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## Power Quality Enhancement Across A Micro Grid by using Fuzzy Controlled H-Bridge Multilevel PV Inverter

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**Abstract:** The inverters are categorized according to the configuration of the PV system, the configuration of the conversion stages within the inverter and whether they use transformers. After the introduction of the state of the art of inverters for PV systems with and without transformers, the paper focuses on some known problems and challenges for transformer less inverters. Topologies without transformers have big advantages like low weight, volume and cost. In addition they often reach higher efficiencies than topologies with transformers. Eliminating the leakage current is one of the most important issues for transformer less inverters in grid-connected photovoltaic system applications, where the technical challenge is how to keep the system common-mode voltage constant to reduce the leakage current. To realize better utilization of PV modules and maximize the solar energy extraction, a distributed maximum power point tracking control scheme is applied to both single- and three-phase multilevel inverters, which allows independent control of each dc-link voltage. For three-phase grid-connected applications, PV mismatches may introduce unbalanced supplied power, leading to unbalanced grid current. The intend of the fuzzy logic approach is to meet high quality output, minimum THD, fast response and high robustness. Finally Total Harmonics Distortion (THD) generated by the inverter is compared with conventional proportional Integral controls (PI) and fuzzy controller is evaluated. The results are verified with the help of MATLAB/Simulink.

**Keywords:** Fuzzy Logic Controller, Grid Connected System, Cascaded Multilevel Inverter, Distributed Maximum Power Point (MPP) Tracking (MPPT), Modulation Compensation, Photovoltaic (PV).

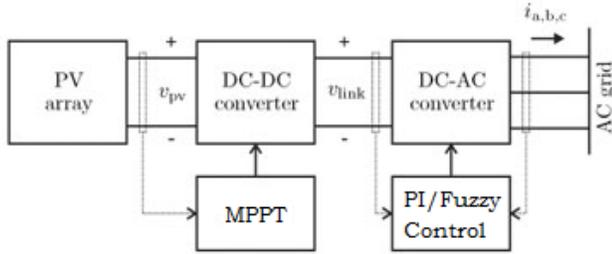
### I. INTRODUCTION

Nowadays 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 greenhouse gases, 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. Cascaded inverters consist of several converters connected in series; thus, the high power and/or high voltage from the combination of the multiple modules would favor this topology in medium and large grid-connected PV systems [1]. Five inverter families can be characterized, which are identified with diverse designs of the PV system: 1) focal inverters; 2) string inverters; 3) multistring inverters; 4) air conditioning module inverters; what's more, 5) cascaded inverters. Cascaded inverters comprise of a few converters connected in arrangement; accordingly, the high power and/or high voltage from the mix of the different modules would support this topology in medium and substantial lattice connected PV systems.

There are two sorts of cascaded inverters. Fig. 1(e) demonstrates a cascaded dc/dc converter association of PV modules. Each PV module has its own particular dc/dc converter, and the modules with their related converters are still connected in arrangement to make a high dc voltage, which is given to a rearranged dc/ac inverter. This methodology consolidates parts of string inverters and ac module inverters and offers the benefits of person module most maximum power point (MPP) following (MPPT), yet it is not so much excessive but rather more productive than air conditioning module inverters[2]. Notwithstanding, there are two power transformation phase s in this arrangement. This new scenario introduces many technical, economic, and political challenges because it is changing the way in which the electrical energy resources (generators and transmission/distribution networks) are designed and managed. From the technical viewpoint, the use of electronic power converters

introduces new and challenging issues, including increased topological complexity, additional power losses, and electromagnetic interferences (EMIs), thus reducing the overall quality of service, efficiency, and network stability [3]-[5].



