Analysis of Fuzzy Based Hysteresis Current Controller for Power Quality Improvement in Single Phase Grid Connected PWM Inverter

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Abstract— The analysis of fuzzy logic based hysteresis current controller for power quality improvement in single phase grid connected PWM inverter has been presented in this paper. The ever growing demand for electrical energy and the keen scarcity of conventional energy sources leads to the burgeon of distributed generation (DG) system. The main abstruse is the harmonization of the DG to the utility grid. Generally, current regulated PWM voltage-source inverters (VSI) are used for synchronizing the utility grid with DG source in order to meet the following objectives: 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. In this paper, fuzzy with hysteresis controller is proposed to enhance the power quality by diminishing current error at higher band width. The studied system is modeled and simulated in the MATLAB/Simulink environment and the results obtained are compared with conventional hysteresis controller.

Keywords— Hysteresis current controller, Fuzzy logic controller, Point of common coupling (PCC), distributed generation (DG), utility grid, Power quality.

I. INTRODUCTION

To meet the future energy demand of electricity DGs 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 green house gasses, and 4) improve the power quality and system stability. In spite of the several advantages, the main technical challenge is the synchronization of the DGs with the utility grid according to the grid code requirements [1].In most of the cases power electronics converter, especially current controlled PWM-VSI are used for the integration of the DGs with the utility grid.
However, the converter performance largely depends on the applied current control strategy. Very extensive research work has been done besides current control techniques and is available in the literature. [2]. The common strategies of current controllers can be classified as ramp comparator, hysteresis controller, and predictive controller amongst which the hysteresis controllers are widely used because of their inherent simplicity and fast dynamic response [3]. 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. In this paper fuzzy with hysteresis controller is proposed to enhance the power quality by diminishing current error at higher bandwidth. The studied system is modeled and simulated in the MATLAB/Simulink environment and the result obtained is compared with the conventional hysteresis controller.
DES technologies have very different issues compared with traditional centralized power sources. For example, they are applied to the mains or the loads with a voltage of 480 volts or less; and require power converters and different strategies of control and dispatch. All of these energy technologies provide a DC output which requires power electronic interfaces with the distribution power networks and its loads. In most cases, the conversion is performed by using a voltage source inverter (VSI) with a possibility of pulse width modulation (PWM) that provides fast regulation for voltage magnitude. Power electronic interfaces introduce new control issues, but at the same time, new possibilities.

II. POWER QUALITY

The contemporary container crane industry, like many other industry segments, is often enamored by the bells and whistles, colorful diagnostic displays, high-speed performance, and levels of automation that can be achieved. Although these features and their indirectly related computer-based enhancements are key issues to an efficient terminal operation, we must not forget the foundation upon which we are building [4]. Power quality is the mortar which bonds the foundation blocks. Power quality also affects terminal operating economics, crane reliability, our environment, and initial investment in power distribution systems to support new crane installations. To quote the utility company newsletter which accompanied the last monthly issue of my home utility billing: ‘Using electricity wisely is a good environmental and business practice which saves you money, reduces emissions from generating plants, and conserves our natural resources.’ As we are all aware, container crane performance requirements continue to increase at an astounding rate. Next generation container cranes, already in the bidding process, will require average power demands of 1500 to 2000 kW – almost double the total average demand three years ago. The rapid increase in power demand levels, an increase in container crane population, SCR converter crane drive retrofits and the large AC and DC drives needed to power and control these cranes will increase awareness of the power quality issue in the very near future.

III. MODELING AND CONTROL OF INVERTER INTERFACED DG UNITS

Basically, each DG unit may have DC type or rectified generation unit (Fuel cell, solar cell, wind turbine, micro turbine…), storage devices, DC-DC converter, DC-AC inverter, filter, and transformer for connecting to loads or utility in order to exchange power. Model and dynamic of each of this part may have influence in system operation. But here for simplification, it is considered that DC side of the units has sufficient storage and considered as a constant DC source. Hence only DC-AC inverter modeling and control investigated in this paper.
A circuit model of a three-phase DC to AC inverter with LC output filter is further described in Fig. 1. The system consists of a DC voltage source (V_{dc}), a three- phase PWM inverter, an output filter (Lf and C with considering the parasitic resistance of filter-R_f). Sometimes a transformer may be used for stepping up the output voltage and hence Lf can be transformer inductance.

