

THREE-PHASE MULTILEVEL CASCADED H-BRIDGE PV INVERTER WITH FUZZY BASED MPPT FOR GRID- CONNECTED APPLICATIONS

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ABSTRACT- Photovoltaic energy conversion becomes main focus of many researches due to its promising potential as source for future electricity and has many advantages than the other alternative energy sources like wind, solar, ocean, biomass, geothermal etc. In Photovoltaic power generation multilevel inverters play a vital role in power conversion. The modular cascaded multilevel topology helps to improve the efficiency and flexibility of PV systems. 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 Here we are using the fuzzy controller compared to other controllers i.e. The fuzzy controller is the most suitable for the human decision-making mechanism, providing the operation of an electronic system with decisions of experts. In addition, using the fuzzy controller for a nonlinear system allows for a reduction of uncertain effects in the system control and improve the efficiency. Fuzzy Logic based Intelligent Controller has been implemented for voltage regulation at Point of Common Coupling of Grid connected PV Power System. Simulation results are presented to verify the feasibility of the proposed approach.

I. INTRODUCTION

In Photovoltaic power generation multilevel inverters play a vital role in power conversion. In the countries of the equatorial region solar energy is abundant, so Photovoltaic Power Systems are the commonly used renewable energy. Considering various different cases, Multilevel Inverters play major role in the Power Quality improvement in renewable energy power systems. Five inverter families can be defined, which are related to different configurations of the PV system: 1) central inverters; 2) string inverters; 3) multistring inverters; 4) ac-module inverters; and 5) cascaded inverters. The configurations of PV systems are shown in Fig. 1. Among the three topologies, cascaded h-bridge multilevel inverter is more suitable for photovoltaic applications since each PV array can act as a separate dc source for each h-bridge module. 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. There are two types of cascaded inverters. Fig. 1(e) shows a cascaded dc/dc converter connection of PV module. Each PV module has its own dc/dc converter, and the modules with their associated converters are still connected in series to create a high dc voltage, which is provided to a simplified dc/ac inverter.

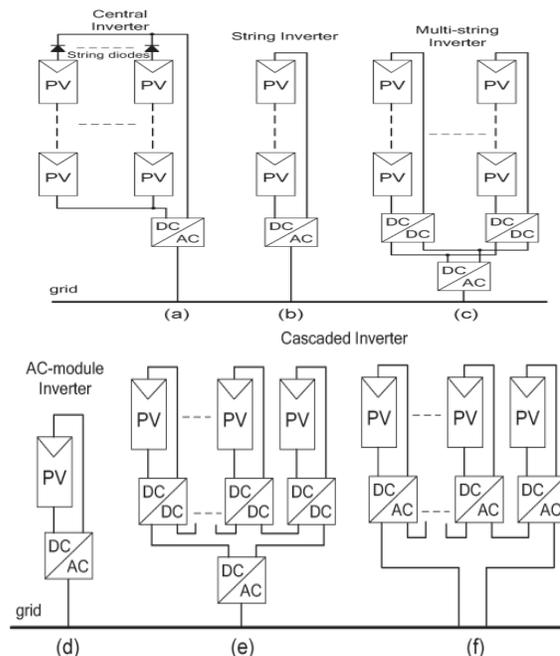


Fig. 1. Configurations of PV systems. (a) Central inverter. (b) String inverter.(c) Multi string inverter. (d) AC-module inverter. (e) Cascaded dc/dc converter. (f) Cascaded dc/ac inverter.

As a result, individual MPPT control in each PV module can be achieved, and the energy harvested from PV panels can be maximized. Fuzzy logic based intelligent controller is used in continuous monitoring of the grid connected photovoltaic power system and controlling the cascaded H-bridge inverter This cascaded inverter would maintain the benefits of “one converter per panel,” such as better utilization per PV module, capability of mixing different sources, and

redundancy of the system. In addition, this dc/ac cascaded inverter removes the need for the per-string dc bus and the central dc/ac inverter, which further improves the overall efficiency.

