Implementation of Intelligent Controller for Single Phase Grid Connected PWM Inverter

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***Abstract*—**Development of distributed generation system has resulted due to the ever growing demand of electrical energy. The main objective is coordinating 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 paper will implement 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.

IndexTerms—Grid, THD, Fuzzy, PIC, Hysteresis

I. INTRODUCTION

Distributed generation (DG) systems 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 the requirements to reduce the Greenhouse Gas Emissions etc.[1]. 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 [2]. 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 are: 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.

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.[3]. Among the various PWM techniques, the hysteresis band current control is used very often because of its simplicity of implementation. Also, besides fast response current loop, the method does not need any knowledge of load parameters. There are many researches in implementation hysteresis current control, for example in [4]-[7], but many have yet to implement together with the grid. 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 [5]. 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 [6].

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

i) PI controller
ii) Fuzzy Logic Controller

A hysteresis controller is used in coordination with Fuzzy and PI controllers. The analysis of hysteresis along with these controllers is verified. The work is implemented in MATLAB/Simulink.

II. MODELING OF GRID

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.

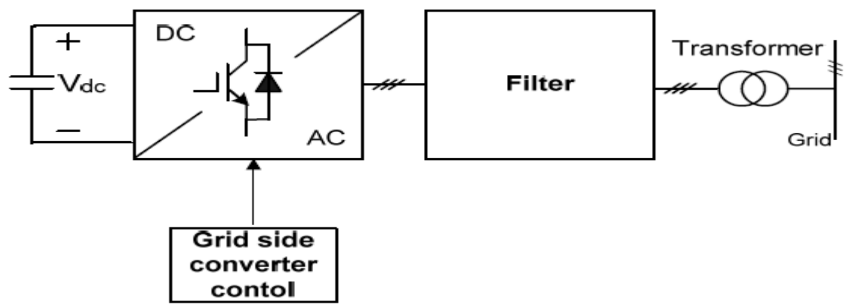

Fig.1. Layout of the model system

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.

A. 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.

B. 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.

III. CONTROLLER DESIGN

A. Hysteresis 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.

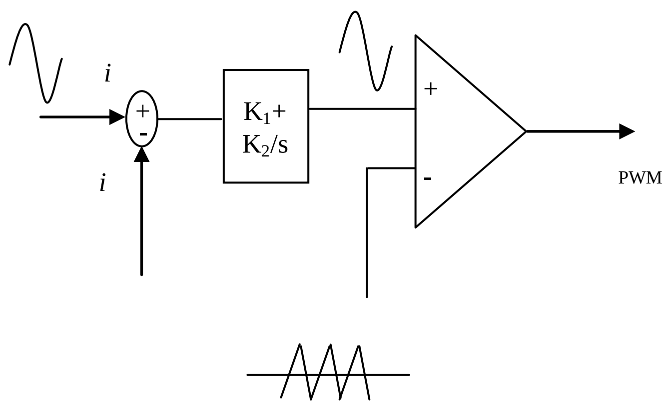

Fig.2. PWM obtained from hysteresis current control

B. 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:

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

The transfer function of a PI controller is:

$$H(s) = K_P(1 + \frac{1}{T_i s}) \qquad (2)$$

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.

C. Fuzzy Logic Controller

Fuzzy logic controller is used as an intelligent controller as one of methods used to control grid voltage and grid current. To eliminate the uneven switching frequency which cause noise, at the same time current error will be produced which produces more harmonic distortion in the output current the drawbacks of hysteresis current controller can be eliminated by Fuzzy Logic Controller.

Here the membership function is chosen as triangular as shown in fig. 3. The input is taken as error (e) and the change in error (Δe)

A 7*7 membership function having 49 rules are taken into account, shown in table 1. 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.