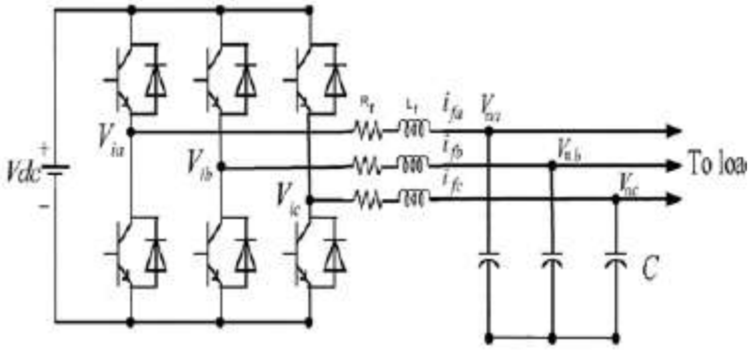


Fig. 1 PWM inverter diagram

There are two ways for controlling an inverter in a distributed generation system

A. PQ Inverter Control

This type of control is adopted when the DG unit system is connected to an external grid or to an island of loads and more generators. In this situation, the variables controlled by the inverter are the active and reactive power injected into the grid, which has to follow the set points P_{ref} and Q_{ref}, respectively. These set points can be chosen by the customer or by a central controller. The PQ control of an inverter can be performed using a current control technique in qd reference frame which the inverter current is controlled in amplitude and phase to meet the desired set-points of active and reactive power.
With the aim of Park transform and equations between inverter input and output, the inverter controller block diagram for supplying reference value of P_{ref} and Q_{ref} is as Fig. 2. For the current controller, two Proportional-Integral (PI) regulators have been chosen in order to meet the requirements of stability of the system and to make the steady state error be zero. With this control scheme, it is possible to control the inverter in such way that injects reference value of P_{ref}, Q_{ref} into another part of the stand-alone network. When the output voltage is needed to be regulated, the PV control scheme that is similar to PQ mode with feedback of voltage used to adjust Q_{ref}.

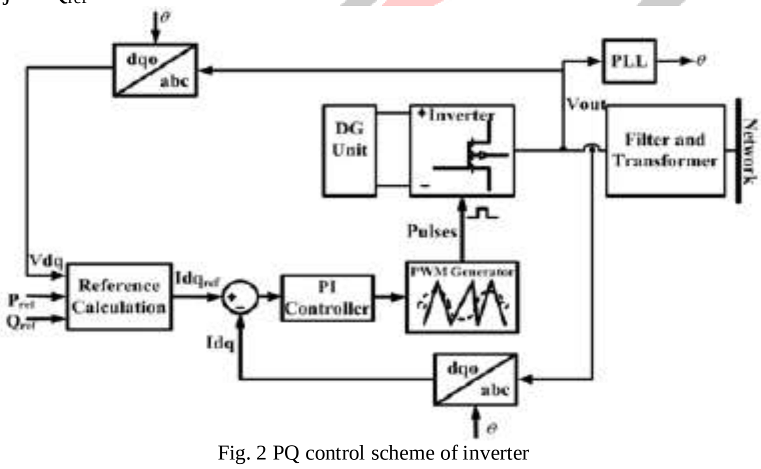


Fig. 2 PQ control scheme of inverter

B. V/f Inverter Control

This controller has to act on the inverter whenever the system is in the stand-alone mode of operation. In fact, in this case, it must regulate the voltage value at a reference bus bar and the frequency of the whole grid. Regulators work in order to keep the measured voltages upon the set points. Moreover, the frequency is imposed through the modulating signals of the inverter PWM control by mean of an oscillator. A simple PI controller can regulate bus voltage in reference value with getting feedback of real bus voltage. Fig. 3 outlines this control strategy. In this case, it is obvious that the DG unit should have a storage device in order to regulate the power and voltage.

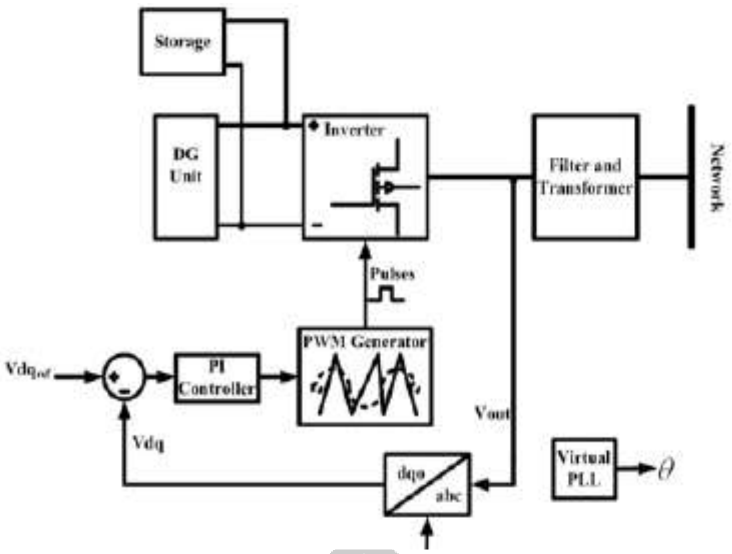


Fig. 3 V/f control scheme of inverter

IV. HYSTERESIS CURRENT CONTROLLER

The basic structure of PWM voltage source inverter with hysteresis controller is shown in the Fig. 4. In this circuit, three phase RL load is connected to the PWM voltage source inverter. The load currents i_a, i_b and i_c are compared with the reference currents i_a*, i_b* and i_c* and error signals are passed through hysteresis band to generate the firing pulses, which are operated to produce an output voltage in a manner to reduce the current error. The principle of Hysteresis current control is very simple [5]. 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 three independent Hysteresis comparators having a hysteresis band 'h'. The output signals of the comparators are used to activate the inverter power switches [6]. The inverter switches produce six active vectors and two inactive vectors according to the switching sequence and the hysteresis controllers impose dead band in the α-β plane which forms hexogen which is shown in the Fig.5. The concept of voltage (current) vector is defined as because it is a very convenient representation of a set of three phase voltages.

