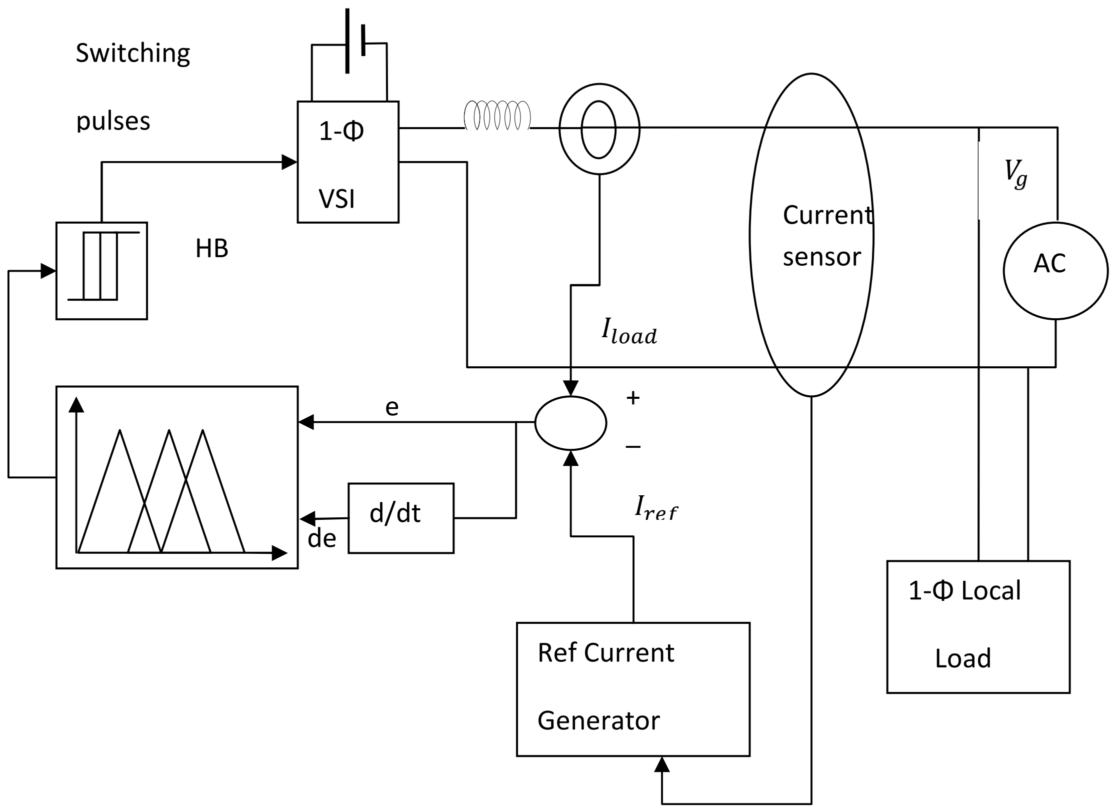


Fig.3.6 Block diagram for adaptive hysteresis current control of single phase grid connected VSI.

CHAPTER 4
IMPLEMENTATION USING FLC

4.1 INTRODUCTION

Fuzzy logic controller is used as an intelligent controller as one of method used to control grid voltage and grid current. In this chapter will be described one method for controlling the grid currents. Fuzzy logic is a logic having many values. Unlike the binary logic system, here the reasoning is not crisp, rather it is approximate and having a vague boundary. The variables in fuzzy logic system may have any value in between 0 and 1 and hence this type of logic system is able to address the values of the variables those lies between completely truth and completely false. The variables are called linguistic variables and each linguistic variable is described by a membership function which has a certain degree of membership at a particular instance. System based on fuzzy logic carries out the process of decision making by incorporation of human knowledge into the system. Fuzzy inference system is the major unit of a fuzzy logic system. The decision making is an important part of the entire system. The fuzzy inference system formulates suitable rules and based on these rules the decisions are made. This whole process of decision making is mainly the combination of concepts of fuzzy set theory, fuzzy IF THEN rules and fuzzy reasoning. The fuzzy inference system makes use of the IF-THEN statements and with the help of connectors present (such as OR, AND), necessary decision rules are constructed.

The basic Fuzzy inference system may take fuzzy inputs or crisp inputs depending upon the process and its outputs, in most of the cases, are fuzzy sets.

The fuzzy inference system in Fig. 4.2 can be called as a pure fuzzy system due to the fact that it takes fuzzy sets as input and produces output that are fuzzy sets. The fuzzy rule base is the part responsible for storing all the rules of the system and hence it can also be called as the knowledge base of the fuzzy system. Fuzzy inference system is responsible for necessary decision making for producing a required output. In most of the practical applications where the system is used as a controller, it is desired to have crisp values of the output rather than fuzzy set values. Therefore a method of defuzzification is required in such cases which convert the fuzzy values into corresponding crisp values.

4.1.1 Fuzzy Sets And Membership Functions

Zadeh introduced the term fuzzy logic in his seminal work "Fuzzy sets," which described the mathematics of fuzzy set theory (1965). Plato laid the foundation for what would become fuzzy logic, indicating that there was a third region beyond True and False. It was Lukasiewicz who first proposed a systematic alternative to the bi valued logic of Aristotle. The third value Lukasiewicz proposed can be best translated as "possible," and he assigned it a numeric value between True and False. Later he explored four-valued logic and five-valued logic, and then he declared that, in principle, there was nothing to prevent the derivation of infinite-valued logic. FL provides the opportunity for modelling conditions that are inherently imprecisely defined. Fuzzy techniques in the form of approximate reasoning provide decision support and expert systems with powerful reasoning capabilities. The permissiveness of fuzziness in the human thought process suggests that much of the logic behind thought processing is not traditional two valued logic or even multivalued logic, but logic with fuzzy truths, fuzzy connectiveness and fuzzy rules of inference. A fuzzy set is an extension of a crisp set. Crisp sets allow only full membership or no membership at all, whereas fuzzy sets allow partial membership. In a crisp set, membership or non membership of element x in set A is described by a characteristic function $\mu_A(x)$, where $\mu_A(x)$=1 if xϵA and $\mu_A(x)$ =0 if x Fuzzy set theory extends this concept by defining partial membership. A fuzzy set A on a universe of discourse U is characterized by a membership function $\mu_A(x)$, that takes values in the interval [0 1] .Fuzzy sets represent commonsense linguistic labels like slow, fast, small, large, heavy, low, medium, high, tall, etc. A given element can be a member of more than one fuzzy set at a time. A fuzzy set 'A' in U may be represented as a set of ordered pairs. Each pair consists of a generic element *x* and its grade of membership function; that is, i A=$\{(x, \mu_A)|x\epsilon U\}$, x is called a support value if $\mu_A(x) > 0$. A linguistic variable *x* in the universe of discourse *U* is characterized by T(x)=$\{T_{x,}^1\ T_{x,\ldots\ldots\ldots\ldots}^2 T_{x,}^k\}$ and $\mu(x) = \{\mu_{x,}^1 \mu_{x,}^2 \ldots \ldots . \mu_{x,}^k\}$ where T(x) is the term set of *x* — that is, the set of names of linguistic values of *x*, with each T_x^i being a fuzzy number with membership function μ_x^i defined on *U*. For example, if x indicates height, then T(x) may refer to sets such as short, medium or tall. A membership function is essentially a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and1.

4.2 OPERATION WITH FLC

Fuzzy logic is a branch of artificial intelligence that deals with reasoning algorithms used to emulate human thinking and decision making in machines. These algorithms are used in applications where process data cannot be represented in binary form. Fuzzy logic requires knowledge in order to reason. This knowledge, which is provided by a person who knows the process or machine (the expert), is stored in the fuzzy system. The FLC general scheme is shown in Fig. 4.1 in which the error & rate of change of error is fed to FLC to control the Current error and Voltage. The error is the difference of actual current from the reference current.

