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Implementation of Intelligent Controller for a Single Phase Grid Connected Voltage Source Inverter

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Abstract: *Ever growing demand of electrical energy has resulted in the development of distributed generation systems (DG). The main problem associated with the DG systems is its coordination with the utility grid. The PWM based Voltage Source inverters are mostly meant for synchronizing the utility grid to the DG systems. This research paper presents the performance analysis of intelligent controller for grid stability and reduction of harmonics. In this paper 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 and Fuzzy logic controller is analyzed for controlling the harmonic content in current. The studied system is modeled and simulated in the MATLAB/Simulink environment and the result obtained from fuzzy logic controller is compared with hysteresis Controller.*

1. 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 is 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 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.

1) Hysteresis controller
2) Fuzzy Logic Controller

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

2. 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.

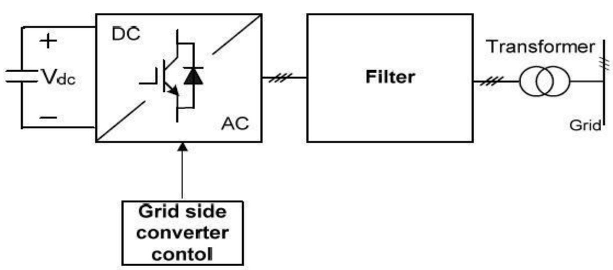


Fig. 1: Layout of the model system

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, and 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. Behavior 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.

3. CONTROLLER DESIGN

3.1 Hysteresis Controller

In this circuit single phase load is connected to the PWM voltage source inverter. The load currents is compared with the reference currents 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.

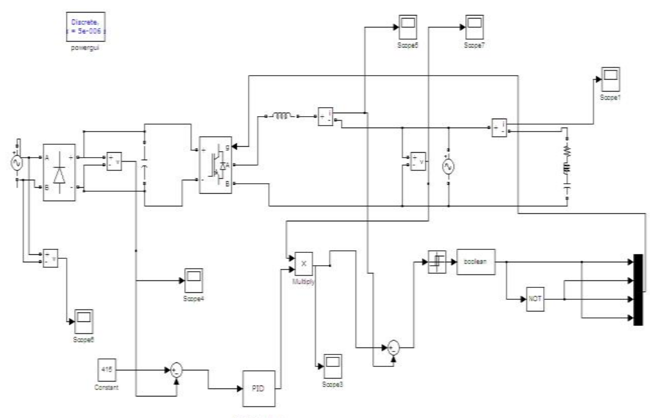


Fig. 2: Simulink model of control strategy for grid connected Inverter using Hysteresis.

3.2 Fuzzy 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 and thus the drawbacks of hysteresis current controller can be eliminated by Fuzzy Logic Controller.

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

A 5*5 membership function having 25 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 1: Rule Base

e / delta e	**PM**	**PS**	**Z**	**NS**	**NM**
PM	NVL	NL	NM	NS	Z
PS	NL	NM	NS	Z	PS
Z	NM	NS	Z	PS	PM
NS	NS	Z	PS	PM	PL
NM	Z	PS	PM	PL	PVL

Where various linguistic variables are:

NVL Negative very Large
NL Negative Large
NM Negative Medium
NS Negative Small
Z Zero
PS Positive Small
PM Positive Medium
PL Positive Large
PVL Positive very Large