The voltage vector is defined as

$$V = \frac{2}{3}\left[V_a + aV_b + a^2 V_c\right] \quad (1)$$

Where $a = e^{\frac{j2\Pi}{3}}$, V_a, V_b, V_c are phase voltages. Similarly, the inverter current vector is defined As

$$i = \frac{2}{3}\left[i_a + ai_b + a^2 i_c\right] \quad (2)$$

The actual voltage can be recovered from

$$V_a = [v]\cos\theta$$
$$V_b = [v]\cos\left(\theta - \frac{2\Pi}{3}\right) \quad (3)$$
$$V_c = [v]\cos\left(\theta + \frac{2\Pi}{3}\right)$$

Where θ is the angle between voltage vector and real axes

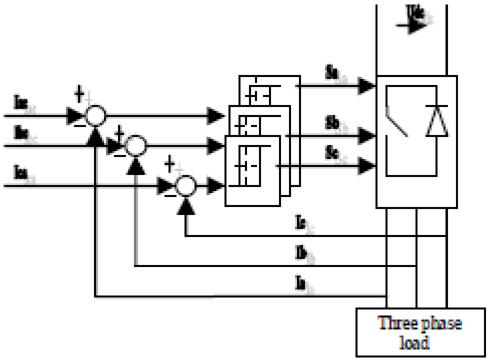


Fig.4 Three-phase VSI with Hysteresis current controller

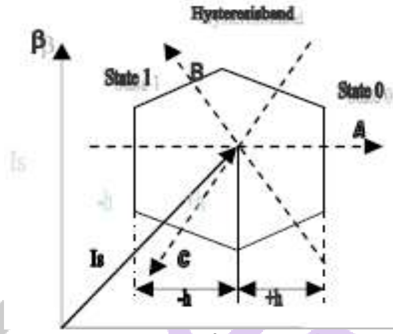


Fig. 5 Structure of Hysteresis band

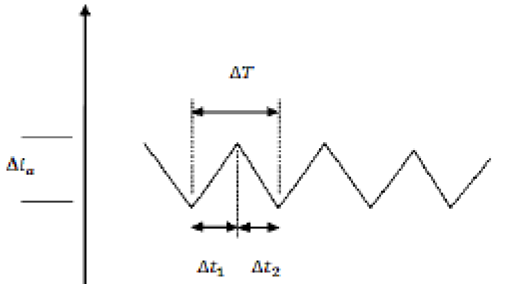


Fig. 6 Switching current waveforms

V. MODELING OF SINGLE PHASE GRID-CONNECTED VSI

The single-phase grid connected inverter shown in Fig.7 Which is composed of a dc voltage source (VDC), four switches (S_1-S_4), a filter inductor (L_f) and utility grid (V_g). In inverter-based DG, the produced voltage from inverter must be higher than the Vg in order to assure power flow to the 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 [7].

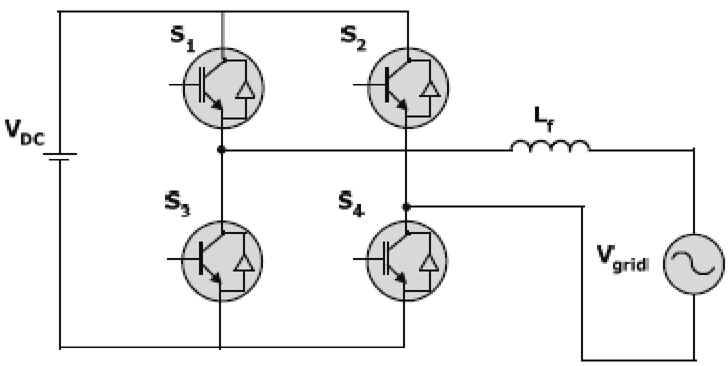


Fig. 7 Single phase inverter connected to utility grid

VI. ANALYSIS OF HYSTERESIS AND FUZZY WITH HYSTERESIS CURRENT CONTROLLER

A. Hysteresis band current controller: In spite of several advantages, some drawbacks of a conventional type of hysteresis controller are limit cycle oscillations, overshoot in current error, sub-harmonic generation in the current and uneven switching [8].In the case of hysteresis controller as shown in Fig. 8 the error is directly fed to the hysteresis band.