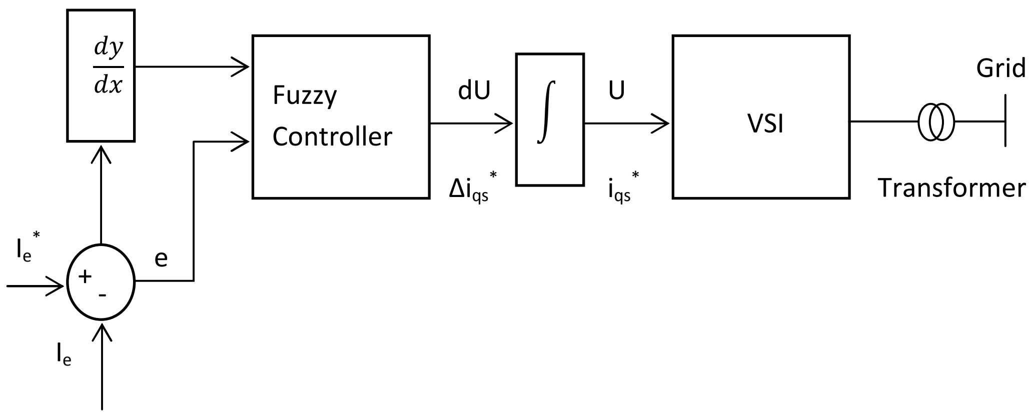


Fig.4.1 Functional block diagram of Fuzzy Logic Controller

Here the first input is the current error ‘e’ and second is the change in current error ‘*ce’* at sampling time ‘t_s’. The two input variables *e (ts)* and *ce (ts)* are calculated at every sampling time as

$$e(t_s) = i_e^*(t_s) - i_e(t_s) \quad (4.1)$$

$$ce(t_s) = e(t_s) - e(t_s - 1) \quad (4.2)$$

Where '*ce*' denotes the change of error '*e*', '$i_e^*(t_s)$' is the reference current, '$i_e(t_s)$' is the actual current, '$e\,(t_s\text{-}1)$' is the value of error at previous sampling time.

The stages of FLC are as follows:

4.2.1 Fuzzification

In this stage the crisp variables of input $e\,(t_s)$ and $ce\,(t_s)$ are converted into fuzzy variables. The fuzzification maps the error and change in error to linguistic labels of fuzzy sets. Membership function is associated to each label with triangular shape which consists of two inputs and one output. The proposed controller uses following linguistic labels *NB, NM, NS, ZE, PS, PM, PB*. Each of the inputs and output contain membership function with all these seven linguistics.

4.2.2 Rule Base and Inference

A fuzzy inference system (FIS) essentially defines a nonlinear mapping of the input data vector into a scalar output, using fuzzy rules. The mapping process involves input/output membership functions, FL operators, fuzzy if–then rules, aggregation of output sets, and defuzzification. An FIS with multiple outputs can be considered as a collection of independent multi input, single-output systems. A general model of a fuzzy inference system (FIS) is shown in Figure 4.2. The FLS maps crisp inputs into crisp outputs. It can be seen from the figure that the FIS contains four components: the fuzzifier, inference engine, rule base, and defuzzifier. The rule base contains linguistic rules that are provided by experts. It is also possible to extract rules from numeric data. Once the rules have been established, the FIS can be viewed as a system that maps an input vector to an output vector. The fuzzifier maps input numbers into corresponding fuzzy memberships. This is required in order to activate rules that are in terms of linguistic variables. The fuzzifier takes input values and determines the degree to which they belong to each of the fuzzy sets via membership functions. The inference engine defines mapping from input fuzzy sets into output fuzzy sets. It determines the degree to which the antecedent is satisfied for each rule. If the antecedent of a given rule has more than one clause, fuzzy operators are applied to obtain one number that represents the result of the antecedent for that rule. It is possible that one or more rules may fire at the same time. Outputs for all rules are then aggregated. During aggregation, fuzzy sets that represent the output of each rule are combined into a single fuzzy set. Fuzzy rules are fired in parallel, which is one of the important aspects of an FIS. In an FIS, the order in which rules are fired does not affect the output. The defuzzifier maps output fuzzy sets into a crisp number. Given a fuzzy set that encompasses a range of output values, the defuzzifier returns one number, thereby moving from a fuzzy set to a crisp number.

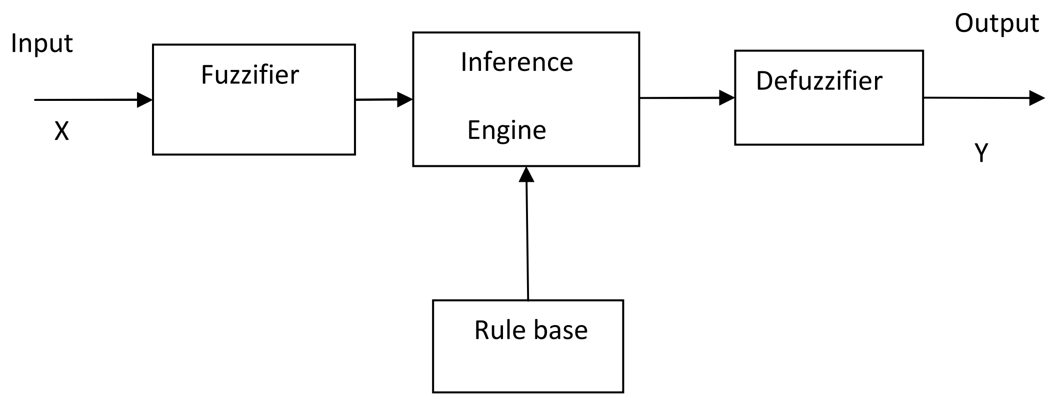


Fig.4.2 Block diagram of a fuzzy inference system

4.2.2.1 Types of Fuzzy Inference

In general there are three main types of Fuzzy Inference systems such as :-

- Mamdani model
- Sugeno model
- Tsukamoto model

Here, Mamdani model is used as fuzzy inference for the proposed work.

The Fuzzy inference process can be described completely in the five steps shown in Fig.4.3

Step 1: Fuzzy Inputs: The first step is to take inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions.

Step 2: Apply Fuzzy Operators: Once the inputs have been fuzzified, we know the degree to which each part of the antecedent has been satisfied for each rule. If a given rule has more than one part, the fuzzy logical operators are applied to evaluate the composite firing strength of the rule.

Step 3: Apply the Implication Method: The implication method is defined as the shaping of the output membership functions on the basis of the firing strength of the rule. The input for the implication process is a single number given by the antecedent, and the output is a fuzzy set. Two commonly used methods of implication are the minimum and the product.

Step 4: Aggregate all Outputs: Aggregation is a process whereby the outputs of each rule are unified. Aggregation occurs only once for each output variable. The input to the aggregation process is the truncated output fuzzy sets returned by the implication process for each rule. The output of the aggregation process is the combined output fuzzy set.

Step 5: Defuzzify: The input for the defuzzification process is a fuzzy set (the aggregated output fuzzy set), and the output of the defuzzification process is a crisp value obtained by using some defuzzification method such as the centroid, height, or maximum. As an example, we consider a system that determines dinner in a restaurant on the basis of the service received. We consider input membership functions with different degrees of overlap. Here, the input x denotes the quality of the service.