**Fig. 1. Generalized Block Diagram of Grid-Connected PV System.**

For such a reason, many researchers are addressing their efforts in proposing new inverter topologies or in modifying the existing ones, aiming at improving the quality of the energy available at the inverter terminals. Among them, pulse width modulated (PWM) multilevel inverters (MLIs) are gaining both popularity and applications, becoming an effective alternative to current inverter topologies. In their early stage, they were employed mainly in high-voltage high-power industrial and traction applications because they distribute the applied voltage among a number of cascaded power devices, thus overcoming their voltage limits and allowing the elimination of output transformers in medium-high voltage systems. Since their output voltage is a modulated staircase, they outperform two-level PWM inverters in terms of total harmonic distortion (THD), without the use of bulky expensive and dissipative passive filters. Therefore, recently, they have been proposed in the field of renewable energies, including photovoltaic (PV) generators [6]. The modular cascaded H-bridge multilevel inverter, which requires an isolated dc source for each H-bridge, is one dc/ac cascaded inverter topology. The separate dc links in the multilevel inverter make independent voltage control possible. As a result, individual MPPT control in each PV module can be achieved, and the energy harvested from PV panels can be maximized.

Meanwhile, the modularity and low cost of multilevel converters would position them as a prime candidate for the next generation of efficient, robust, and reliable grid connected solar power electronics. A modular cascaded H-bridge multilevel inverter topology for single- or three-phase grid-connected PV systems is presented in this paper. The panel mismatch issues are addressed to show the necessity of individual MPPT control, and a control scheme with distributed MPPT control is then proposed. The distributed MPPT control scheme can be applied to both single and three-phase systems [7-9]. In addition, for the presented three-phase grid-connected PV system, if each PV module is operated at its own MPP, PV mismatches may introduce unbalanced power supplied to the three-phase multilevel inverter, leading to unbalanced injected grid current. To balance the three-phase grid current, modulation compensation is also added to the control system. An

improved perturbation and observation maximum power point tracking algorithm for PV arrays is preferred for attaining the maximum power. Improved perturbation and observation method of Maximum Power Point Tracking control for photovoltaic power systems in [10]. He explained about the perturbation observation method. Maximum photovoltaic power tracking an algorithm for rapidly changing atmospheric conditions explained in [11].

Evaluation of maximum power point tracking methods for grid connected photovoltaic systems discussed in [12]. In the maximum power point tracking method so many methods are available but he used the suitable tracker. The fuzzy inference is carried out by using Sugeno's method in [13]. So this is Sugeno, or TakagiSugeno-Kang, method of fuzzy inference. Introduced in 1985[9], it is similar to the Mamdani method in many respects. Hardware Implementation of Fuzzy Logic based Maximum Power Point Tracking Controller for PV System explained in [14]. The electric power supplied by a photovoltaic power generation systems depends on the solar irradiation and temperature. A Rule-Based Fuzzy Logic Controller for a PWM Inverter in Photo-voltaic Energy Conversion Scheme discussed in [15]-[16]. The modeling and simulation of the electric part of a grid connected photovoltaic generation system explained. This work proposed a fuzzy logic based controller to track MPPT in photovoltaic cell.

