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Design and Implementation of Control Strategy for the Grid Integration of Cascaded H-Bridge Multilevel PV Inverter with Individual MPPT

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ABSTRACT: This paper presents a control strategy for the grid integration of cascaded H-bridge seven level PV (Photo-Voltaic) inverter with individual MPPT (Maximum Power Point Tracking). In proposed system, each H-bridge of seven level inverter contains one PV panel or PV string. This seven level inverter integrates the PV systems to the grid through inductor filters. The main novelty of the proposed control strategy is that it operates the individual PV panels at individual maximum power points. One more novelty is that even the power feeding from the seven level inverter in each phase is different it makes the currents balance in each phase of the grid. Proposed control strategy uses zero sequence components based modulation compensation scheme to achieve this. Incremental conductance (INC) based MPPT is used for PV systems. Fuzzy logic controller is used to maintain DC link voltages at reference MPPT voltages. MATLAB/Simulink results are also presented for the verification of individual MPPT capability and grid currents balance.

KEYWORDS: Photo-Voltaic-Bridge, Maximum Power Point Tracking, Modulation Scheme.

I.INTRODUCTION

Rising energy demand is the main reason for intensifying the implementation of renewable energy resources based systems. These renewable energy sources have experienced rapid technological development, which makes them at affordable prices. This advantage allows the energy security of countries to reduce imports of fossil fuels and to improve the living standards by avoiding the emission of greenhouse gases [1-3]. Eco friendliness and sustainability make the choice of renewable power generation. Out of all renewable energy resources solar PV has attained an increased interest owing to total system cost effectiveness and well proven technology [4-5]. These are inexhaustible and free from greenhouse emissions. These renewable systems need to interface to the grid because of the advantages of grid connected operation [6].

Multilevel power inverter structures are very advantageous for high power and medium voltage situations such as grid integration of photovoltaic and wind systems, which can be easily interfaced to a multilevel inverter system for a high power application [7-8].Five different inverter families related to the different configurations of the PV system are available in literature [9-10] as shown in Fig. 1 namely 1.(a) Central inverters, 1.(b) string inverters, 1.(c) multistring inverters, 1.(d) ac module inverters, 1.(e) Cascaded converters, 1.(f) Cascaded Inverters. 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 favour 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 modules. 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. This approach combines aspects of string inverters and ac-module inverters and offers the advantages of individual module maximum power point (MPP) tracking (MPPT), but it is less costly and more efficient than ac-module inverters. However, there are two power conversion stages in this configuration. Another cascaded inverter is shown in Fig. 1 (f), where each PV panel is connected to its own dc/ac inverter, and those inverters are then placed in series to reach a high-voltage level. 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.

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.

Different types of equivalent circuits are available for analysing PV system performance [11-12]. PV system is an inverter based generation system since voltage obtained from PV is DC. Two configurations are available for PV systems. First one is single stage system, in this configuration PV system contains only one multilevel inverter. In single stage grid connected system, multilevel inverter controls the amount of real power, reactive power injection along with MPPT from PV system. Second one is two stage PV system, in this configuration PV system contains one multilevel inverter, one DC to DC inverter. DC to DC inverter extracts maximum power from PV system. Multilevel inverter controls the amount of real power, reactive power injection in grid connected system. The operation of the single stage and two stage are different. There are many algorithms for tracking maximum power in the solar PV system [13-14].