The Flow Chart for Fuzzy Inference:

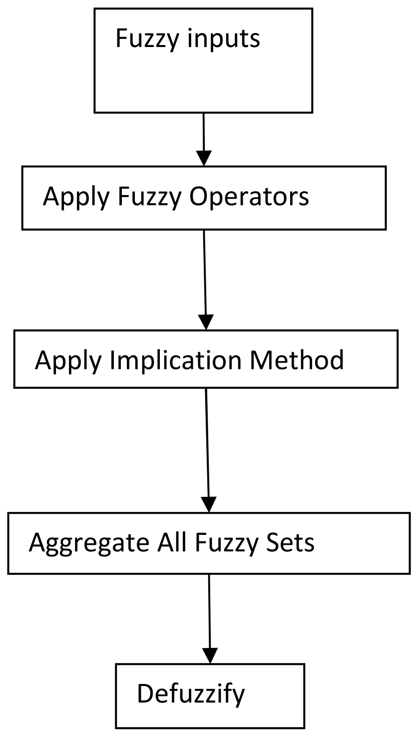


Fig.4.3 Flow Chart for Fuzzy Inference

Rule base

e / Ce	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Table 1.Fuzzy Rule Base

Where various linguistics variables are:

NB Negative Big

NM Negative Medium

NS Negative Small

Z Zero

PS Positive Small

PM Positive Medium

PB Positive Big

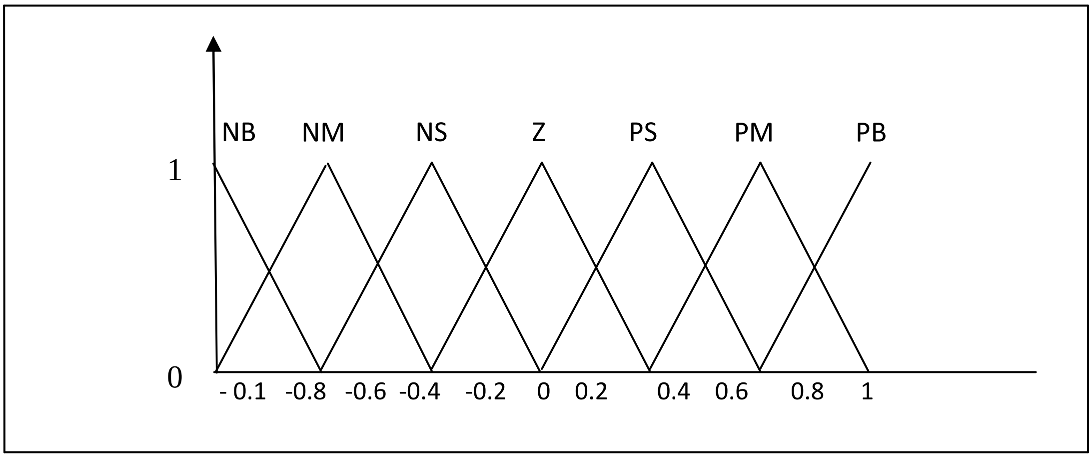
4.2.3 Defuzzification

A fuzzy inference system maps an input vector to a crisp output value. In order to obtain a crisp output, we need a defuzzification process. The input to the defuzzification process is a fuzzy set (the aggregated output fuzzy set), and the output of the defuzzification process is a single number. Many defuzzification techniques have been proposed.

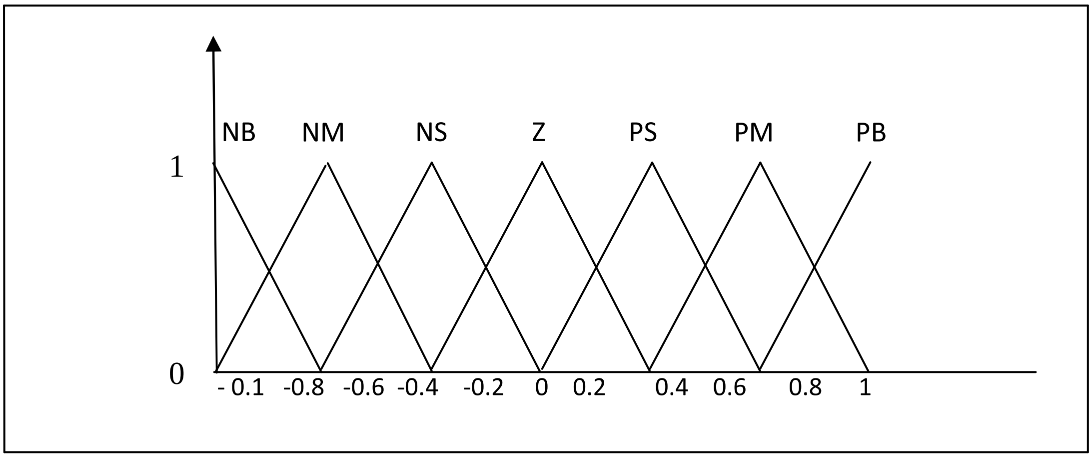
- Mean of maximum method
- Centroid of area method
- Bisector of area method

This stage introduces different methods that can be used to produce fuzzy set value for the output fuzzy variable *ΔT*. Here the centre of gravity or centroids method is used to calculate the final fuzzy value *ΔT (ts).*

A Mamdani type Fuzzy Logic Controller has been designed for the control system. The inputs i.e. the error, e & change in error, ce follow the following membership function plot seen below as plotted in MATLAB, shown in Fig.4.4



Input Variable



Output Variable

Fig.4.4 Input and Output membership function representation

4.2.4 Tuning of Fuzzy Logic Controller

Tuning FLC is most important part of the process. Proper values of gains need to be choosen so that the FLC membership values are properly selected so as to ensure proper functioning of the controller. The FLC shown in Fig. can be tuned in a similar way of PI controller where we can find K_p & K_i as follows

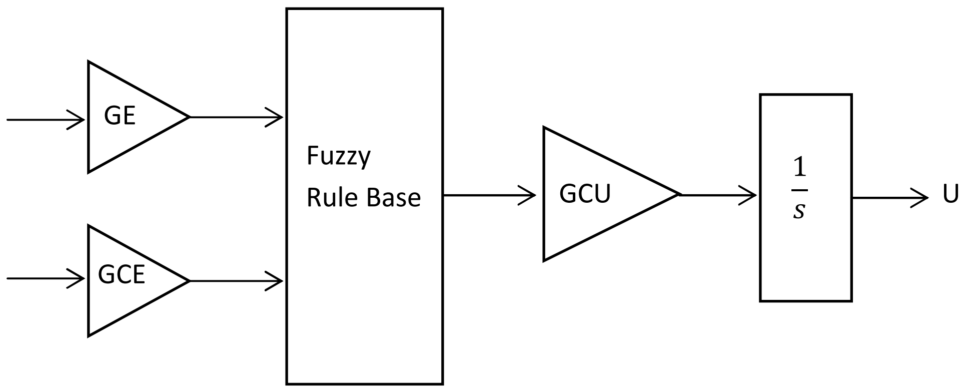


Fig.4.5 Fuzzy incremental controller

The values are

$$\boldsymbol{GCE * GCU = K_p} \tag{4.3}$$

$$\boldsymbol{\frac{GE}{GCE} = \frac{1}{\tau_i}} \tag{4.4}$$

So now like the PI controller we tune the parameters *GCE,GCU & GE* to find the possible values of K_p & K_i to best fit the values & provide the best control possible through the fuzzy logic controller.

4.2.5 Fuzzy Controller with PI

The fuzzy logic controller outperforms the conventional PI controller due to robustness and the superior transient response. However FLC have some significant disadvantages. The main drawback of the FLC is the requirement of an expert for the design of the membership functions and the fuzzy rules. To overcome this disadvantage, a novel artificial intelligent controller called “fuzzy-tuned PI controller” The fuzzy-tuned PI controller in fig. is a combination of the fuzzy controller and the PI controller. Using the fuzzy part we can estimate the gains *Kp* and K_I of the PI controller.

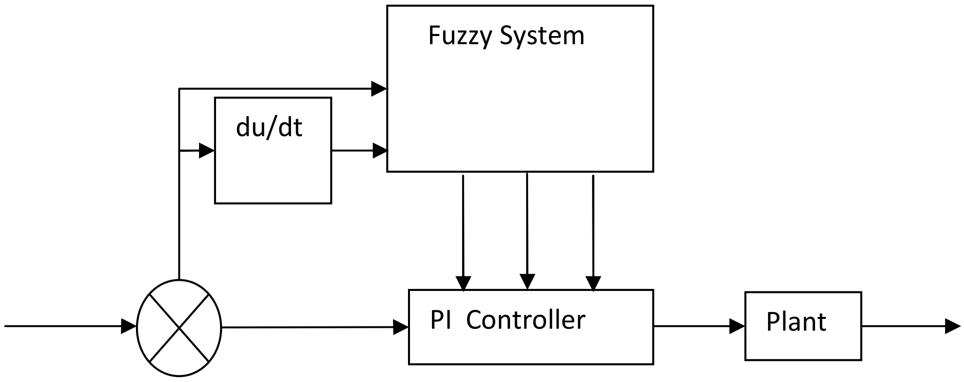


Fig.4.6 General structure of the fuzzy-tuned PI controller

CHAPTER 5
SIMULATION AND RESULTS

5.1 INTRODUCTION

This chapter presents a detailed simulation study of a grid connected PWM inverter controlled though two control techniques in MATLAB/Simulink. Simulation study of the said is performed to understand the physical behavior of the system. The tuning of PI speed controller and FLC controller were carried out through simulation study and the necessary tuning parameters were determined. The performance of the controllers is observed in improving the power quality by reducing the harmonic content in the current.