Multi level converters would position them as a prime candidate for the next generation of efficient, robust, and reliable grid connected solar power electronics. In this paper a modular cascaded H-bridge multilevel inverter topology for single- or three-phase grid-connected PV systems is presented. The distributed MPPT control scheme can be applied to both single and three-phase systems. 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. By using the simulation results we can analyze the modular design will increase the flexibility of the system and reduce the cost as well.

II. SYSTEM DESCRIPTION

Photovoltaic cells are devices capable of converting the energy from the sun into a flow of electrons by Photovoltaic effect. Combinations of PV cells provide module and several modules together form a Photovoltaic Array. The energy produced by the Photovoltaic Array is unswerving reliant on the Temperature and Irradiation of the sunlight. 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 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: -vdc, 0, or +vdc. This (2n + 1)-level voltage waveform enables the reduction of harmonics in the synthesized current, reducing the size of the needed output filters.

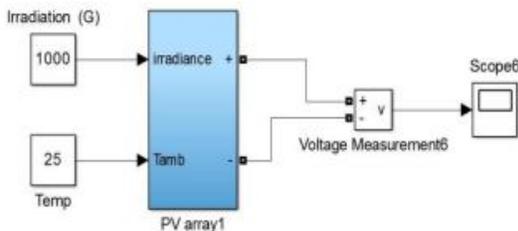


Fig 2 Simulation of photovoltaic array

The simulation of the photovoltaic array in MATLAB, Simulink is shown in figure 2. An irradiation of 1000G and ambient temperature of 25°C is provided as the input for the solar array.

III. PANEL MISMATCHES

Generally Multilevel Inverters requires more number of components for increasing the number of levels in the output level. Increasing the components leads to high loss. Power quality of Renewable energy power system can be increased by reducing the components used and increasing the output level. 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. To show the necessity of individual MPPT control, a five-level two-H-bridge single-phase inverter is simulated in MATLAB/SIMULINK.

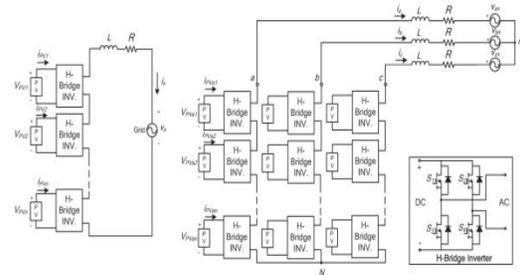


Fig. 3. Topology of the modular cascaded H-bridge multilevel inverter for grid-connected PV systems.

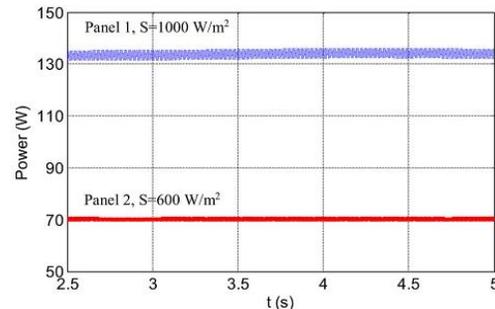


Fig. 4 Power extracted from two PV panels

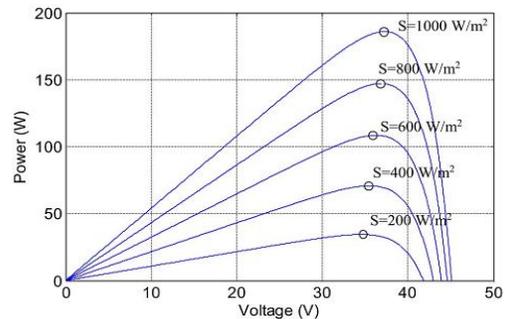


Fig. 5. P-V characteristic under the different irradiance

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

IV. CONTROL SCHEME

A. Distributed MPPT Control

Keeping in mind the end goal to dispose of the antagonistic impact of the befores and expand the productivity of the PV system, the PV modules need to work at various voltages to enhance the usage per PV module. The different dc links in the cascaded H-bridge multilevel inverter make free voltage control conceivable. 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.