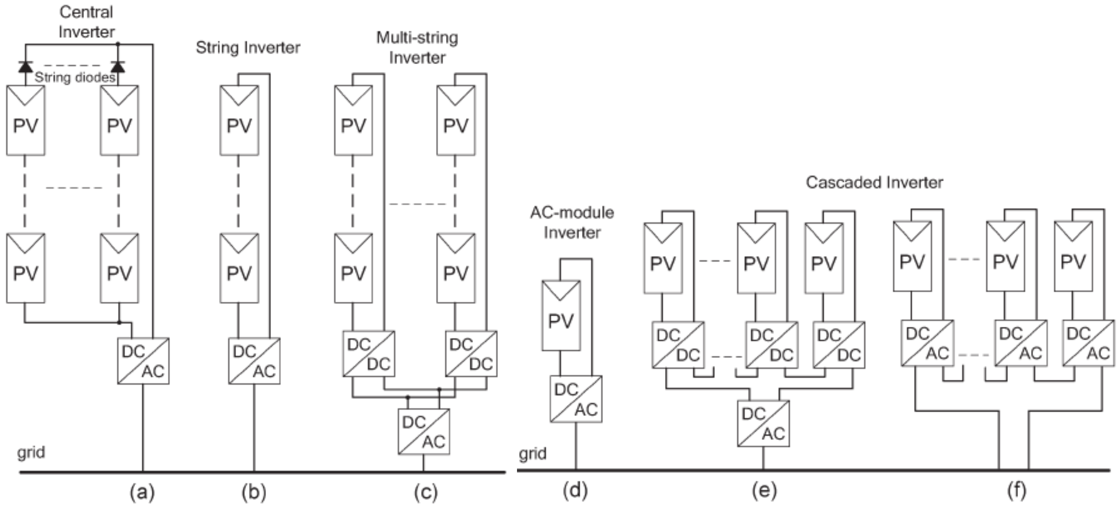

Fig. 1Possible PV system configurations: (a) Central inverter. (b) String inverter. (c) Multi-string inverter. (d) AC-module inverter. (e) Cascaded dc/dc converter. (f) Cascaded dc/ac inverter

II.SYSTEM CONFIGURATION

Configuration of proposed modular cascaded H-bridge seven level inverter for three-phase grid-connected PV systems is shown in Fig. 2. Each phase consists of threeH-bridge converters connected in series, and the DC link of each H-bridge is fed by an individual PVpanel. The cascaded seven levelinverter is connected to the grid through L filters, which areused to reduce the switching harmonics in the current.

By different combinations of the four switches in eachH-bridge module, three output voltage levels can be generated: $-V_{dc}$, 0, or $+V_{dc}$. A cascaded seven level inverter with threeinputsources will provide seven $(2n + 1)$ levels to synthesize the ac outputwaveform. This seven $(2n + 1)$level voltage waveform enables thereduction of harmonics in the synthesized current, reducingthe size of the needed output filters. Seven level inverter alsohave other advantages such as reduced voltage stresses on the semiconductor switches and having higher efficiency whencompared to other converter topologies.

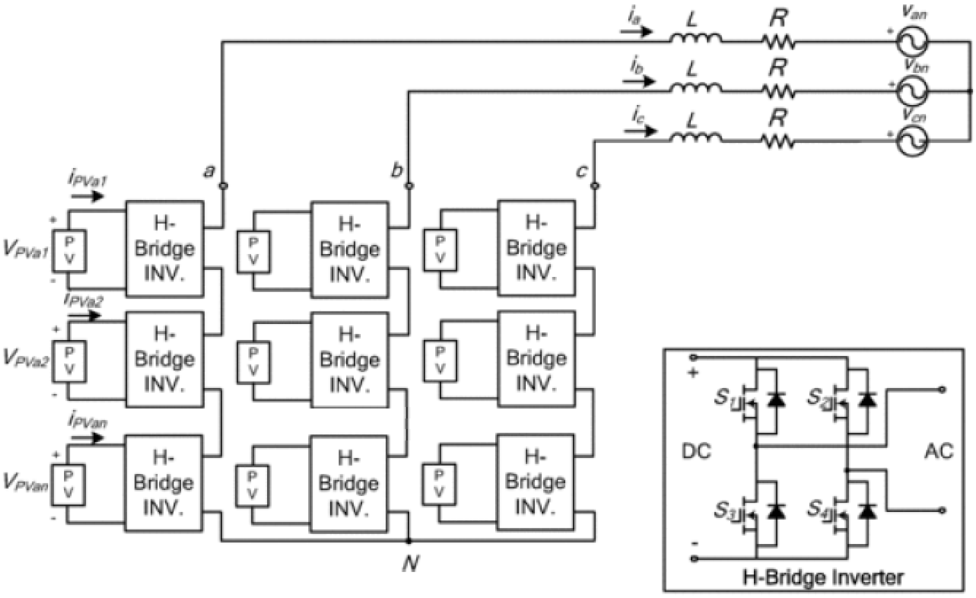

Fig. 2 Grid integrated modular cascaded H-bridge seven level PV inverter

III.CONTROL STRATEGY

This section explains the PV panel’s mismatches and proposed control strategy. Proposed control strategy is shown in Fig. 3. In this controller, individual MPPT control is used. It is helpful to extract maximum power from every panel. Zero sequence component based modulation compensation scheme is used to compensate the problems of PV panel mismatches. Fuzzy logic controller is used to maintain DC link voltages at their reference values. Synchronous reference frame PLL is used for the synchronization of seven level PV inverter system with the grid. Level shift PD PWM is used to generate switching logic for 12 MOSFET’s of seven level cascaded H bridge multilevel inverter.