5.2 MATLAB MODEL

A MATLAB model is shown in Fig. 5.1 with (a) PI controller (b) Fuzzy Logic Controller. It consists of a single phase IGBT inverter controlled through pulses. The reference voltage and the DC link are fed to a PI controller to develop the reference current. This current is then compared with the actual source current and fed to (a) PI controller (b) FLC, in order to improve the quality of the source current though pulses from Hysteresis controller.

A diode bridge rectifier is meant to provide a DC link to the inverter, using a capacitor to maintain the DC voltage. A source inductor is incorporated of proper value. An RLC load is applied to the grid, in order to analyse the performance of the model under loaded conditions. The source voltage of 415 V is applied, whereas the grid voltage is kept below it at 240 V. Proper tuning of PI and FLC will result in improving the quality of source current.

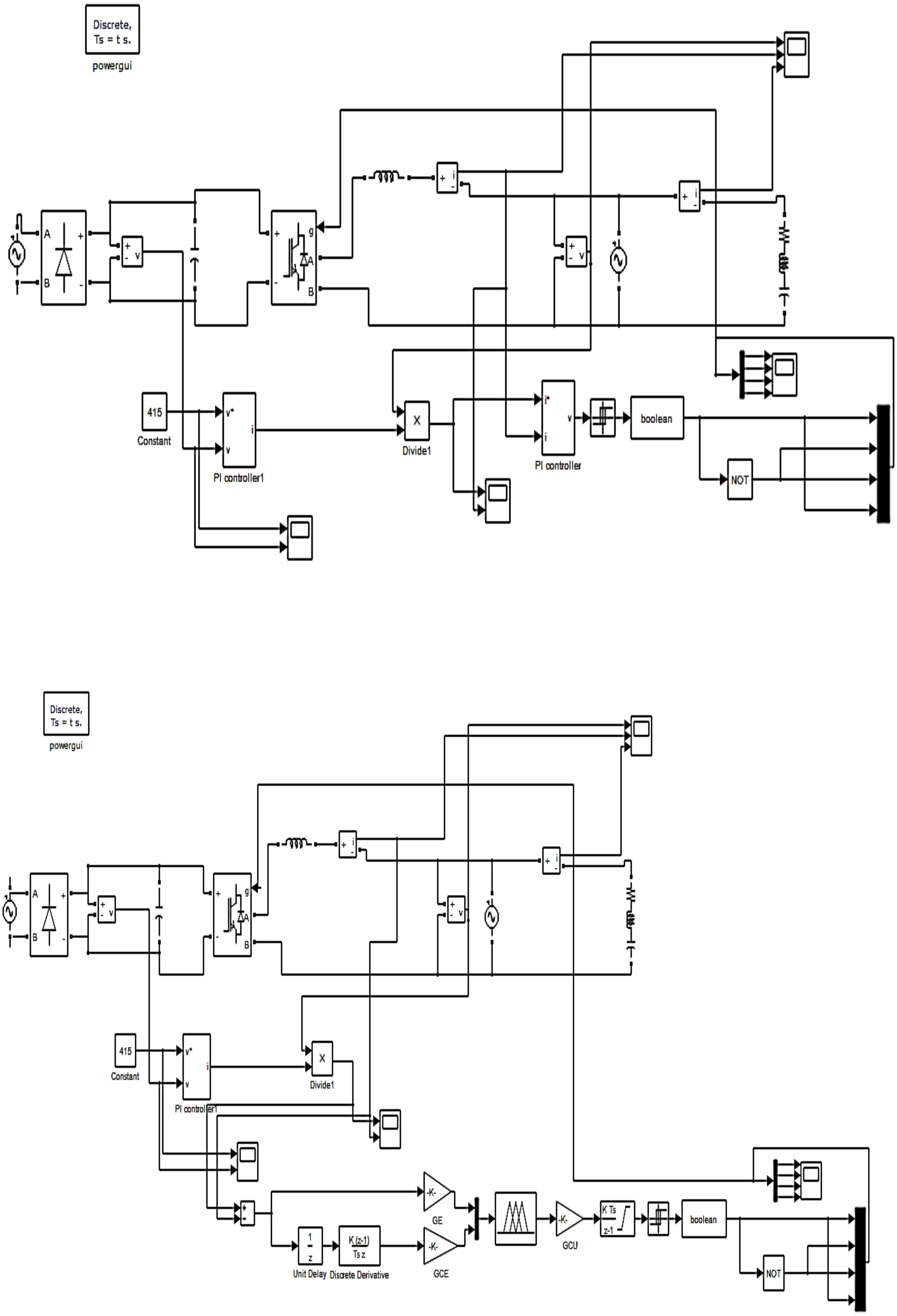


Fig. 5.1 MATLAB Model of Control Strategy for Grid Connected Inverter using

(a) PI controller (b) FLC

5.3 PERFORMANCE EVALUATION OF CONTROL STRATEGY FOR GRID CONNECTED INVERTER

5.3.1 Analysis Using Hysteresis controller

In Fig. 5.2, the grid voltage, source current and load current is shown for a grid connected PWM inverter when controlled using a Hysteresis controller only. The source current shows higher content of harmonics.

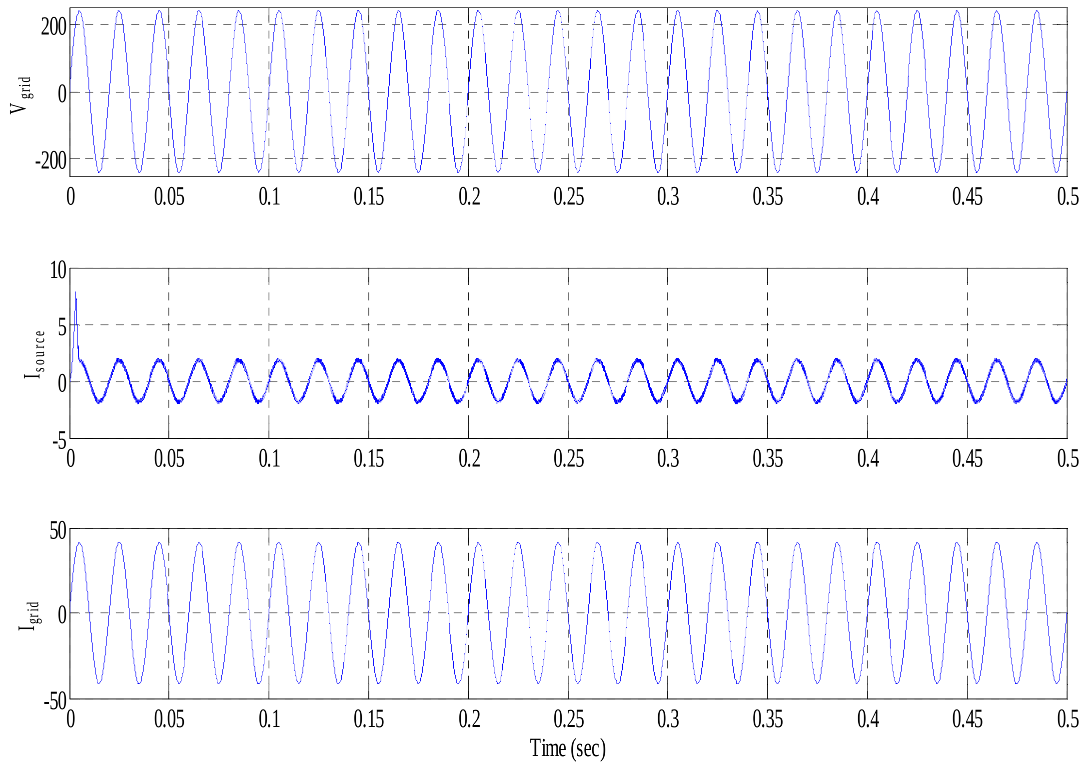


Fig. 5.2 grid voltage, source current and load current is shown for a grid connected PWM inverter when controlled using a Hysteresis controller

5.3.2 Analysis Using PI controller

In Fig. 5.3, the grid voltage, source current and load current is shown for a grid connected PWM inverter when controlled using a PI controller. The DC link to the Voltage Source inverter is fed through a diode bridge rectifier, where the source voltage is 415 V and grid voltage is 240 V. The source current can be observed, having been generated from Hysteresis controlled inverter, has a value of 2 Amps.