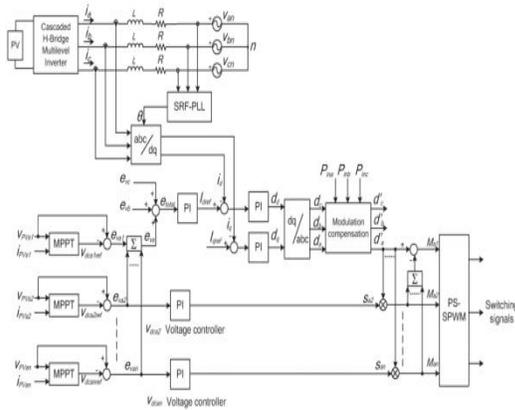


Fig. 6. Control scheme for three-phase modular cascaded H-bridge multilevel PV inverter.

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} . 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 [20], [21]. The synchronous reference frame phase-locked loop (PLL) has been used to find the phase angle of the grid voltage. 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. 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.

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. Many MPPT methods have been developed and implemented. The incremental conductance method has been used in this paper.

B. Modulation Compensation

To a three-phase modular cascaded H-bridge multilevel PV inverter a PV mismatch may cause more problems. 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.

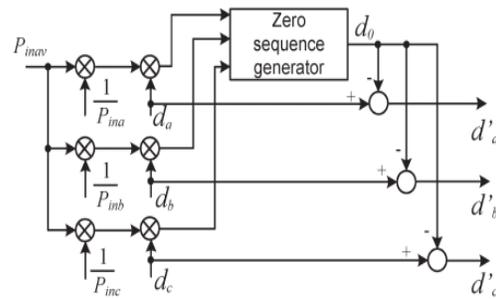


Fig. 7. Modulation compensation scheme.

First, the unbalanced power is weighted by ratio r_j , which is calculated as

$$r_j = \frac{P_{inav}}{P_{inj}} \quad (1)$$

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

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

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

$$d'_j = d_j - d_0 \quad (3)$$

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

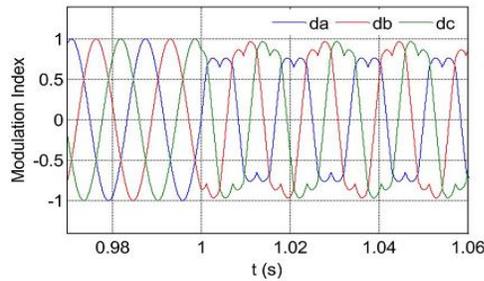
$$P_{ina} = 0.8 \quad P_{inb} = 1 \quad P_{inc} = 1 \quad (4)$$


Fig. 8. Modulation indices before and after modulation compensation.

It can be seen that, with the compensation, the updated modulation index is unbalanced proportional to the power, which means that the output voltage (v_j N) of the three-phase inverter is unbalanced, but this produces the desired balanced grid current.

Table I
System parameters

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

FUZZY LOGIC CONTROLLER

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.

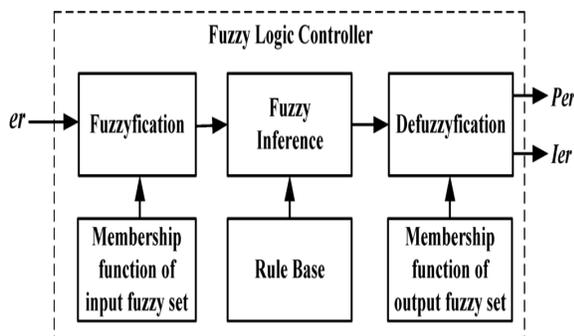


Fig.9.Fuzzy logic controller

The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as i. seven fuzzy sets for each input and output. ii. Triangular membership

functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mamdani's, 'min' operator. v. Defuzzification using the height method.

TABLE II: Fuzzy Rules

Change in error	Error						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

Fuzzification: Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The Partition of fuzzy subsets and the shape of membership $CE(k)$ $E(k)$ function adapt the shape up to appropriate system. The value of input error and change in error are normalized by an input scaling factor.

In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular $E(k)$ input there is only one dominant fuzzy subset. The input error for the FLC is given as

$$E(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}} \quad (5)$$

$$CE(k) = E(k) - E(k-1) \quad (6)$$

Inference Method: Several composition methods such as Max-Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. Table 2 shows rule base of the FLC.