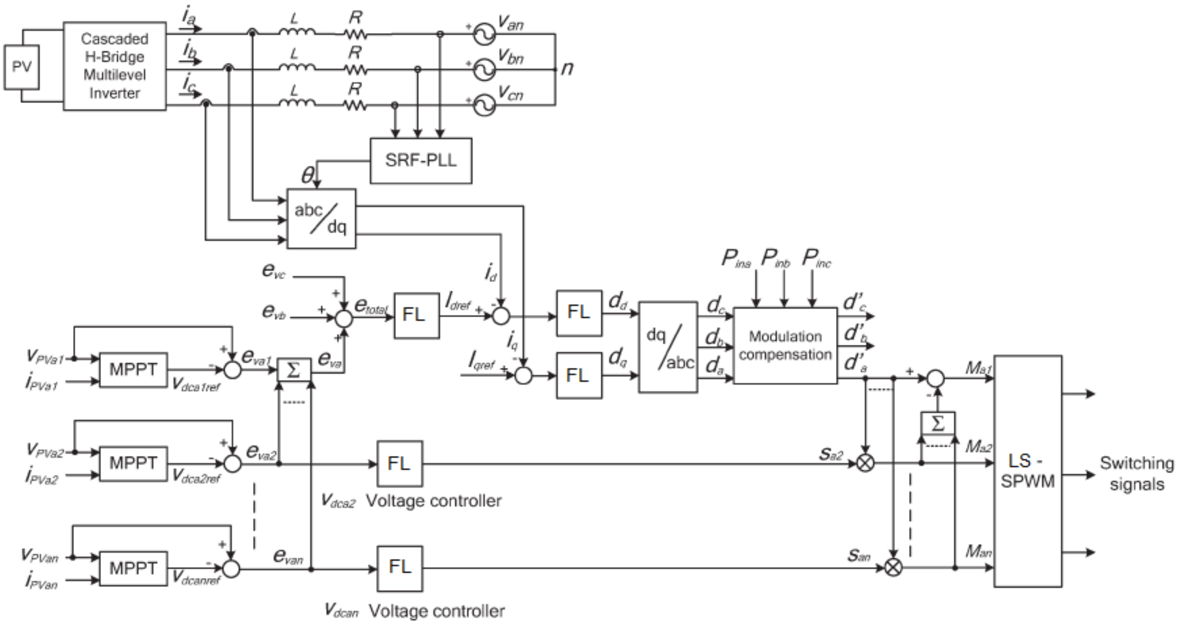

Fig. 3 Proposed control strategy

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A. PV PANEL MISMATCHES

PV mismatch is an important issue in the PV system. Due to the unequal received irradiance, different temperature and aging of the PV panels, the MPP of eachPV module may be different. If each PV module is not controlled individually, the efficiency of the overall PV system will be decreased. In a three phase grid interfaced PV system, PV mismatches causes more issues. Besides decreasing the overall efficiency, PV mismatches also introduces the unbalanced power per each phase supplied to the three-phase grid-interfaced system. If there are PV mismatches between 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 unbalance is calculated by taking the maximum deviation from the average current and dividing it by the average current. To solve the PV mismatch issues, a control scheme with individual MPPT and modulation compensation is proposed, as shown in Fig. 3.

B. PV MPPT CONTROLLER

Incremental conductance (INC) based MPPT controller is used for tracking maximum power point (MPP) [13].