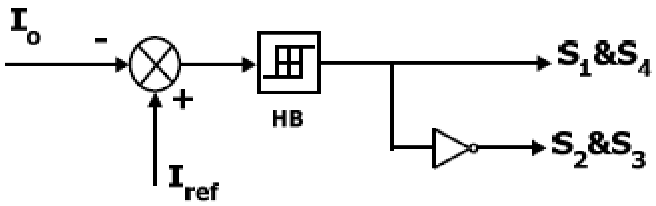


Fig. 8 Hysteresis –Band Current Controller

As given by equation (1) 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) [9]. The hysteresis band current controller assigns the switching pattern of grid connected inverter.

$$e = i_o - i_{ref} \quad (4)$$

The switching logic is formulated as follows:
If e >HB then switch S1 and S4 is on
If e <-HB switch S2 and S3 is on
The average load power is computed as:

$$P_L = \frac{1}{n}\sum_{j=1}^{n} v_s(j) i_L(j) \quad (5)$$

The reference source current is computed as [5]:

ref g i =kv (6)

Where k is the scaling factor and computed as

$$k = \frac{2P_L}{V_m^2} \quad (7)$$

The switching frequency of the system can be calculated as

$$V_{dc} = L_f \frac{di_o}{dt} + V_s \quad (8)$$

From equation (4)

o ref i = i + e (9)

By rearranging equation (8 and 9) we can calculate

$$T_{om} = \frac{2L_f HB}{V_{dc} - V_s} \quad (10)$$

And

$$T_{off} = \frac{2L_f HB}{V_{dc} + V_s} \quad (11)$$

$$\frac{1}{f_s} = T_s = T_{on} + T_{off} \quad (12)$$

$$f_s = \frac{(v_{dc}^2 - v_s^2)}{4v_{dc} L_f HB} \quad (13)$$

Hence, the switching frequency varies with the dc voltage, grid voltage, load inductance and the hysteresis band [10].

B. The 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 [11]. To eliminate drawback up to certain extent fuzzy is used along with hysteresis current controller as shown in Fig.9

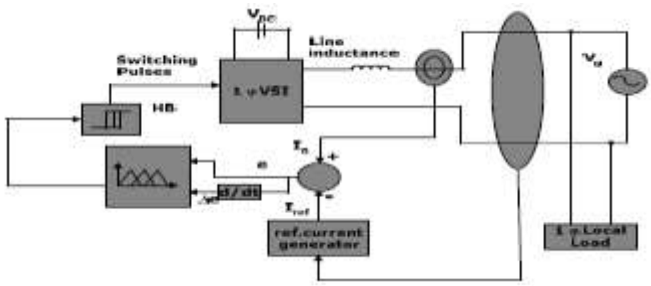


Fig. 9 Block diagram for fuzzy with hysteresis current control for single-phase grid-connected VSI

The structure of fuzzy logic controller is given below in Fig. 10.

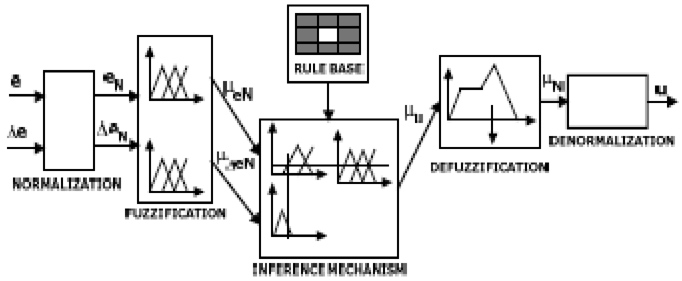


Fig. 10 Structure of Fuzzy logic controller

Here the membership function is chosen as triangular as shown in Fig. 11. The input is taken as an error (e) and the change in error (Δe).Total 49 rules are taken into account as given in table -1.

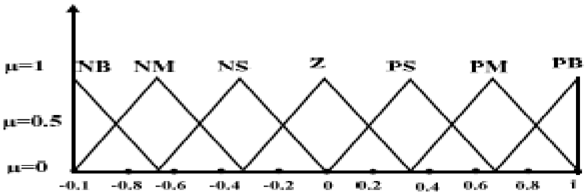


Fig. 11 Membership function

For example, If e is negative small (NS) and Δe is positive big (PB) Then the output is positive medium (PM).

Table-1-Rule base for fuzzy controller

e \ de	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

VII. SIMULATION RESULTS AND DISCUSSION

This section reveals the simulation results for fuzzy with hysteresis current control algorithm applied to single-phase mains connected inverter system and also the result is compared with conventional hysteresis controller on the basis of current error and harmonic distortion. The studied model has been developed and simulated in the MATLAB/Simulink environment. For simulation, the Dc-link voltage is taken 400V, and the grid voltage is 240V, the inductance of the line is 5mH and the utility grid frequency is 50 Hz. The simulation results are presented from Fig. 12 to Fig. 19.