TABLE I. RULE BASE

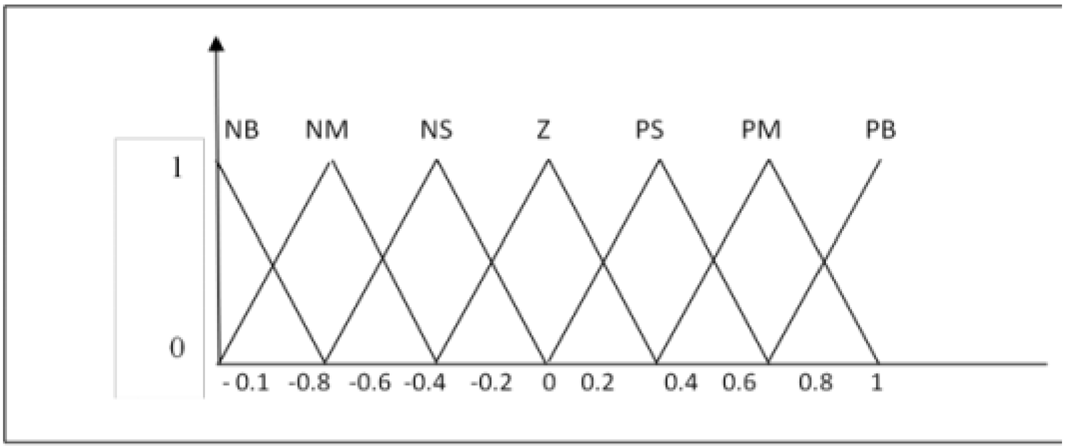

Fig.3 Membership function

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

IV. RESULTS

A. Analysis using Hysteresis Controller

In Fig. 4, 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. Our these results also match with the results obtained by Satyaranjan Jena et al [8].

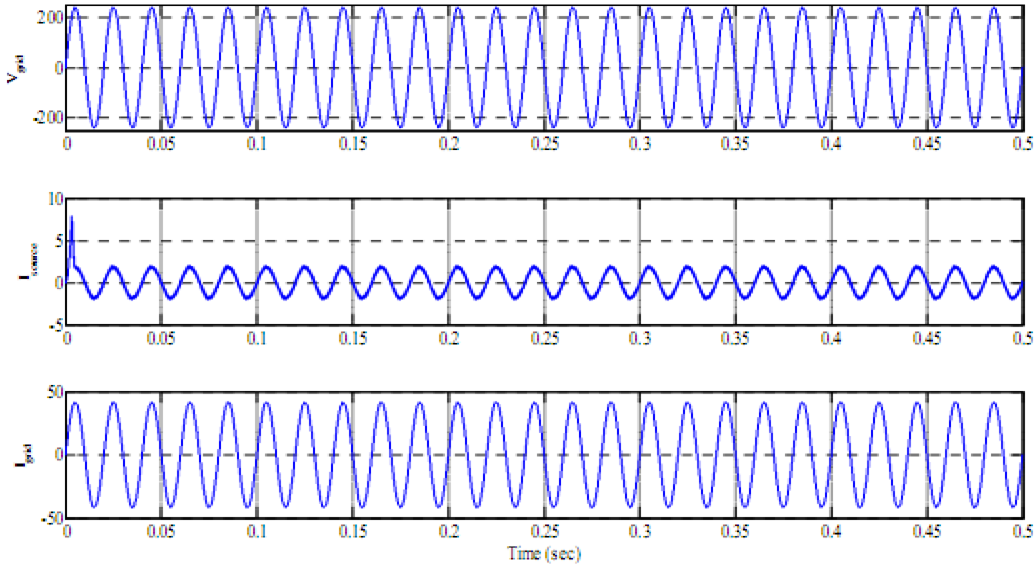

Fig.4 Grid voltage, source current and load current is shown for a grid connected PWM inverter when controlled using a Hysteresis controller