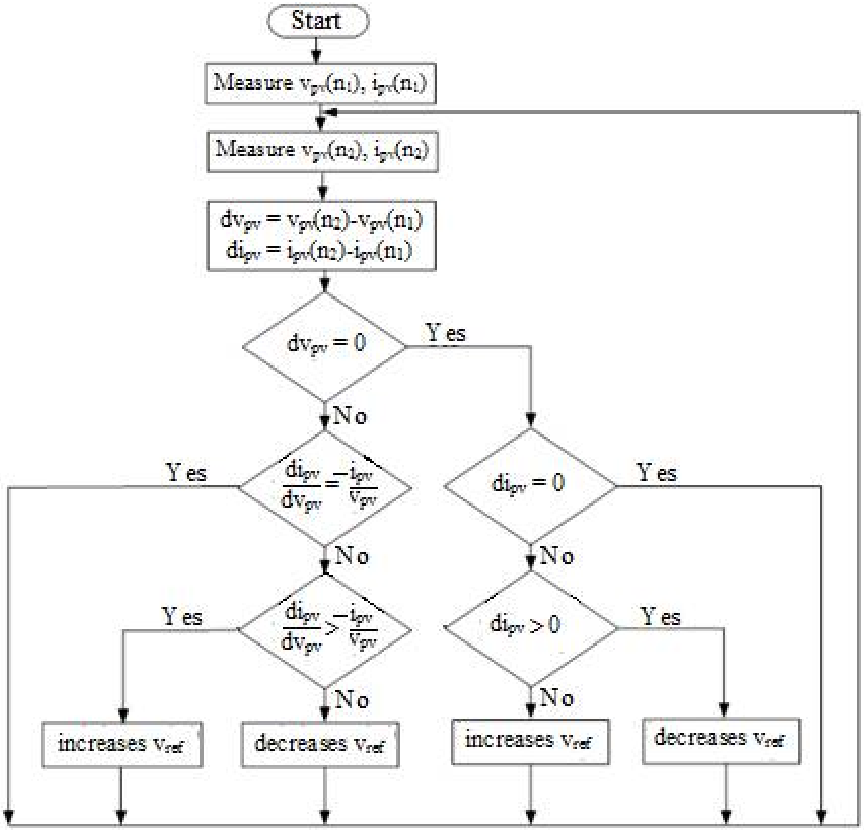

Fig. 4 Flow chart of Incremental Conductance based MPPT algorithm

This INC controller tracks the MPP even under rapidly changing weather conditions and easy to implement also. The derivative of power with respect to voltage is zero at MPP in P-V characteristics of solar panel, it can be stated as follows,

$$\frac{dP}{dV}=0 \quad \text{for} \quad V=V_{mp} \text{ (at MPP)}$$

$$\frac{dP}{dV} > 0 \quad \text{for} \quad V<V_{mp} \text{(left of MPP)} \qquad (1)$$
$$\frac{dP}{dV} < 0 \quad \text{for} \quad V>V_{mp} \text{ (right of MPP)}$$

At the MPPT point of PV curve, the derivative of the power with respect to the voltage equals to zero which means that the sum of the instantaneous conductance (I_{pv}/V_{pv}) and incremental conductance (dI_{pv}/dV_{pv}) equals zero

$$\frac{dp}{dv}=0 \;=>\; i\frac{dv}{dv}+v\frac{di}{dv}=0 \;=>\; \frac{di}{dv}=-\frac{i}{v} \qquad (2)$$

Above Eq. decides whether to increase or decrease the V. Fig. 4 shows the flowchart of the INC based MPPT controller

C. INVERTER CONTROLLER

In each H-bridgemodule, an MPPT controller (INC) is added to generate the DC-link voltage reference. Each DC-link voltage is comparedto the corresponding voltage reference, and the sum of all the errors is controlled through a total voltage controller that determines the current reference I_{dref}. The reactive current referenceI_{qref}can be set to zero. The Synchronous Reference Frame Phase-locked Loop (SRF-PLL (or) dq PLL) has been used to findthe phase angle of the grid voltage. As the classic control scheme in three-phase systems, the grid currents in *abc* coordinates are converted to *dq* coordinates, and regulated through fuzzy controllers to generate the modulation index in *dq* coordinates, which is then converted back to three-phase.