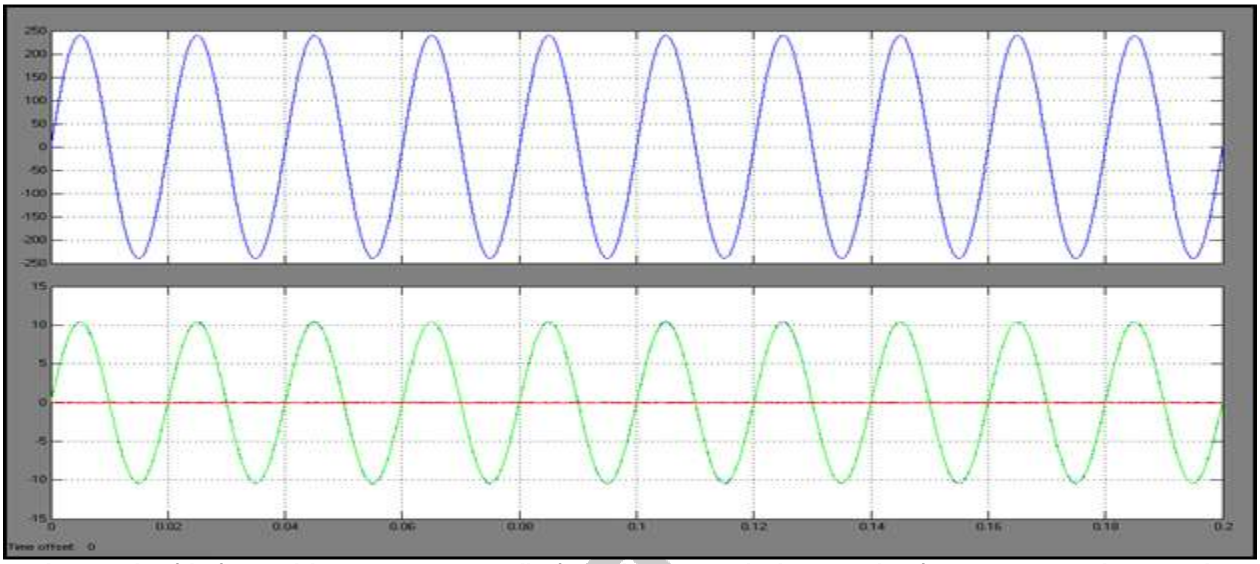


Fig. 12 Simulation results of the fuzzy with hysteresis current controller for steady state (a) grid voltage (Vg) (b) reference current, actual current and current error

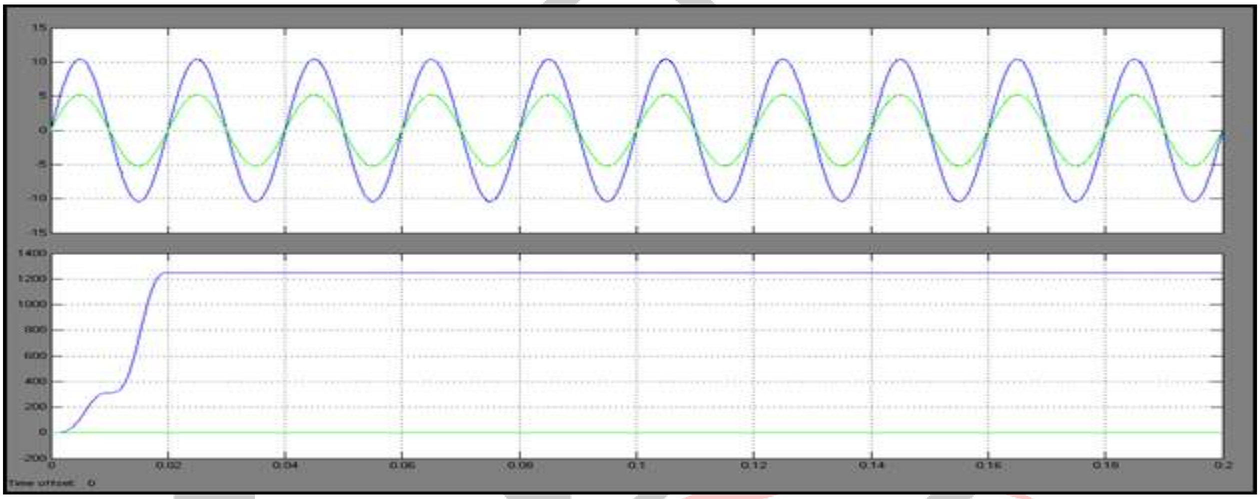


Fig. 13 Response of parameters (a) Grid current and load current (b) Active power & reactive power