The load current is very high about 40 Amps because of loading. The PI controller is tuned resulting in efficient control of the source current.

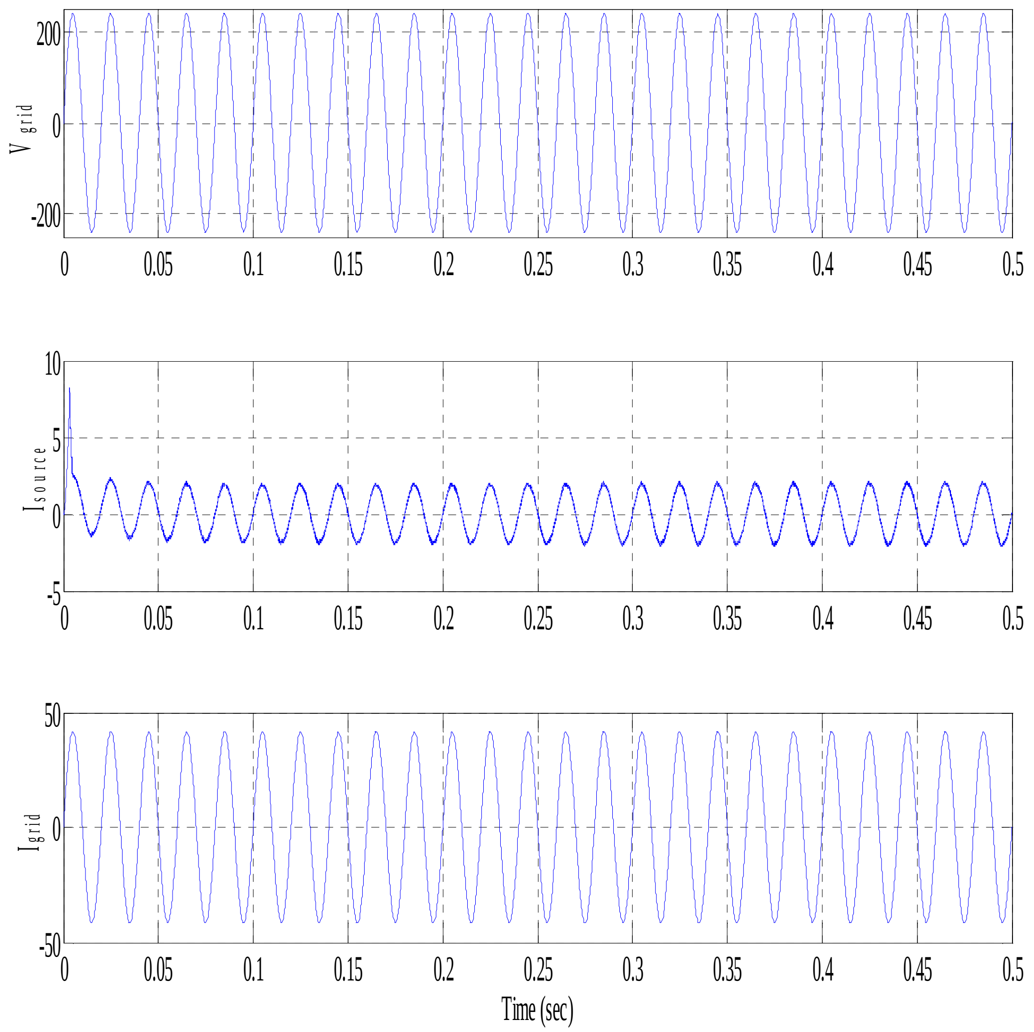


Fig. 5.3 grid voltage, source current and load current is shown for a grid connected PWM inverter when controlled using a PI controller

In Fig. 5.4, reference current and source current is shown. The fig, when observed shows that the source current approaches the reference current with a slight offset. The source current reaches steady state only after 0.07 sec.

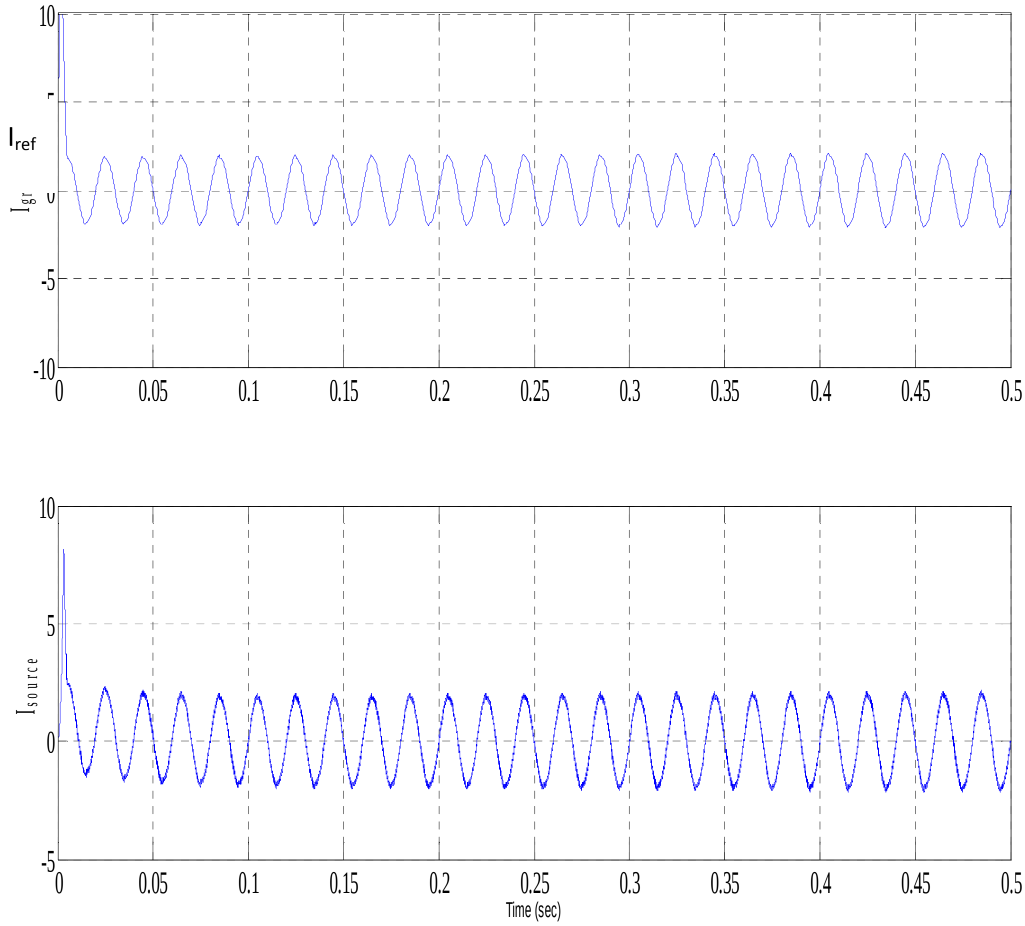


Fig. 5.4 Reference current and source current

In Fig. 5.5, the reference voltage and the source voltage is shown. The reference was set at 415 V and the output from the capacitor is set to 400 V.