To make the connected PV string of each H-bridge module operate at its own MPP, take phase '*a* 'as an example; the voltages $V_{dca2}$to $V_{dca3}$are controlled individually throughtwoloops. Each voltage controller gives the modulation index proportion of one H-bridge module in phase *a*. Aftermultiplied by the modulation index of phase *a*, two modulation indices can be obtained. Also, the modulationindex for the first H-bridge can be obtained by subtraction. The control schemes in phase *b* and *c* are almost the same.The only difference is that all the DC-link voltages are regulated through fuzzy controllers, and three modulation index proportions are obtained for each phase. Level-shifted Phase Disposition SPWM (LS-PD-SPWM) 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 nine modules whose modulation index is obtained by subtraction. The reason is that nine voltage loops are necessary to manage different voltage levels on nineH-bridges, and one is the total voltage loop, which gives the current reference. Soonly eight modulation indices can be determined by the last eight voltage loops, and one modulation index has to be obtained by subtractions.

D. MODULATION COMPENSATION

With the individual MPPT control in each H-bridge, the input 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. The idea can be explained by the followingequations,

$$v_{aN} = v_{an} + L\frac{di_a}{dt} + Ri_a - v_{Nn} \qquad (3)$$
$$v_{bN} = v_{bn} + L\frac{di_b}{dt} + Ri_b - v_{Nn} \qquad (4)$$
$$v_{cN} = v_{cn} + L\frac{di_c}{dt} + Ri_c - v_{Nn} \qquad (5)$$

where $v_{iN}(i = a, b, c)$ is the output phase voltage of the three-phase inverter as shown in Fig. 2,$v_{in}$is the phase voltage of the grid, L and R are the decoupling inductance and its resistance respectively. By injecting the zero sequence voltage v_{Nn}, the output phase voltage of the inverter will be unbalanced. If the unbalanced voltage is proportional to the unbalanced power, the grid current will be balanced.

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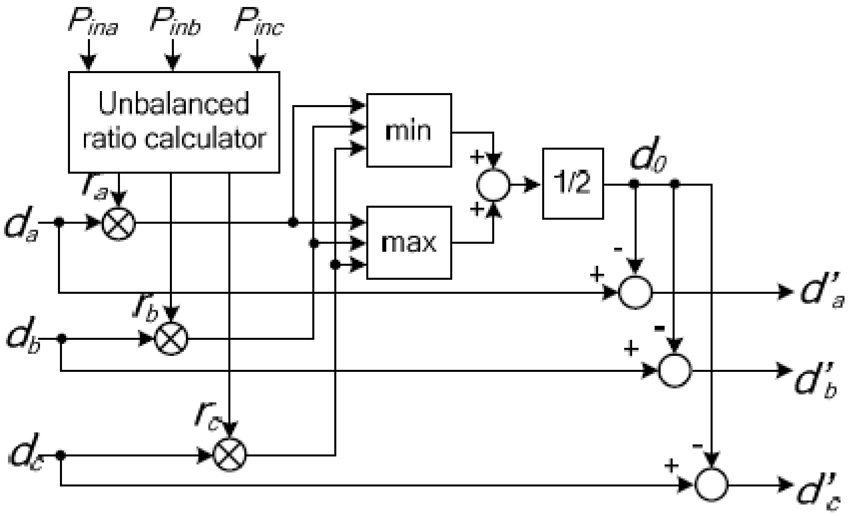

Fig. 5 Modulation compensation scheme

Thus, the modulation compensation scheme is applied and shown in Fig. 5. 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_i, which is calculated as

$$r_i = \frac{P_{inav}}{P_{ini}} \qquad (6)$$

Where$P_{ini}$is the input power of phase *i* ($i = a, b, c$), and$P_{inav}$is the average input power.
Then, the injected zero sequence modulation index canbe generated as,

$$d_0 = \frac{1}{2}[\min(r_a . d_a, r_b . d_b, r_c . d_c) + \max(r_a . d_a, r_b . d_b, r_c . d_c)] \qquad (7)$$

where $d_i$is the modulation index of phase *i*, and determinedby the current loop controller.
The modulation index of each phase is updated by

$$d_i' = d_i - d_0 \qquad (8)$$

Only simple calculations are needed in the scheme,which will not increase the complexity of the controlsystem. With the compensation, the updated modulation index is unbalanced proportional to the power, which meansthe phase voltage v_{iN} of the three-phase inverter is unbalanced proportional to the power and finally results in abalanced grid current.