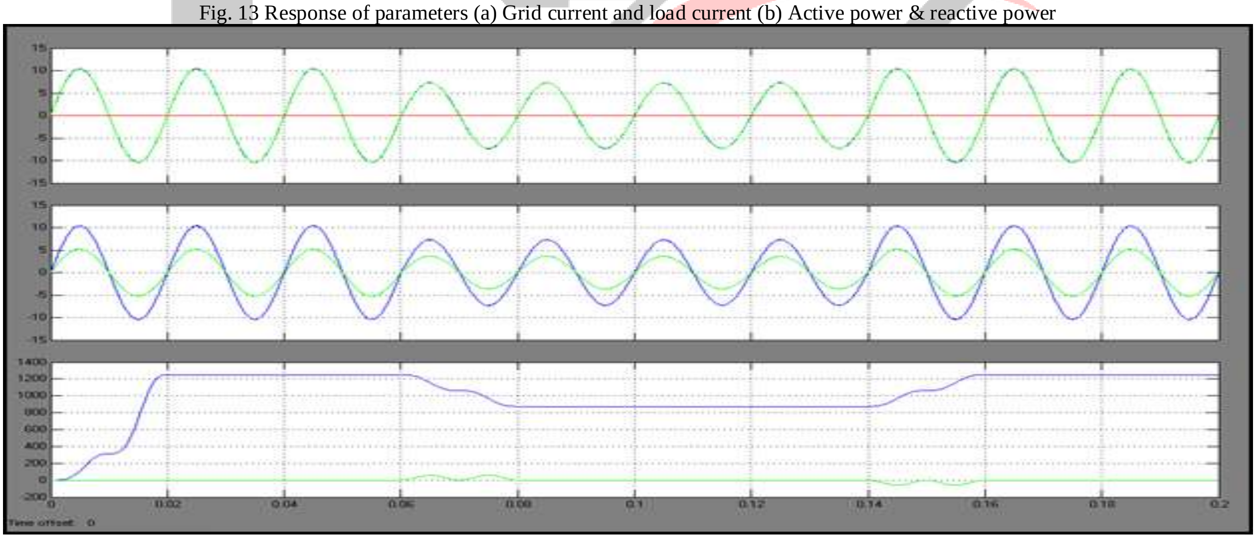


Fig. 14 Simulation results of reference current, actual current, and error for change in load fuzzy with hysteresis current controller

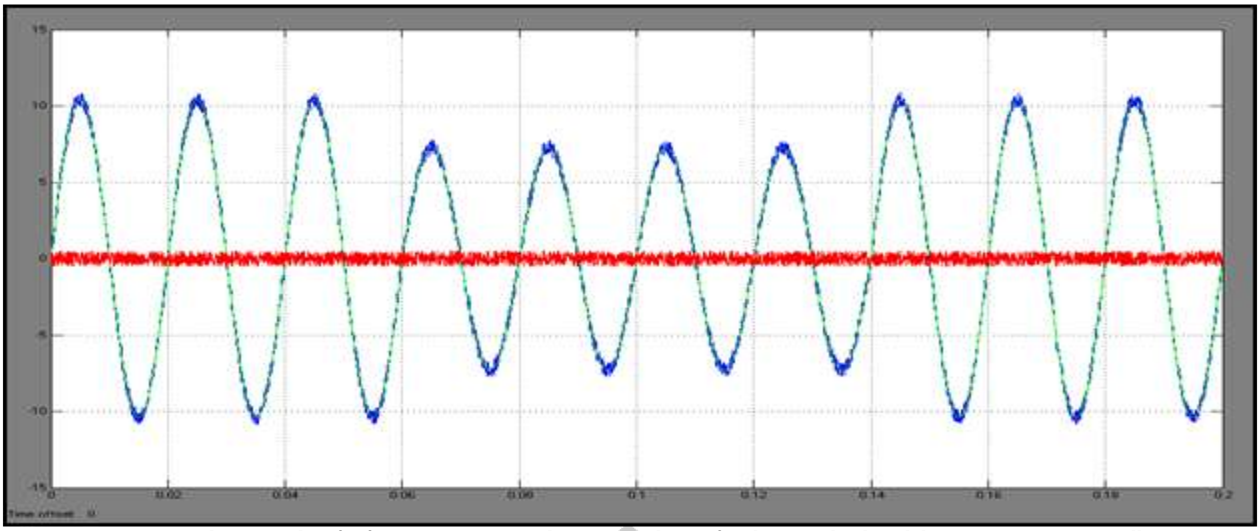


Fig. 15 Simulation results of reference current, actual current, and error for change in load with hysteresis current controller