## II. SYSTEM DESCRIPTION

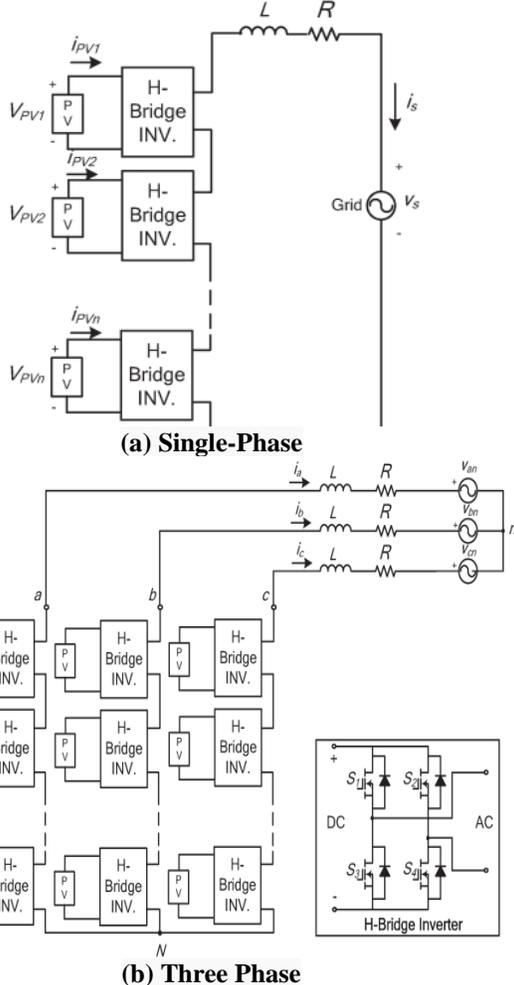
Modular cascaded H-bridge multilevel inverters for single and three-phase grid-connected PV systems are shown in Fig.1. Each phase consists of n H-bridge converters connected in series, and the dc link of each H-bridge can be fed by a PV panel or a short string of PV panels. The cascaded multilevel inverter is connected to the grid through L filters, which are used to reduce the switching harmonics in the current. By different combinations of the four switches in each H-bridge module, three output voltage levels can be generated:  $-v_{dc}$ , 0, or  $+v_{dc}$ . A cascaded multilevel inverter with n input sources will provide  $2n + 1$  levels to synthesize the ac output waveform. This  $(2n + 1)$ -level voltage waveform enables the reduction of harmonics in the synthesized current, reducing the size of the needed output filters. Multilevel inverters also have other advantages such as reduced voltage stresses on the semiconductor switches and having higher efficiency when compared to other converter topologies.

## III. PANEL MISMATCHES

PV mismatch is an important issue in the PV system. Due to the unequal received irradiance, different temperatures, and aging of the PV panels, the MPP of each PV module may be different. If each PV module is not controlled independently, the efficiency of the overall PV system will be decreased. In a three-phase grid-connected PV system, a PV mismatch may cause more problems. Aside from decreasing the overall efficiency, this could even introduce unbalanced power supplied to the three-phase grid-connected system. If there are PV mismatches between

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phases, the input power of each phase would be different. Since the grid voltage is balanced, this difference in input power will cause unbalanced current to the grid, which is not allowed by grid standards. For example, to unbalance the current per phase more than 10% is not allowed for some utilities, where the percentage imbalance is calculated by taking the maximum deviation from the average current and dividing it by the average current.



**Fig.2. Topology of the modular cascaded H-bridge multilevel inverter for grid-connected PV systems.**

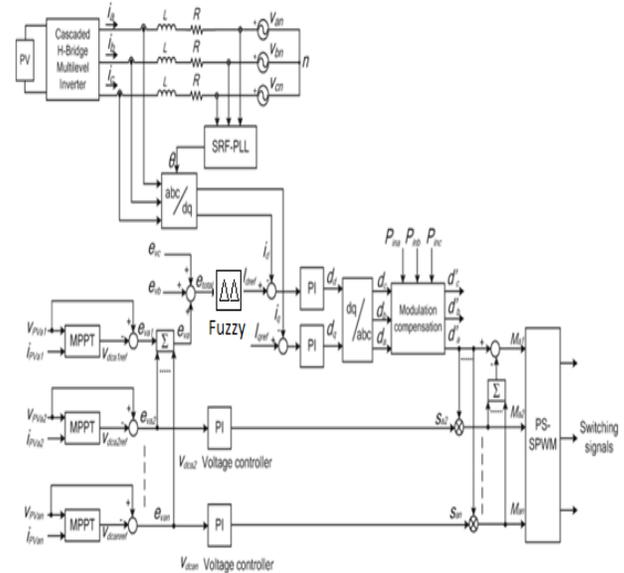
To solve the PV mismatch issue, a control scheme with individual MPPT control and modulation compensation is proposed as shown in Fig.2. The details of the control scheme will be discussed in the next section.