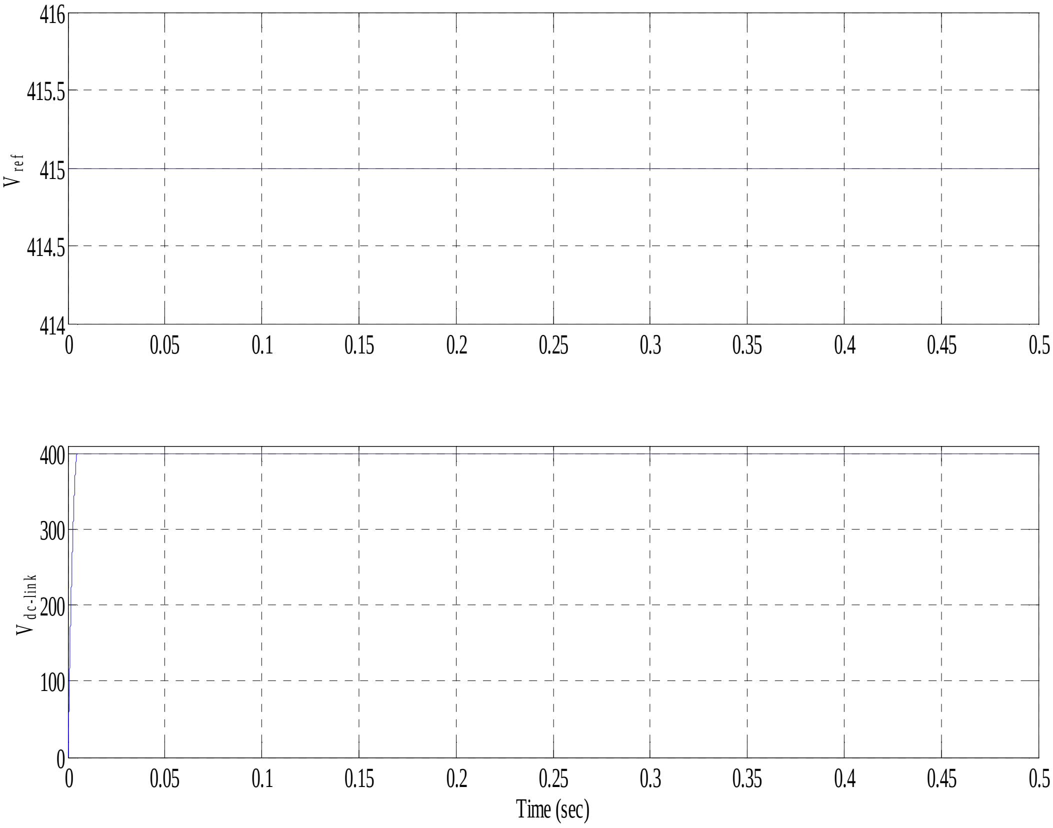


Fig. 5.5 Reference voltage and source voltage

5.3.3 Analysis Using Fuzzy logic Controller

In Fig. 5.6, the grid voltage, source current and load current is shown for a grid connected PWM inverter when controlled using a FLC. The DC link to the Voltage Source inverter is fed through a diode bridge rectifier, where the source voltage is 415 V and grid voltage is 240 V. The source current can be observed, having been generated from Hysteresis controlled inverter, has a value of 2 Amps. The load current is very high about 40 Amps because of loading. The FLC parameters are tuned resulting in efficient control of the source current.

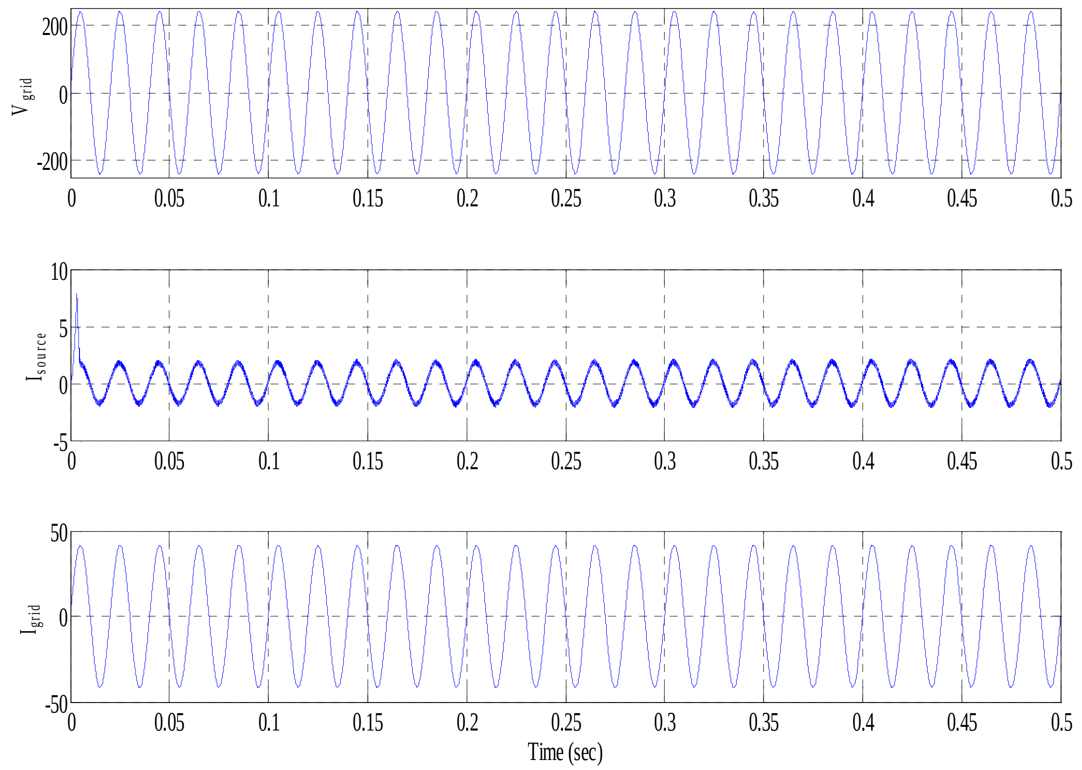


Fig. 5.6 grid voltage, source current and load current is shown for a grid connected PWM inverter when controlled using an FLC