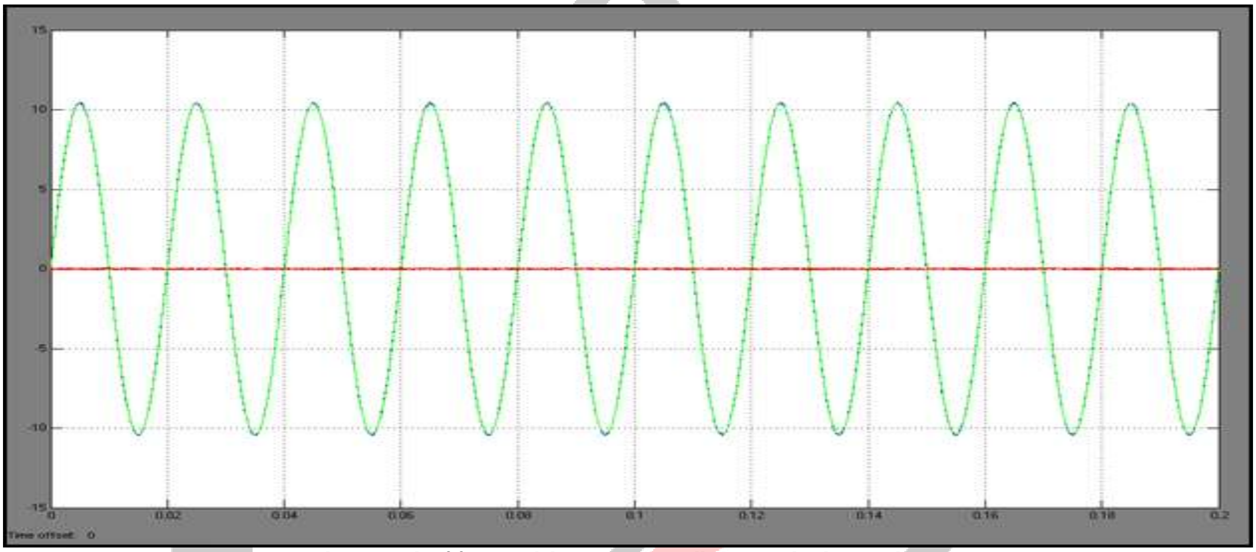


Fig. 16 Simulation result of fuzzy with hysteresis controller. (a) grid voltage and inverter current

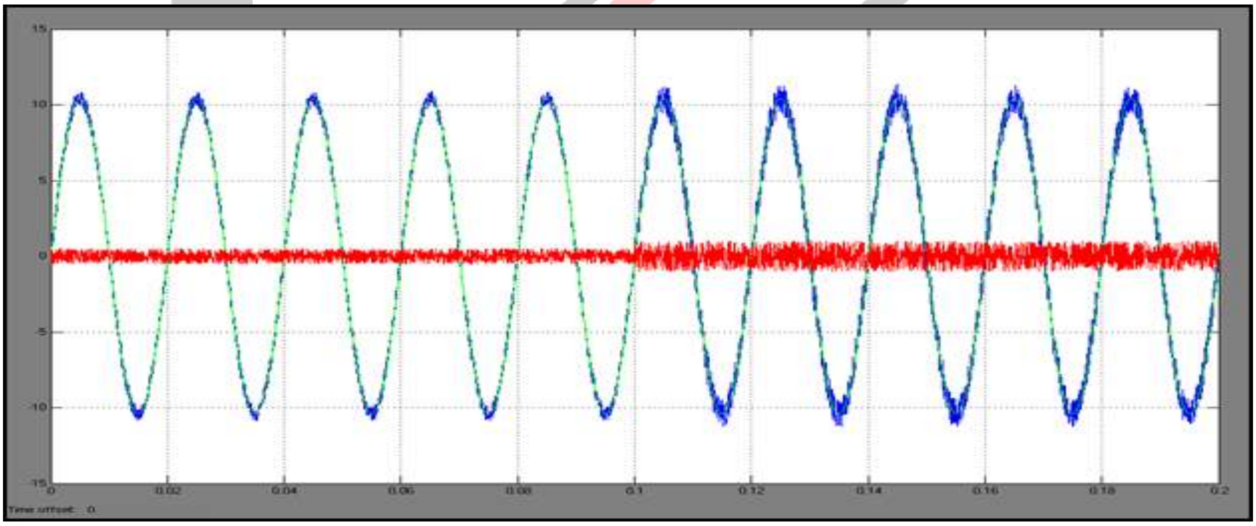


Fig. 17 Simulation result of grid current and error (a) for hysteresis controller