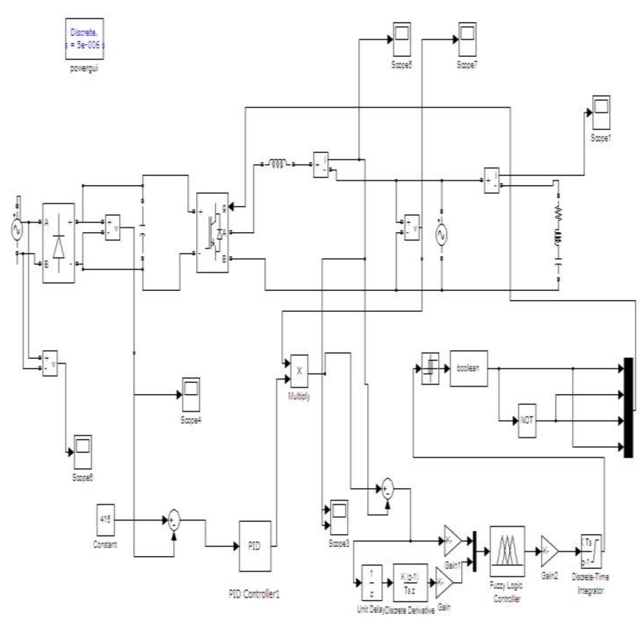


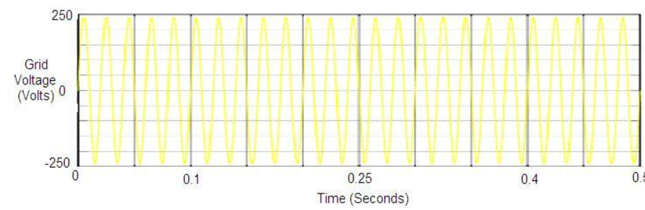
Fig. 3: Simulink Model of control strategy for grid connected inverter using Fuzzy controller.

4. RESULTS

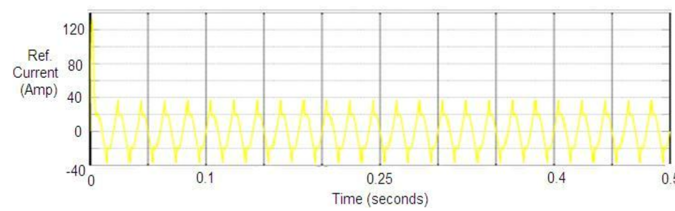
4.1 Analysis using hysteresis controller

In Fig. 4, the grid voltage, reference 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 and these results also matched with the results obtained by Satyaranjan Jena et al [7].

Grid Voltage:



Reference Current:



Load Current:

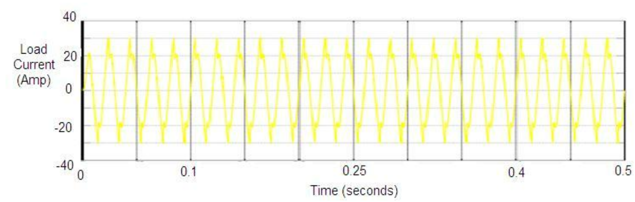


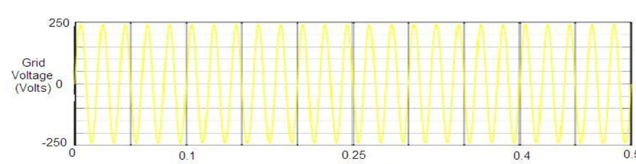
Fig. 4: Grid Voltage, Reference Current, and Load current

are shown for a grid connected PWM inverter when controlled using a hysteresis controller.

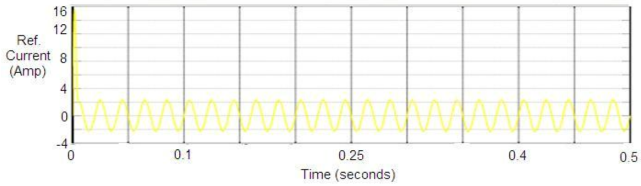
Analysis using Fuzzy controller

In Fig. 5, the grid voltage, reference 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 400 V and grid voltage is 240 V. The FLC parameters are tuned resulting in efficient control of the load current.