**IV. CONTROL SCHEME**

**A. Distributed MPPT Control**

In order to eliminate the adverse effect of the mismatches and increase the efficiency of the PV system, the PV modules need to operate at different voltages to improve the utilization per PV module. The separate dc links in the cascaded H-bridge multilevel inverter make independent voltage control possible. To realize individual MPPT control in each PV module, the control scheme proposed is updated for this application. The distributed MPPT control of the three-phase cascaded H-bridge inverter is shown in Fig.3. In

each H-bridge module, an MPPT controller is added to generate the dc-link voltage reference. Each dc-link voltage is compared to the corresponding voltage reference, and the sum of all errors is controlled through a total voltage controller that determines the current reference  $I_{dref}$ .



**Fig.3. Control scheme for three-phase modular cascaded H-bridge multilevel PV inverter.**

The reactive current reference  $I_{qref}$  can be set to zero, or if reactive power compensation is required,  $I_{qref}$  can also be given by a reactive current calculator. The synchronous reference frame phase-locked loop (PLL) has been used to find the phase angle of the grid voltage. As the classic control scheme in three-phase systems, the grid currents in abc coordinates are converted to  $d_q$  coordinates and regulated through proportional-integral (PI) controllers to generate the modulation index in the  $d_q$  coordinates, which is then converted back to three phases. The distributed MPPT control scheme for the single-phase system is nearly the same. The total voltage controller gives the magnitude of the active current reference, and a PLL provides the frequency and phase angle of the active current reference. The current loop then gives the modulation index. To make each PV module operate at its own MPP, take phase a as an example; the voltages  $v_{dca2}$  to  $v_{dcan}$  are controlled individually through  $n - 1$  loops. Each voltage controller gives the modulation index proportion of one H-bridge module in phase a. After multiplied by the modulation index of phase a,  $n - 1$  modulation indices can be obtained. Also, the modulation index for the first H-bridge can be obtained by subtraction. The control schemes in phases b and c are almost the same. The only difference is that all dc-link voltages are regulated through PI controllers, and  $n$  modulation index proportions are obtained for each phase.

A phase-shifted sinusoidal pulse width modulation switching scheme is then applied to control the switching devices of each H-bridge. It can be seen that there is one H-bridge module out of  $N$  modules whose modulation index is obtained by subtraction. For single-phase systems,  $N = n$ ,

and for three-phase systems,  $N = 3n$ , where  $n$  is the number of H-bridge modules per phase. The reason is that  $N$  voltage loops are necessary to manage different voltage levels on  $N$  H-bridges, and one is the total voltage loop, which gives the current reference. So, only  $N - 1$  modulation indices can be determined by the last  $N-1$  voltage loops, and one modulation index has to be obtained by subtraction. Many MPPT methods have been developed and implemented. The incremental conductance method has been used in this paper. It lends itself well to digital control, which can easily keep track of previous values of voltage and current and make all decisions.

**B. Modulation Compensation**

As mentioned earlier, a PV mismatch may cause more problems to a three-phase modular cascaded H-bridge multilevel PV inverter. With the individual MPPT control in each H-bridge module, the input solar power of each phase would be different, which introduces unbalanced current to the grid. To solve the issue, a zero sequence voltage can be imposed upon the phase legs in order to affect the current flowing into each phase. If the updated inverter output phase voltage is proportional to the unbalanced power, the current will be balanced. Thus, the modulation compensation block, as shown in Fig. 4, is added to the control system of three-phase modular cascaded multilevel PV inverters. The key is how to update the modulation index of each phase without increasing the complexity of the control system. First, the unbalanced power is weighted by ratio  $r_j$ , which is calculated as

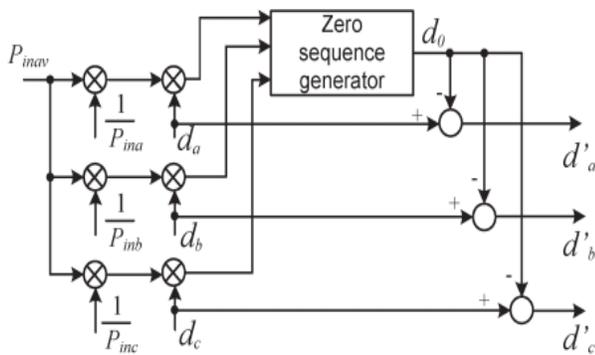


Fig.4. Modulation compensation scheme.