IV.SIMULATION RESULTS AND DISCUSSION

The complete grid interfaced seven level cascaded H-bridge PV inverter along with controller is modelled and implemented on MATLAB/Simulink platform for the verification of individual MPPT capability and grid currents balance. The power circuit. Parameter values considered for proposed system are shown in below table.

Parameter	Value
DC-link capacitor	3600 µF
Connection Inductor L	2.5 mH
Grid Resistor R	0.1 ohm
Grid rated Phase Voltage	60 Vrms
Switching Frequency	1.5 kHz

Table: System parameters

To verify the proposed control scheme, the three-phase grid connected PV inverter is simulated in two different conditions. First, all PV panels are operated under the same irradiance $G = 1000$ W/m^2 and temperature $T = 25$ °C. At *t*

= 0.8 s, the solar irradiance on the first and second panels of phase *a* decreases to 600 W/m^2, and that for the other panels stays the same. The DC-link voltages of phase *a* are shown in Fig. 6. At the beginning, all PV panels are operated at an MPP voltage of 36.4 V. As the irradiance changes, the first and second DC link voltages decrease and track the new MPP voltage of 36 V, while the third panel is still operated at 36.4 V

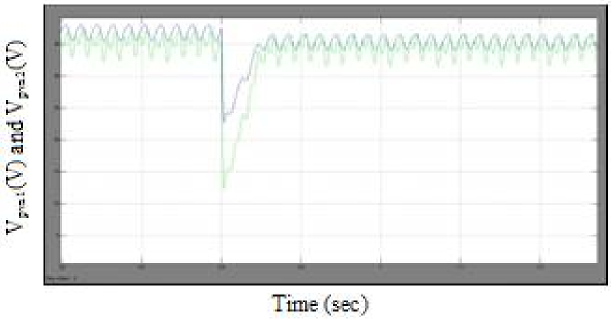

Fig. 6.(a)

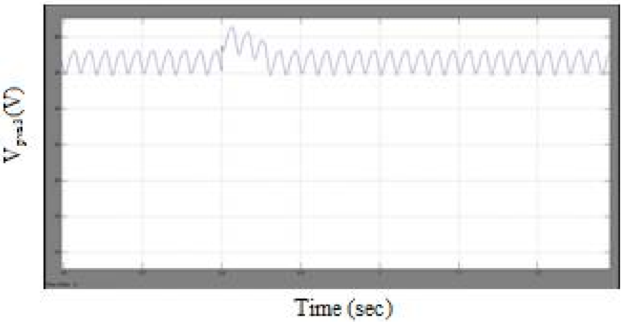

Fig. 6.(b)

Fig. 6. 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.

. The PV current waveforms of phase *a* are shown in Fig. 7. After *t* = 0.8 s, the currents of the first and second PV panels are much smaller due to the low irradiance, and the lower ripple of the DC-link voltage can be found in Fig. 6(a).

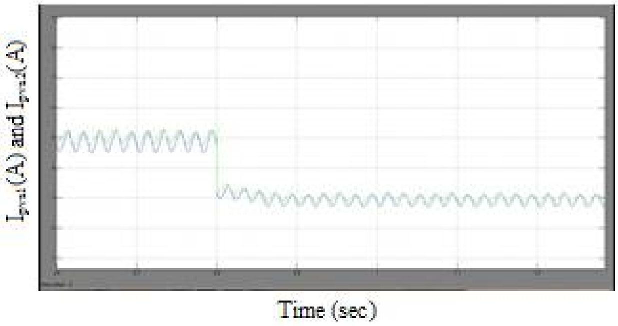

Fig. 7.(a)

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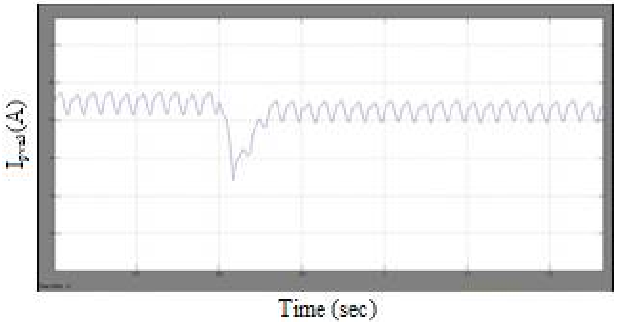

Fig. 7.(b)

Fig. 7. PV currents of phase *a* with distributed MPPT (T = 25 ◦C). (a) PV currents of modules 1 and 2. (b) PV current of module 3.