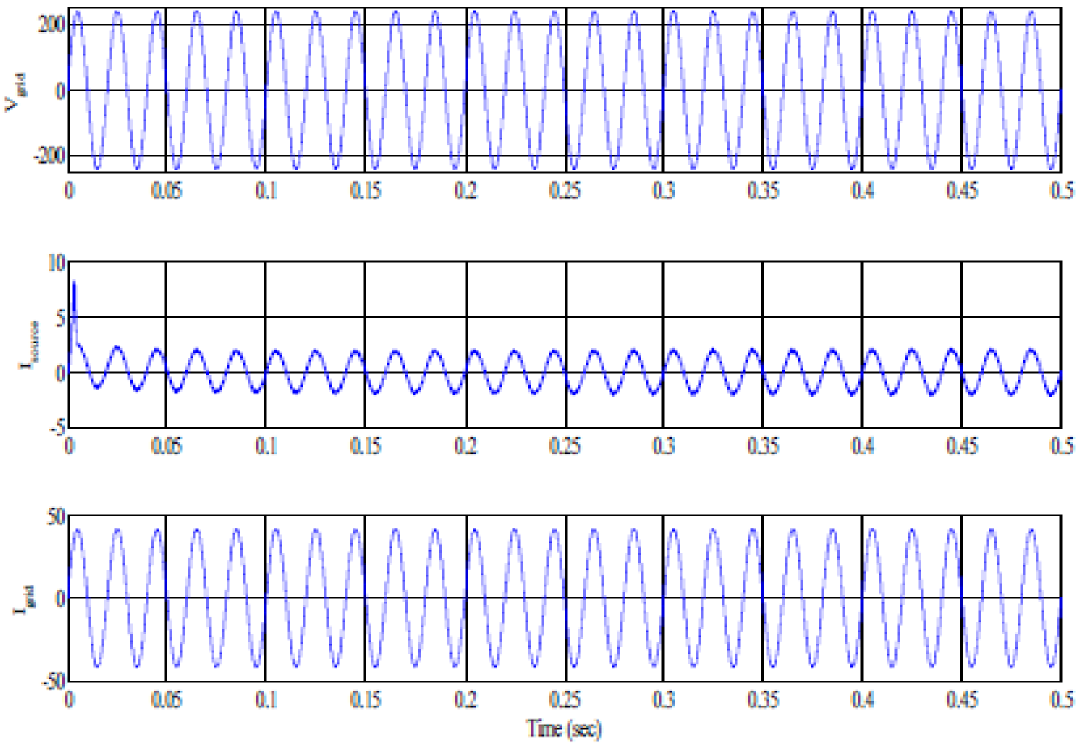

Fig.5 Grid voltage, source current and load current is shown for a grid connected PWM inverter when controlled using a PI controller

B. Analysis using PI Controller

In Fig. 5, 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. Our these results also match with the results obtained by Satyaranjan Jena et al [8].

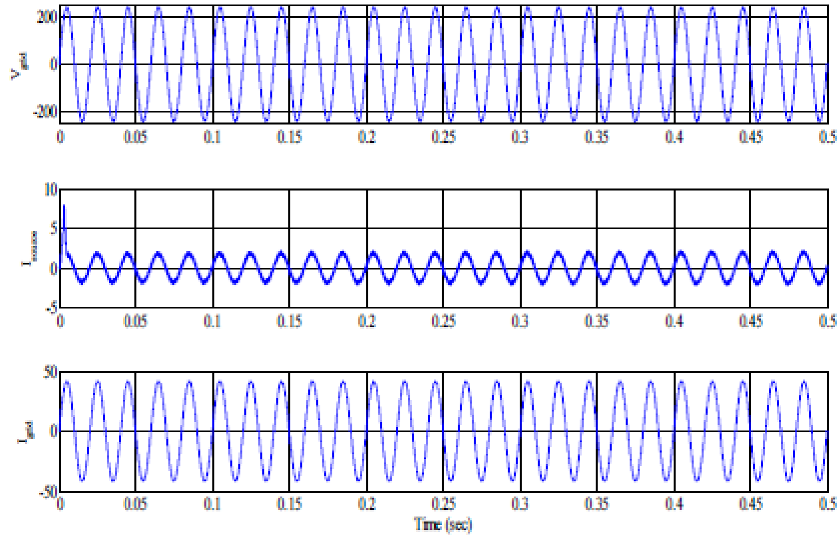

Fig.6 Grid voltage, source current and load current is shown for a grid connected PWM inverter when controlled using an FLC

C. Analysis using FLC

In Fig. 6, the grid voltage, source current and load current is shown for a grid connected PWM inverter when controlled using a FLC. The source current can be observed, having been pgenerated from Hysteresis controlled inverter, has a value of 2 Amps, having smoother and quicker response than Hysteresis Controller and Hysteresis plus PI controller. 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. Our these results also match with the results obtained by Satyaranjan Jena et al [8].

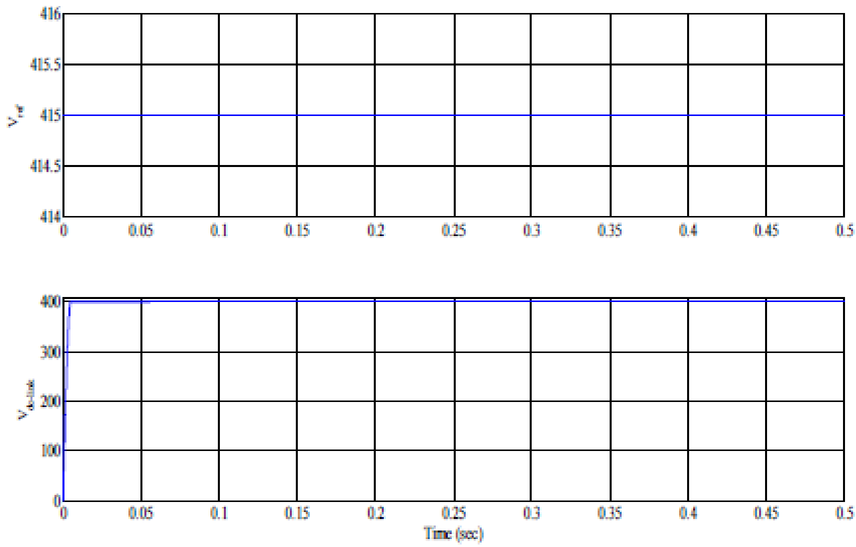

Fig.7 Reference voltage and source voltage

In Fig. 7, 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.