$$r_j = \frac{P_{inav}}{P_{inj}} \tag{1}$$

Where  $P_{inj}$  is the input power of phase  $j$  ( $j = a, b, c$ ), and  $P_{inav}$  is the average input power. Then, the injected zero sequence modulation index can be generated as

$$d_0 = \frac{1}{2} [\min(r_a \cdot d_a, r_b \cdot d_b, r_c \cdot d_c) + \max(r_a \cdot d_a, r_b \cdot d_b, r_c \cdot d_c)] \tag{2}$$

Where  $d_j$  is the modulation index of phase  $j$  ( $j = a, b, c$ ) and is determined by the current loop controller. The modulation index of each phase is updated by

$$d'_j = d_j - d_0. \tag{3}$$

Only simple calculations are needed in the scheme, which will not increase the complexity of the control system. An example is presented to show the modulation compensation scheme more clearly. Assume that the input power of each phase is unequal

$$P_{ina} = 0.8 \quad P_{inb} = 1 \quad P_{inc} = 1 \tag{4}$$

**V. FUZZY CONTROLLER**

The control scheme consists of Fuzzy controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a Fuzzy controller, which contributes to zero steady error in tracking the reference current signal. A fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database. Firstly, input voltage  $V_{dc}$  and the input reference voltage  $V_{dc-ref}$  have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presented by the control Current  $I_{max}$ . To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in Fig.5. The fuzzy controller is characterized as follows:

- Seven fuzzy sets for each input and output;
- Fuzzification using continuous universe of discourse;
- Implication using Mamdani's 'min' operator;
- De-fuzzification using the 'centroid' method.

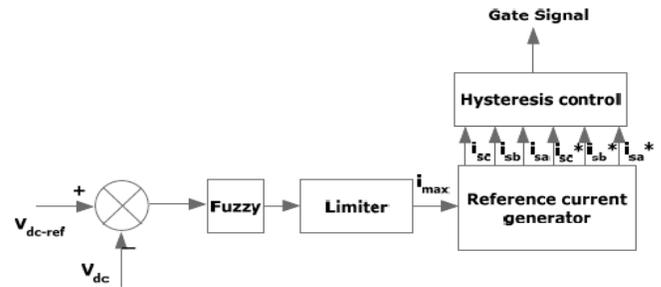


Fig.5. Conventional fuzzy controller.

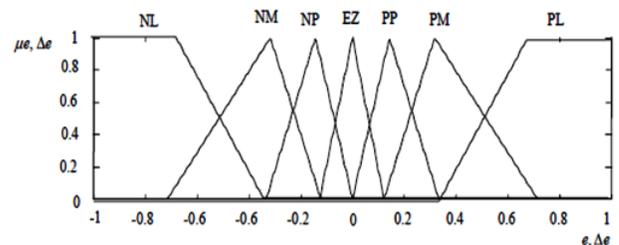


Fig.6. Membership functions.

**Fuzzification:** the process of converting a numerical variable (real number) convert to a linguistic variable (fuzzy number) is called fuzzification.

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**De-fuzzification:** the rules of FLC generate required output in a linguistic variable (Fuzzy Number), according to real world requirements, linguistic variables have to be transformed to crisp output (Real number).