Defuzzification: As a plant usually requires a non-fuzzy value of control, a defuzzification stage is needed. To compute the output of the FLC, „height“ method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. In order to control these parameters, they are sensed and compared with the reference values. To achieve this, the membership functions of FC are: error, change in error and output

The set of FC rules are derived from

$$u = -[\alpha E + (1-\alpha) * C] \quad (7)$$

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable. A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible. One the other hand, small value of the error E indicates that the system is near to balanced state.

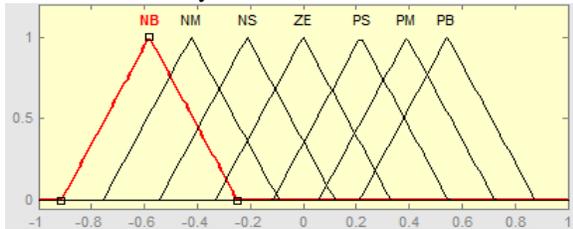


Fig 10 input error membership functions

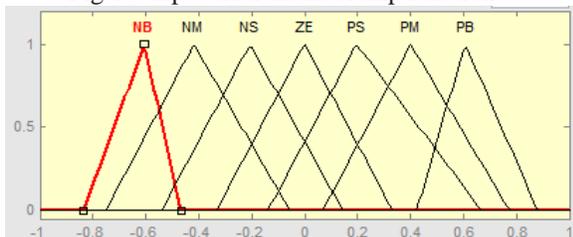


Fig 11 change as error membership functions

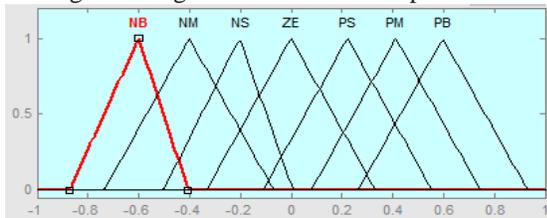


Fig 12 Output variable membership functions

V. S IMULATION RESULTS

Simulation tests are carried out to validate the proposed ideas. The inverter is connected to the grid through a transformer, and the phase voltage of the secondary side is 60 Vrms.

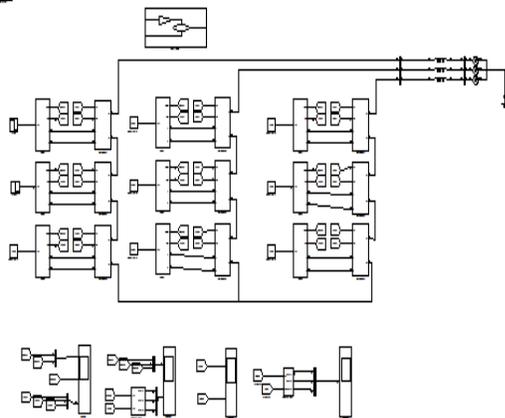


Fig 13 Block diagram of simulation

A. Simulation Results

To verify the proposed control scheme, the three-phase grid connected PV inverter is simulated in two different conditions.

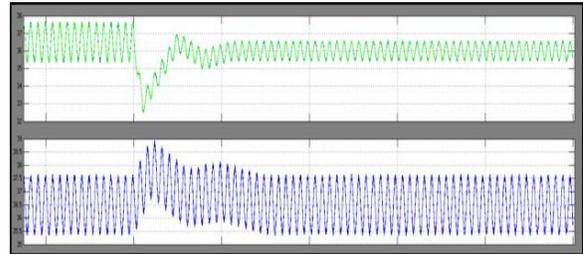


Fig. 14. DC-link voltages of phase a with distributed MPPT (T = 25 ° C). (a) DC-link voltage of modules 1 and 2. (b) DC-link voltage of module 3.