A) when $V_{grid} > V_{source}$

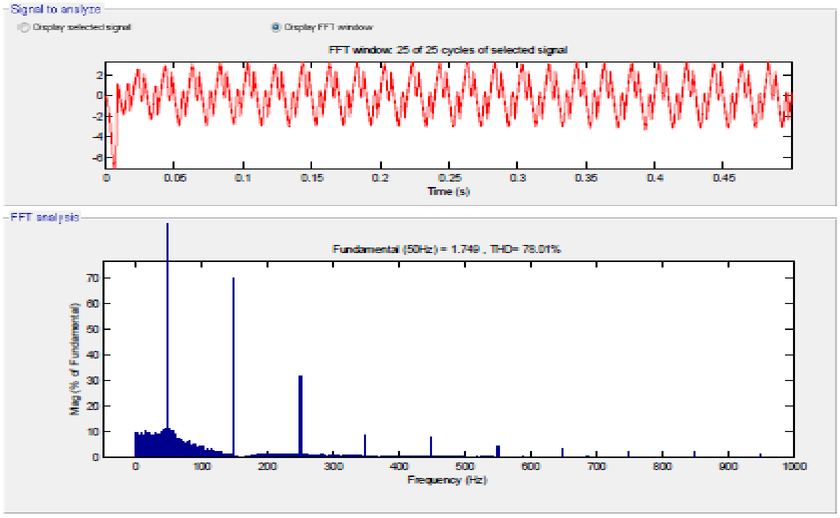

Fig.8 THD for grid connected inverter for $V_{grid} > V_{source}$

It can be seen from Fig. 8, 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.

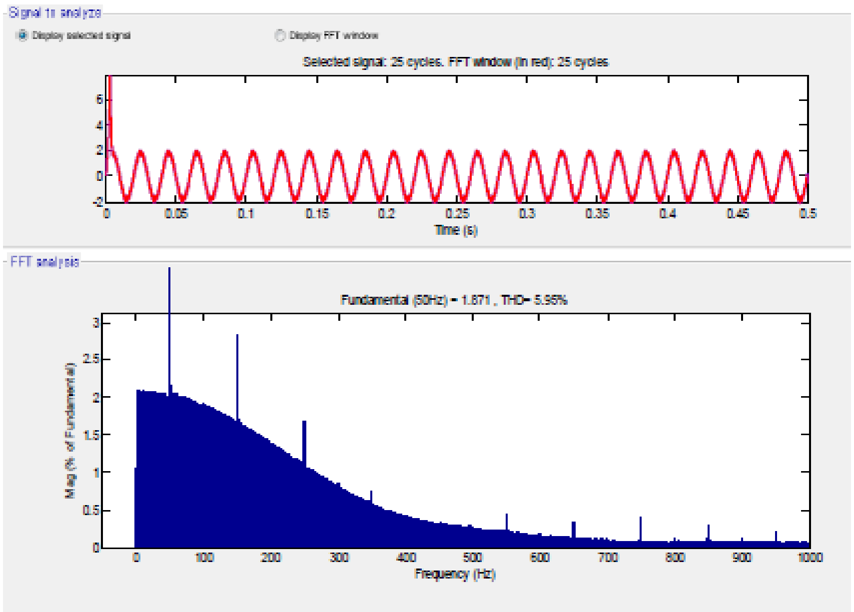

Fig.9 THD for grid connected inverter with hysteresis controller

B) THD of grid connected PWM inverter for hysteresis controller

In Fig. 9, the THD of grid connected PWM inverter is given. The hysteresis controller is able to reduce the current harmonics. The THD of a hysteresis only controller is about 5.95%.

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. 10 and compared with Fig. 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.