**Database:** the Database stores the definition of the membership Function required by fuzzifier and defuzzifier.

**TABLE I: Rules**

$e$	NL	NM	NS	EZ	PS	PM	PL
$\Delta e$	NL	NL	NL	NL	NM	NS	EZ
	NM	NL	NL	NM	NS	EZ	PS
	NS	NL	NM	NS	EZ	PS	PM
	EZ	NL	NM	NS	EZ	PS	PM
	PS	NM	NS	EZ	PS	PM	PL
	PM	NS	EZ	PS	PM	PL	PL
	PL	NL	NM	NS	EZ	PS	PM

**Rule Base:** the elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse input/output variables; in the steady state, small errors need fine control, which requires fine input/output variables as shown in Fig.6. Based on this the elements of the rule table are obtained as shown in Table 1, with ‘Vdc’ and ‘Vdc-ref’ as inputs.

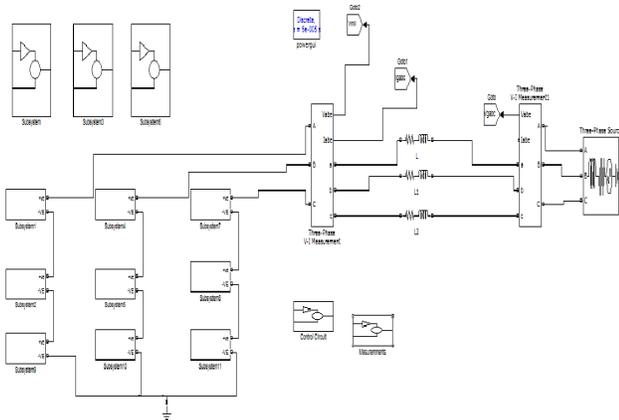
**VI. MTALAB/SIMULATION RESULTS**

The simulation analysis is carried out under the several cases by using Matlab/Simulink tool with respect to the simulation parameters, these parameters are illustrated in Table.2 and results as shown in Figs.7 to 17.

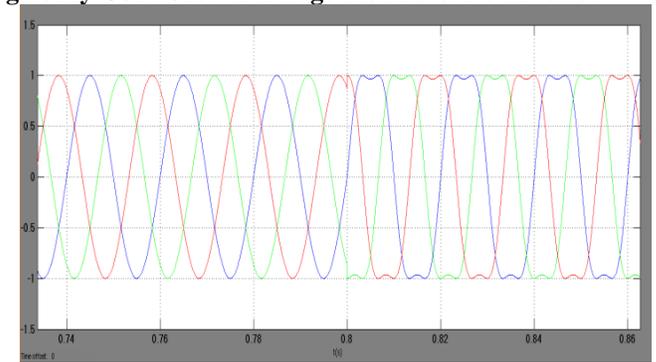
**TABLE II: Simulation Parameters**

Parameters	Value
DC-link capacitor	3600 $\mu$ F
Connection inductor $L$	2.5 mH
Grid resistor $R$	0.1 ohm
Grid rated phase voltage	60 Vrms
Switching frequency	1.5 kHz

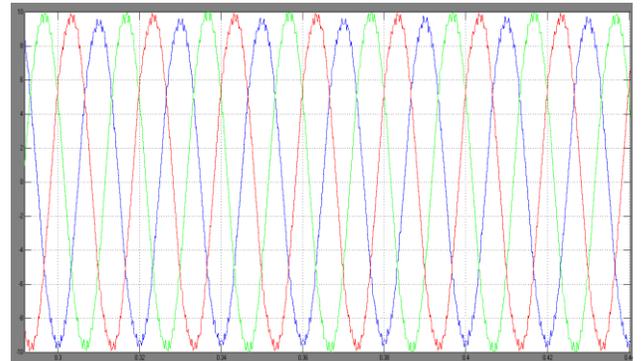
**Case 1: Compensation of Grid Current Using 7-level CHB with PI Controller**