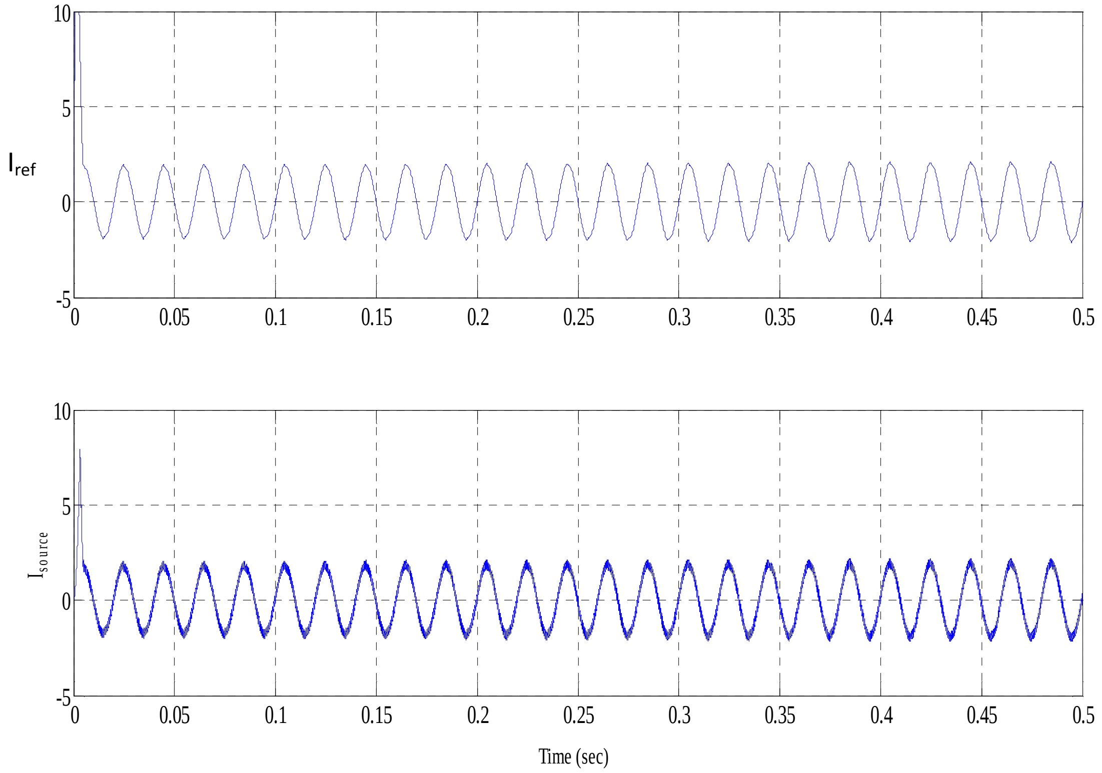


Fig. 5.7 Reference current and source current

In Fig. 5.7, reference current and source current is shown. The fig, when observed shows that the source current approaches the reference current with no offset. The source current reaches steady state in just 0.02 sec. In Fig. 5.8, the reference voltage and the source voltage is shown. The reference was set at 415 V and the output from the capacitor is set to 400 V. Overall, the performance of FLC in controlling the current for the grid connected inverter along with Hysteresis controller is more superior than a PI controller.

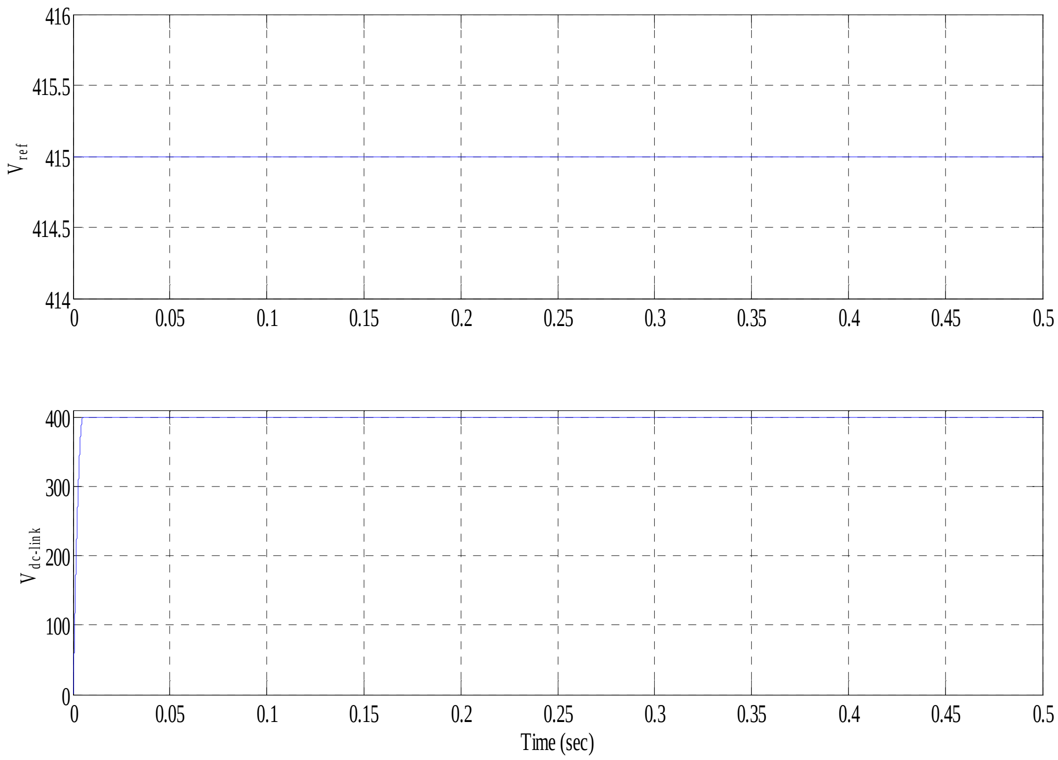


Fig. 5.8 Reference Voltage and source voltage

5.4 ANALYSIS OF HARMONIC CONTENT

The performance of grid connected PWM inverter through Fuzzy Logic controller is studied by analysing the Total harmonic Distortion (THD) of the source current. Two cases are observed

(a) when $V_{grid} > V_{source}$

It can be seen from Fig. 5.9, for this case, the THD is very high, about 78%. In this case the harmonics are huge and distortion in current can be observed. So it is necessary that the proper values of grid voltage and source voltage are maintained.

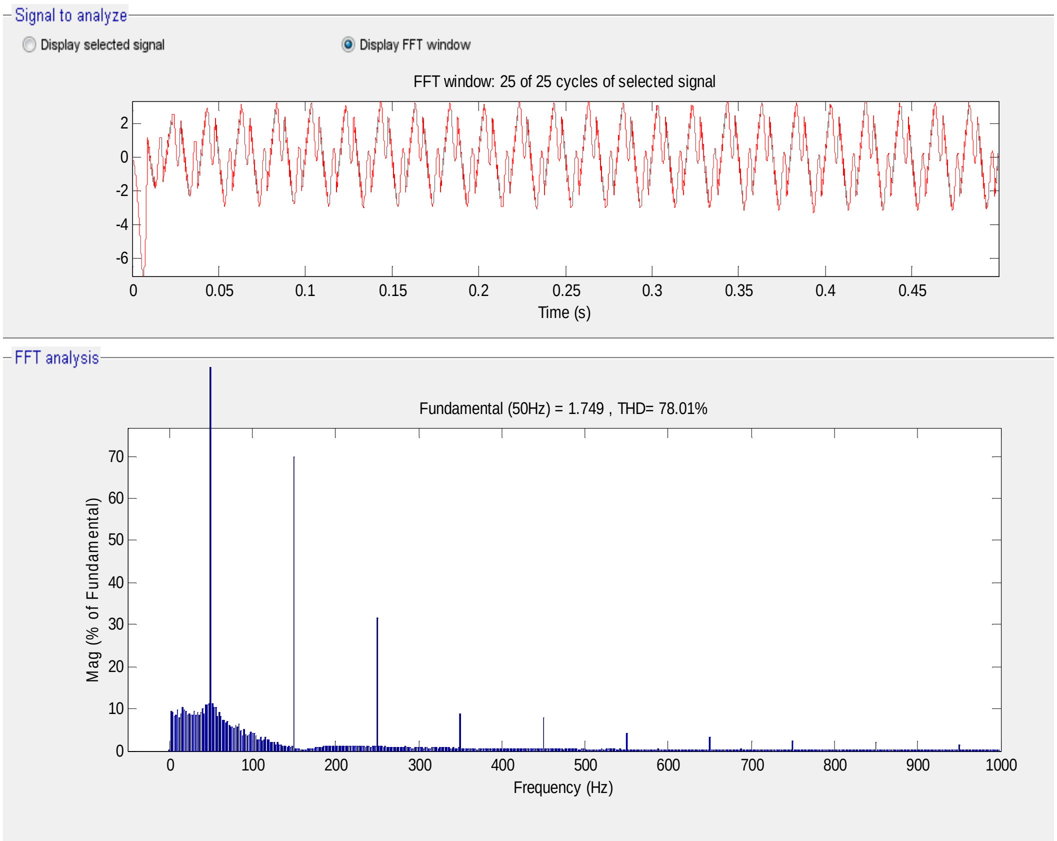


Fig. 5.9 THD for grid connected inverter for $V_{grid} > V_{source}$

(b) THD of grid connected PWM inverter for hysteresis controller

In Fig. 5.10, the THD of grid connected PWM inverter is given. The hysteresis controller is able to reduce the current harmonics. A comparison of hysteresis only controller can be compared with the control of Fuzzy plus hysteresis controller shown in Fig. 5.11. The THD of a hysteresis only controller is about 5.95%.