All phase-*b* panels track the MPP voltage of 36.4 V, they are not influenced by other phases. With the distributed MPPT control, the dc-link voltage of each H-bridge can be controlled independently. In other words, the connected PV panel of each H-bridge can be operated at its own MPP voltage and will not be influenced by the panels connected to other H-bridges. Thus, more solar energy can be extracted, and the efficiency of the overall PV system will be increased.

Fig. 8(a) shows the power extracted from each phase. At the beginning, all panels are operated under irradiance S = 1000 W/m2 and every phase is generating a maximum power of 555 W. After t = 0.8 s, the power harvested from phase *a* decreases to 400 W, and those from the other two phases stay the same. Obviously, the power supplied to the three-phase grid-connected inverter is unbalanced. However, by applying the modulation compensation scheme, the power injected to the grid is still balanced, as shown in Fig. 8(b). In addition, by comparing the total power extracted from the PV panels with the total power injected to the grid, it can be seen that there is no extra power loss caused by the modulation compensation scheme.

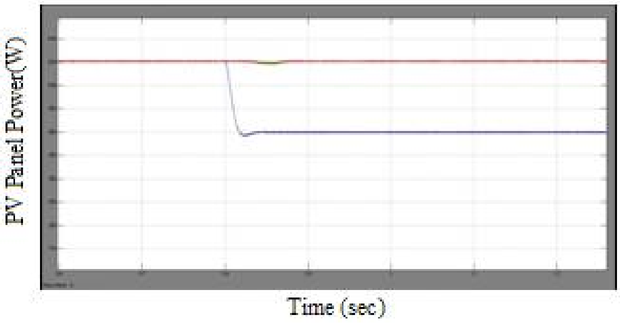

Fig. 8.(a)

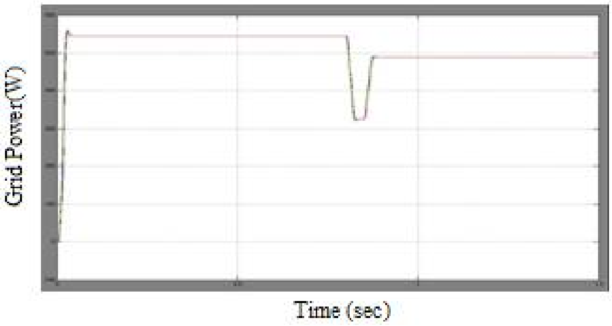

Fig. 8.(b)

Fig. 8(a) Power extracted from PV panels with distributed MPPT, (b) Power injected to the grid with modulation compensation.

Fig. 9 shows the output voltages (v_{jN}) of the three-phase inverter. Due to the injected zero sequence component, they are unbalanced after t = 0.8 s, which help to balance the grid current shown in Fig. 10.

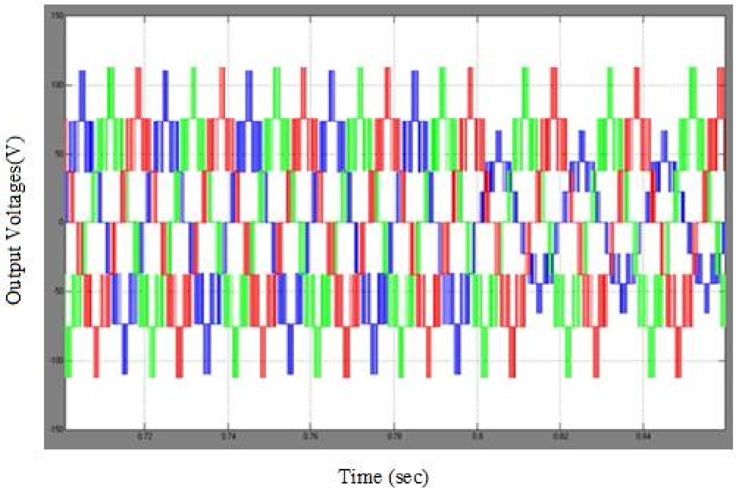

Fig. 9. Three-phase inverter output voltage waveforms with modulation compensation.