Grid Voltage:



Reference Current:



Load Current:

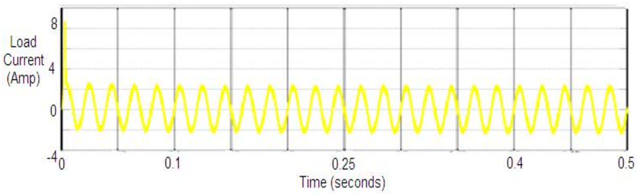


Fig. 5. Grid Voltage, Reference Current, Load Current are shown for a grid connected PWM inverter when controlled using a Fuzzy Controller.

5. CALCULATION OF TOTAL HARMONIC DISTORTION

5.1 THD for Hysteresis controller

When Vgrid > Vsource

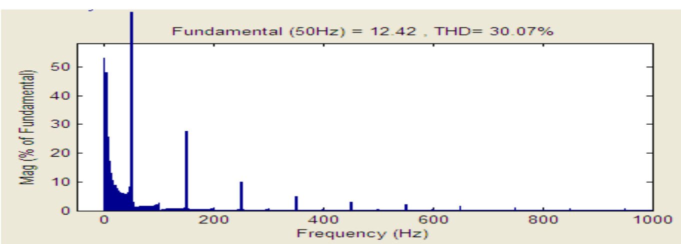


Fig. 6: THD for grid connected inverter using hysteresis controller.

When Vgrid < Vsource

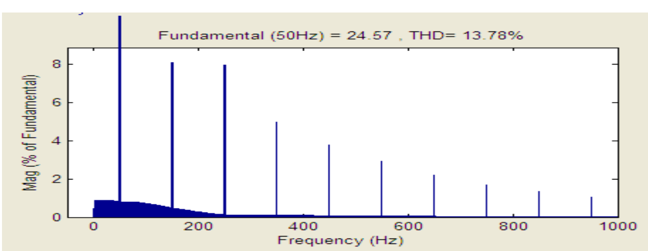


Fig. 7: THD for grid connected inverter using hysteresis controller

It can be seen from Fig. 6 and 7, the THD is very high. In this case the harmonics are huge and distortion in current can be observed and the total harmonic distortion is not according to the IEEE recommendations.

THD for Fuzzy controller

When Vgrid > Vsource

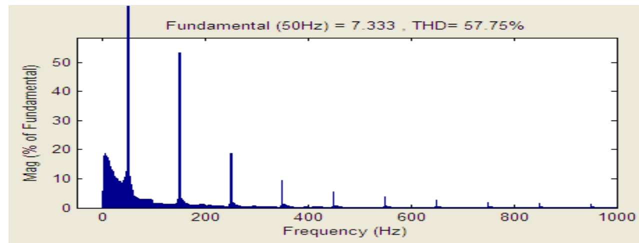


Fig. 8: THD for grid connected inverter using fuzzy controller.

When Vgrid < Vsource

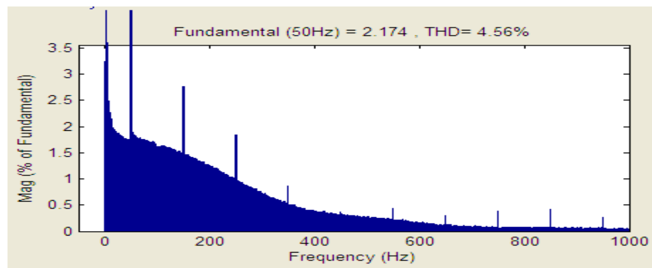


Fig. 9: THD for grid connected inverter using fuzzy controller.

In this case, the THD is less about 4.56%, which is well below the IEEE recommended 5%.

Table I: Comparative study of control techniques

S. No.	Control Techniques	Magnitude of harmonics at fundamental frequency (%)		Total Harmonic Distortion (%)	
		Vgrid > Vsource	Vgrid < Vsource	Vgrid > Vsource	Vgrid < Vsource
1	Hysteresis Controller	12.42	24.67	30.07	13.78
2	Fuzzy Controller	7.33	2.174	57.75	4.56

6. 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 FLC controller was 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 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.

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