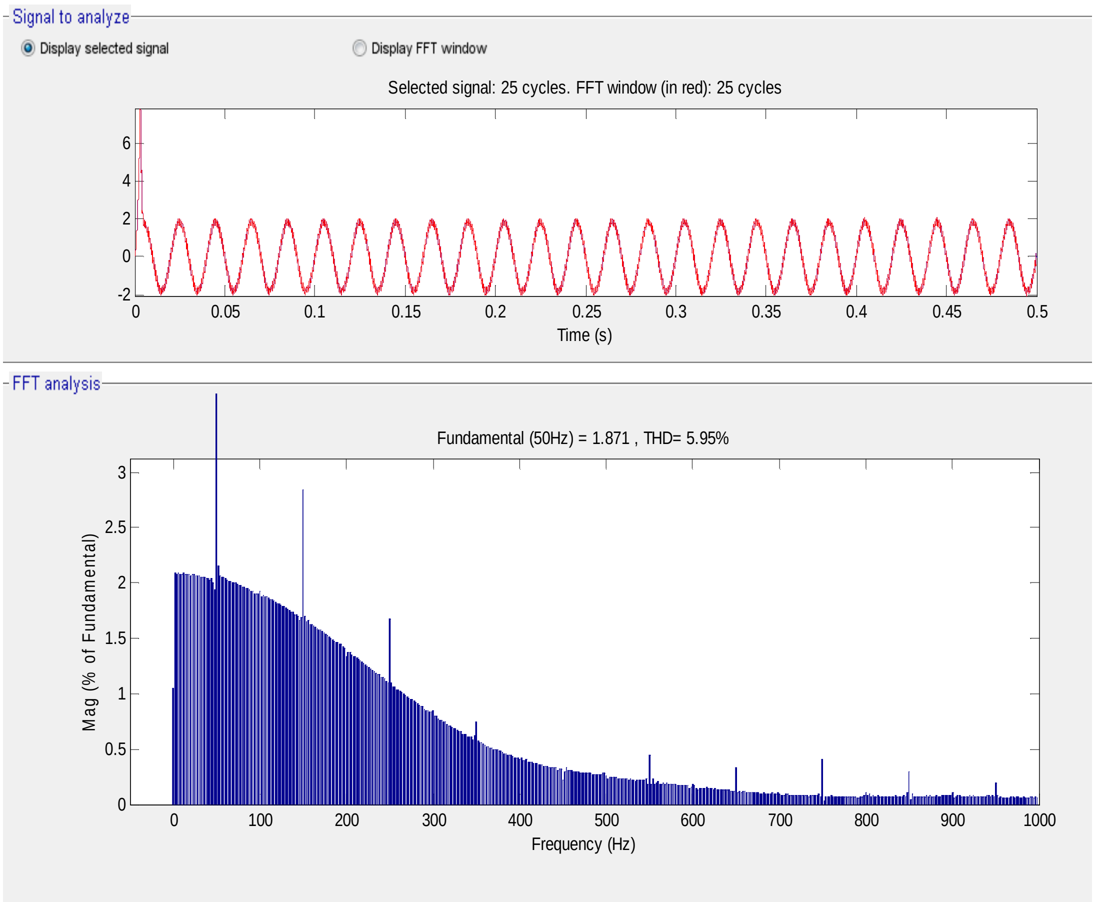


Fig. 5.10 THD for grid connected inverter with Hysteresis Controller

(c) when $V_{grid}<V_{source},$ controlled using Fuzzy plus Hysteresis controller

In this case, the THD is less about 4.75%, which is well below the IEEE recommended 5%. The harmonics are reduced. The magnitude of the harmonics can be seen from Fig. 5.11 and compared with Fig. 5.9. Also noting the harmonics in case of a hysteresis only controller, it can be observed that the Fuzzy Logic controller has resulted in better control of current as the harmonics have reduced.

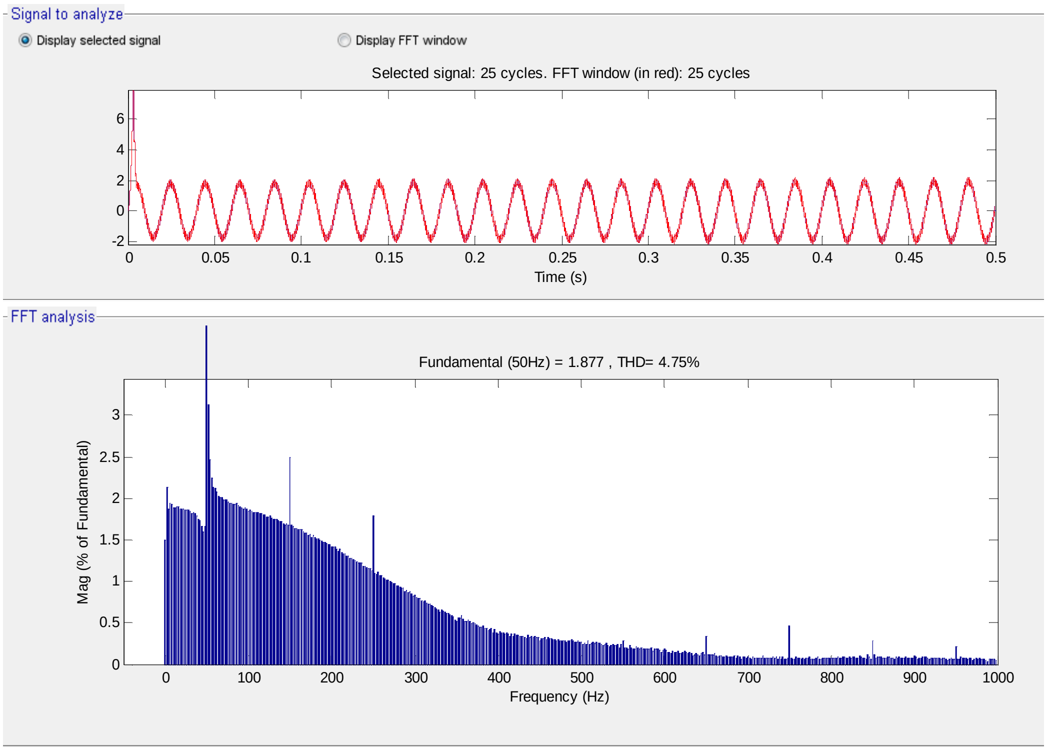


Fig. 5.11 THD for grid connected inverter for $V_{grid}<V_{source}$

The performance of Fuzzy Logic Controller along with Hysteresis Controller shows superior performance as compared to the PI controller.

CHAPTER 6
CONCLUSION AND FUTURE SCOPE

6.1 CONCLUSION

A grid connected PWM voltage source inverter using PI controller and Fuzzy logic controller along with hysteresis controller in the control loop is presented through this work and for the same simulation in MATLAB/Simulink is carried out. From this study we observed that, fuzzy logic controller with hysteresis current controller is able to enhance the power quality of the grid system as it has the capability to reduce the switching frequency even if the band width is increased without any significant increase in the current error. The performance of Fuzzy logic controller is superior to that of PI controller as it has been observed that the Fuzzy logic controller is able to get steady state current in lesser time with reduced error. As a result, the THD level of grid current is considerably reduced as compared to conventional PI controller or stand-alone hysteresis controller. Moreover, switching frequency of the inverter system has been reduced, in that in turn, switching losses are also reduced to certain extent.

6.2 FUTUTRE SCOPE

The use of neural network along with Hysteresis controller will be able to enhance the performance of the inverter connected to a grid system. Moreover the use of SVPWM instead of hysteresis controller is a more suitable option as the pulses acquired from such will reduce the harmonic content in the current due to hysteresis. Adaptive hysteresis current controller provides good dynamic response over SVPWM current controller during transient conditions. But the SVPWM current controller provides better utilization of Dc-link voltage along with lesser THD of grid current under steady state and transient conditions.

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