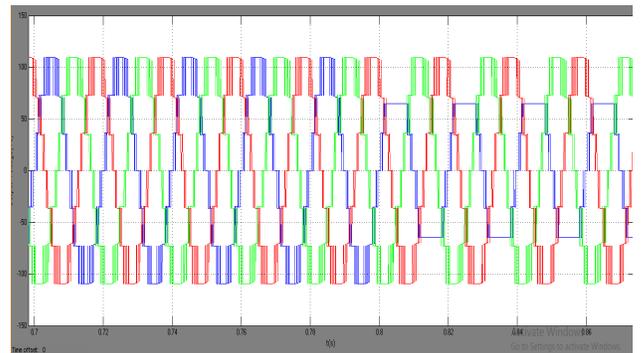
**Fig.7. Simulation model of modular cascaded distributed MPPT control based grid connected system.**



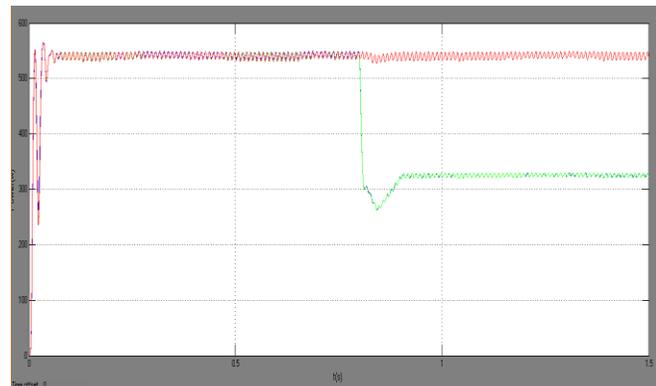
**Fig.8. Simulation waveform of after and before compensation.**



**Fig.9. Simulation waveform of grid current in PI Controller.**

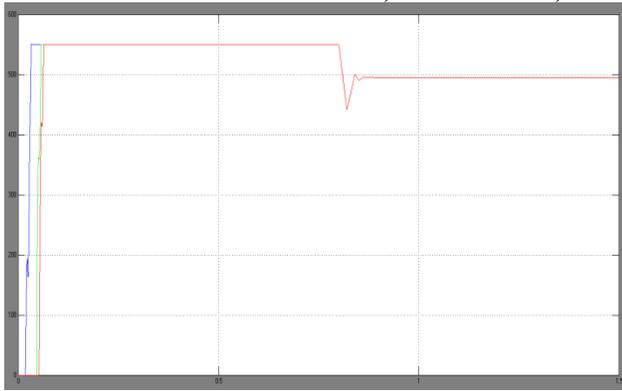


**Fig.10. Simulation waveform of output MLI voltage in PI Controller.**

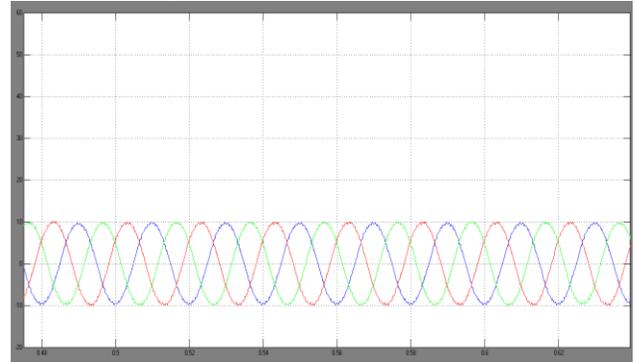


**Fig.11. Simulation waveform of Power extracted from PV panel in PI Controller.**

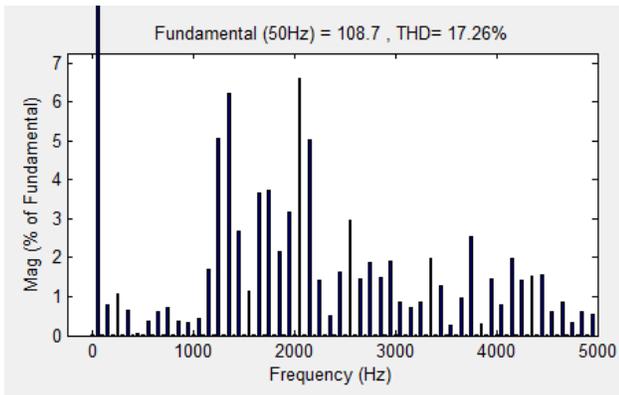
**Case 2: Compensation of Grid Current Using 7-level CHB with Fuzzy Controller**