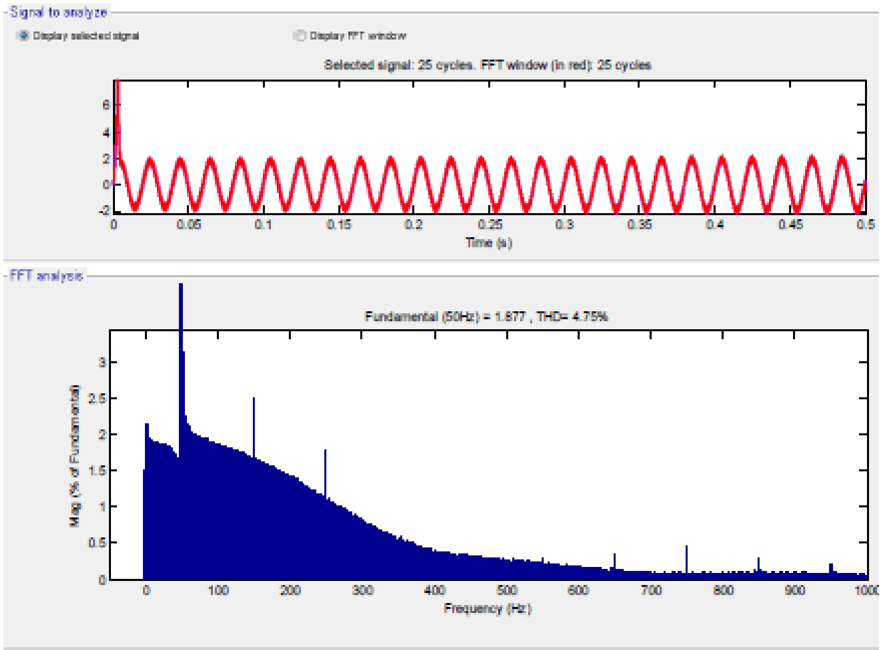

Fig.10 THD for grid connected inverter for $V_{grid}<V_{source}$

Fig.10 THD for grid connected inverter for $V_{grid}<V_{source}$

V. CONCLUSION

A detailed simulation study of a grid connected PWM inverter controlled through two control techniques in MATLAB/Simulink has been carried out is performed to understand the physical behavior of the system. The tuning of PI 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. 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 THD obtained for intelligent controller is less than the Hysteresis Controller.

VI. ACKNOWLEDGEMENT

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APPENDIX

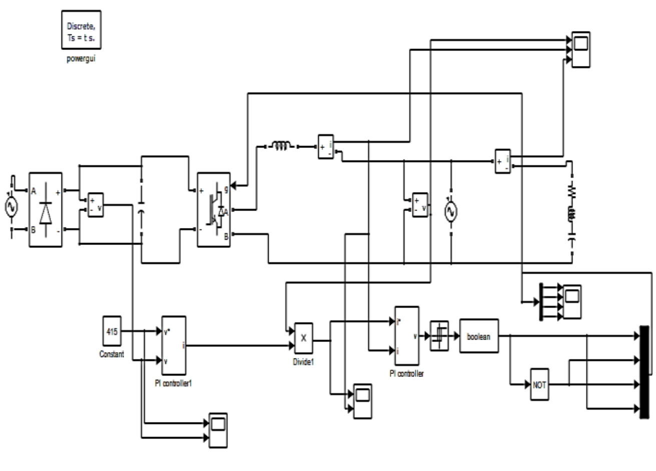

Fig.11 MATLAB Model of Control Strategy for Grid Connected Inverter using PI controller

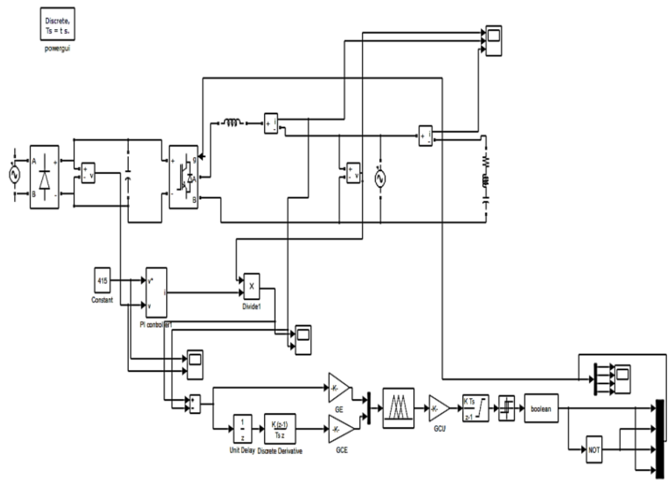

Fig.12 MATLAB Model of Control Strategy for Grid Connected Inverter using FLC