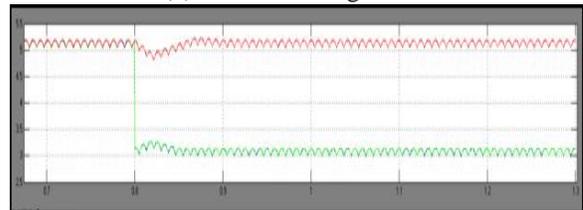


Fig. 15. PV currents of phase a with distributed MPPT (T = 25 ° C)

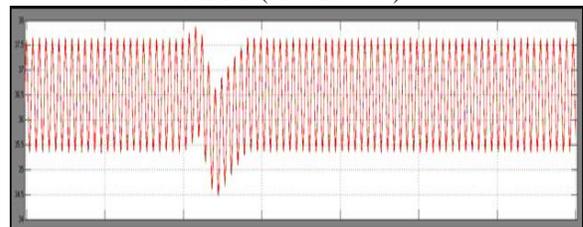


Fig. 16. DC-link voltages of phase b with distributed MPPT (T = 25 ° C).

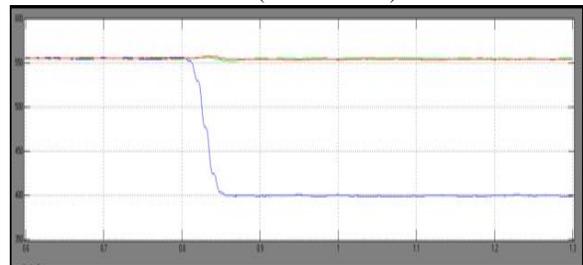


Fig. 17. Power extracted from PV panels with distributed MPPT.

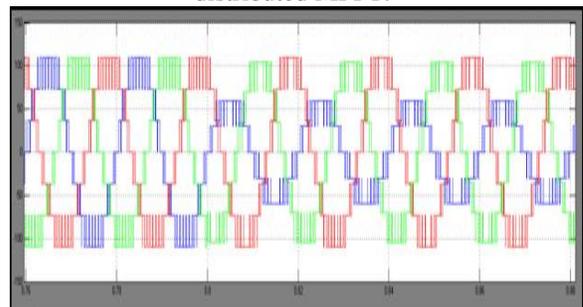


Fig. 18. Three-phase inverter output voltage waveforms with modulation compensation.

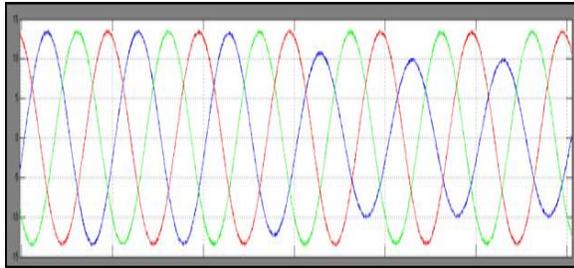
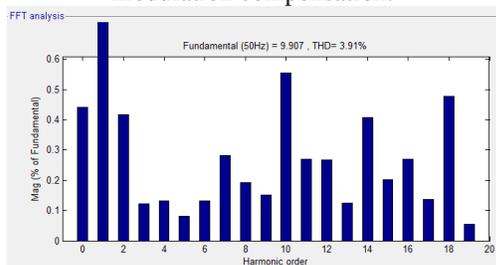
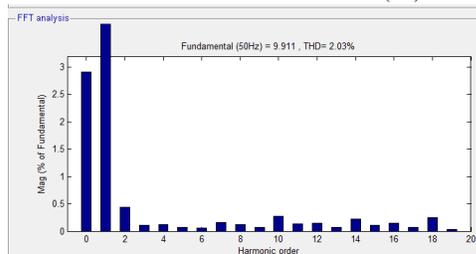


Fig. 19. Three-phase grid current waveforms with modulation compensation.



THD values of Grid Current (PI)



THD values of Grid Current (FUZZY)

VI. CONCLUSION

In this paper, a modular cascaded H-bridge multilevel inverter for grid-connected PV applications has been displayed. The multilevel inverter topology will enhance the use of connected PV modules if the voltages of the different dc connections are controlled autonomously. Thus, a distributed MPPT control scheme for both single- and three-phase PV systems has been applied to increase the overall efficiency of PV systems. For the three-phase grid-connected PV system, PV mismatches may introduce unbalanced supplied power, resulting in unbalanced injected grid current. 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 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. With the proposed control scheme, each PV module can be worked at its own particular MPP to augment the solar energy extraction, and the three-phase system current is adjusted even with the unequal supplied solar based power. And finally by observing the THD values this system gives better performance when fuzzy controller was used.

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