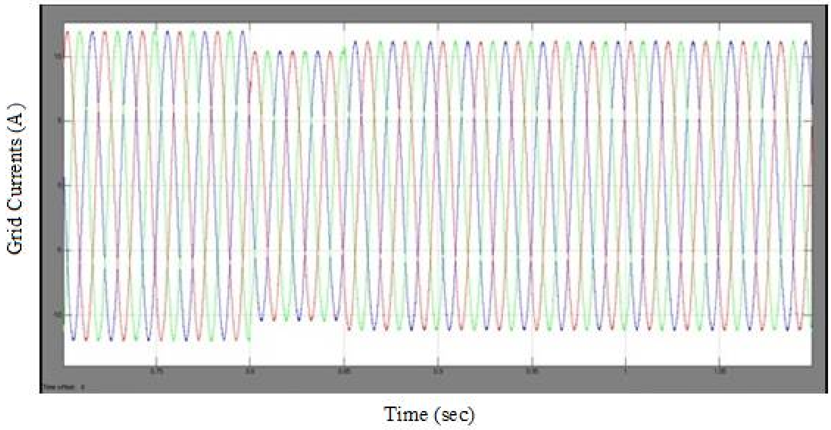

Fig. 10. Three-phase grid current waveforms with modulation compensation

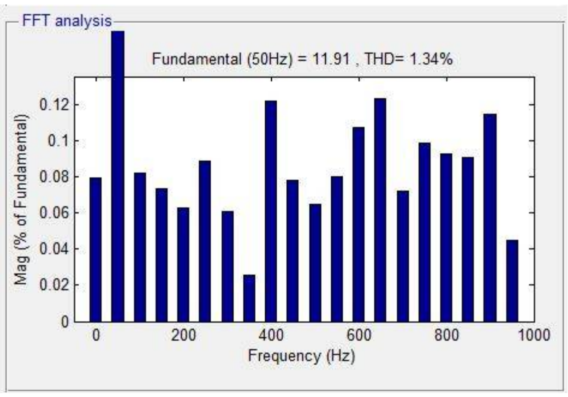

Fig. 11.(a)

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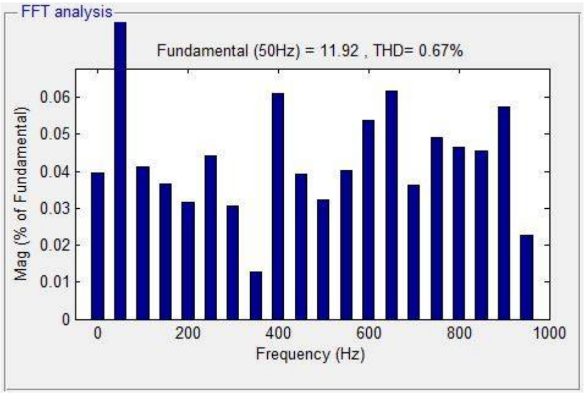

Fig. 11.(b)

Fig. 11 Total harmonic distortion of grid current when (a) PI controller is used, (b) fuzzy controller is used.

Total harmonic distortion of grid current is shown in Figs. 11 (a)-(b) when PI controller and fuzzy controller is used respectively. From these two Figs. One can observe that the THD of grid current is low when fuzzy controller is used. From above simulation results, one can observe that Individual MPPT control, even the PV power feeding from the inverter is unbalanced, the grid currents are balanced and THD is also low because of fuzzy based controller.

V. CONCLUSION

A control strategy for the grid integration of cascaded H-bridge seven level PV inverter with individual MPPT has been presented in this paper. INC MPPT controller has been used for extracting maximum power from PV panels. The individual MPPT capability of proposed control has been shown. Fuzzy logic controller has been used to maintain DC link voltages at their reference MPPT voltages. Detailed explanation of zero sequence components based modulation compensation scheme has been given. The capability of proposed controller to make the grid currents balance at different irradiances of PV panels has also been shown. MATLAB/Simulink results have also been presented for the verification of individual MPPT capability and grid currents balance. The THD (Total Harmonic Distortion) of grid currents have also well below under IEEE 519 standard.

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