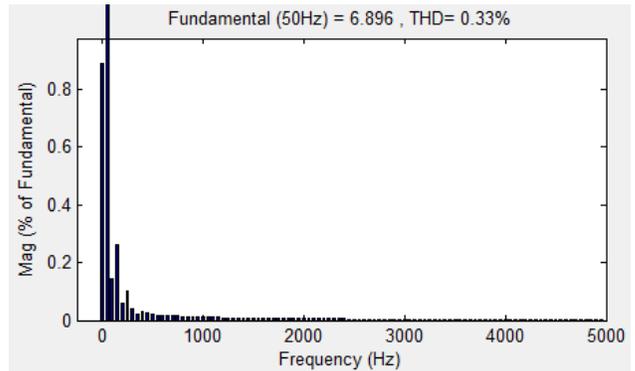
**Fig.12. power injected to grid with modulation compensation using PI Controller.**



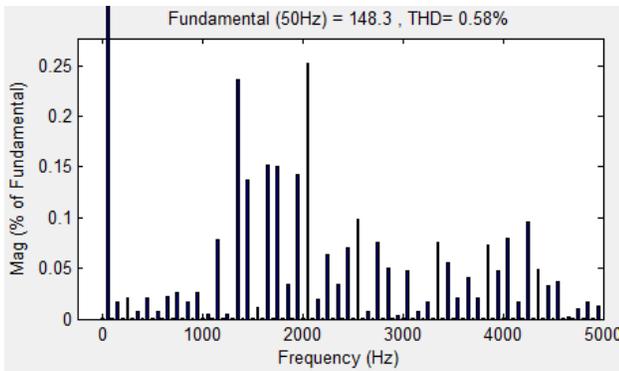
**Fig.16. Simulation waveform of grid current using Fuzzy Logic Controller.**



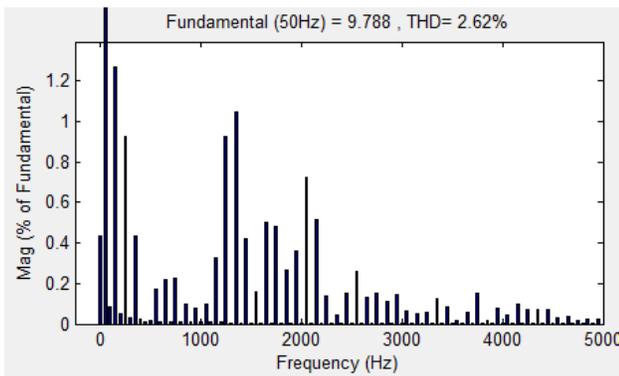
**Fig.13. THD of 7-Level MLI Output voltage without Filter.**



**Fig.17. THD of Grid Current under FUZZY Logic Controller.**



**Fig.14. THD of MLI Output voltage with Filter.**



**Fig.15. THD of Grid Current under PI Controller.**

**VII. CONCLUSION**

A multilevel cascaded H-bridge inverter for PV applications with FL control approach has been proposed. The PV simulation system used in this paper is set up under Matlab/Simulink environment. After accomplishing the model of PV modules, the models of Multilevel inverter and MPPT systems are combined with it to complete the PV simulation system with the MPPT functions. Its performance satisfies the demand of flexible and accurate electric power generation and reduces both the output filter dimensions and the influence of perturbations caused by cloud darkening or seasonal variations. A modulation compensation scheme, which will not increase the complexity of the control system or cause extra power loss, is added to balance the grid current. With the proposed Fuzzy logic control scheme, each PV module can be operated at its own MPP to maximize the solar energy extraction, and the three-phase grid current is balanced even with the unbalanced supplied solar power. Due to its modularity, the proposed system can be improved by increasing the number of levels, further reducing its THD.

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