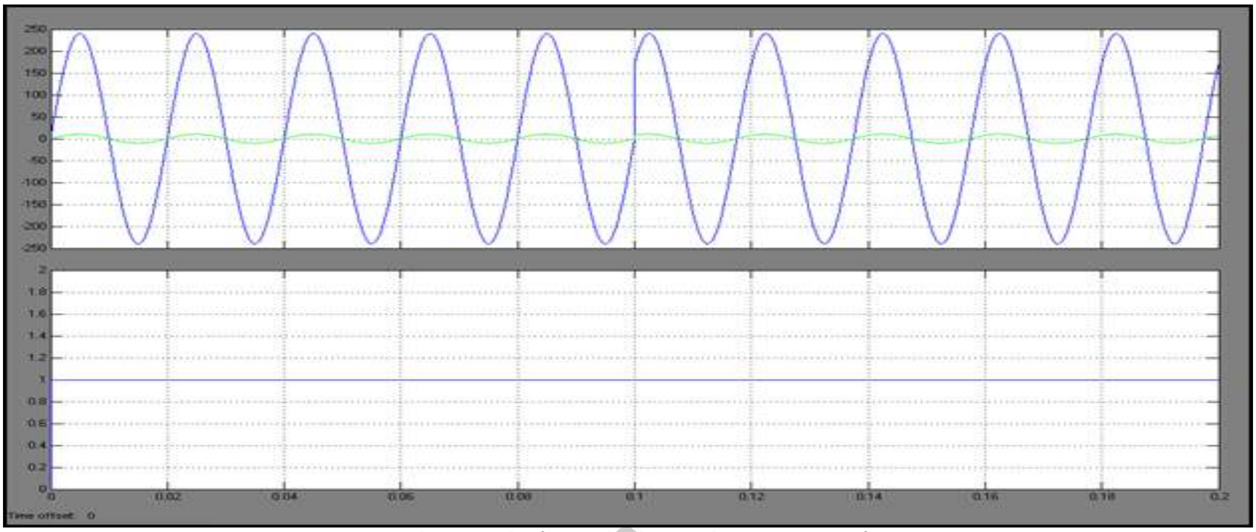
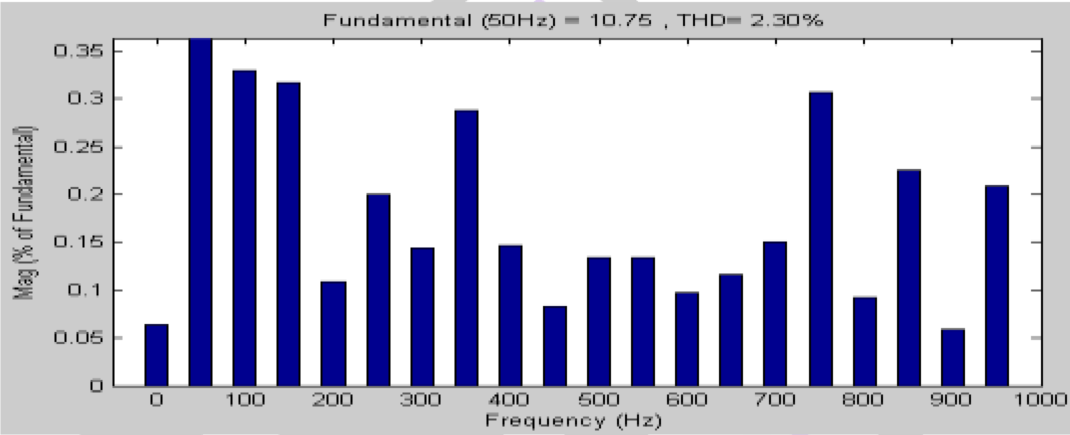


Fig. 18 Simulation result of (a) grid voltage and inverter current frequency
(b) power factor



(a)

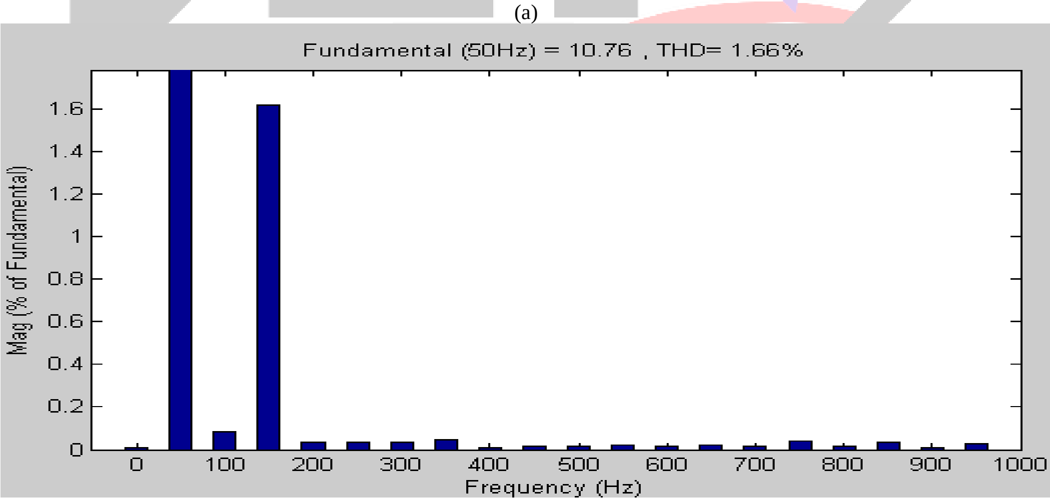


Fig. 19 THD of grid current (a) Hysteresis current controller (b) fuzzy with
hysteresis current comptroller

VIII. CONCLUSION

The paper presents the control grid connected PWM VSI using fuzzy with hysteresis controller in the control loop. From the study, we observed that fuzzy with hysteresis current controller can able to enhance the power quality of the grid system as it is enabled to reduce switching frequency even if the band width increased without any significant increase in the current error. As a result, the THD level of grid current is considerably reduced as compared to the conventional hysteresis current controller. Moreover, switching frequency of the inverter system has been reduced, in that in turn, switching losses are also reduced to a certain extent.

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