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A Nine Level Modular cascaded H-Bridge Multilevel PV Inverter for Grid Connected Applications

[1]P.Jyothi, [2]G.Tejaswi
[1]M.Tech Scholar, [2]Assistant Professor
Department of EEE
Sree Vahini Institute of Science and Technology, Tiruvuru, Andhra Pradesh, India.

***Abstract*—In this paper a nine level modular cascaded H-Bridge Multilevel PV inverter with Distributed maximum power point tracking (DMPPT) for the applications of grid systems. Improvement of efficiency and flexibility of PV systems by the modular cascaded multilevel topology. Distributed maximum power point tracking control scheme is applied to the independent control of each dc-link voltage of both single- and three-phase multilevel inverters. For three-phase grid-connected applications, PV mismatches may introduce unbalanced supplied power, leading to unbalanced grid current. To solve this issue, a control scheme with modulation compensation is also proposed. This paper presents a nine level inverter with the proposed control scheme. This proposed concept simulated in MATLAB/SIMULINK and Simulation results are explained in this paper by each H-bridge module is connected to the solar panel.**

***Index Terms*— Distributed maximum power point tracking (DMPPT), cascaded multilevel inverter, and unbalanced grid current.**

I. INTRODUCTION

A renewable energy application such as photovoltaic (PV) system has been widely used for a few decades since PV energy is free, abundant and distributed throughout the earth. The focus of the Engineers is to make use of abundantly available PV energy and so to design and control an inverter suitable for photo voltaic applications. Solar-electric-energy demand has grown consistently by 20%–25% per annum over the past 20 years [1], and the growth is mostly in grid-connected applications. With the extraordinary market growth in grid-connected photovoltaic (PV) systems, there are increasing interests in grid-connected PV configurations.

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 [2]–[7]. In the conventional PV array systems, the other converter as a DC-DC boost chopper is utilized to increase output DC voltage of the PV. 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 [8]–[10]. There are two types of cascaded inverters. Fig. 1 shows a cascaded dc/dc converter connection of PV modules [11], [12].
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, 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 [13]–[15]. This cascaded inverter would maintain the benefits of “one converter per panel,” such as better utilization per PV module, the 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. 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. 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. A three phase nine level inverter connected to PV system simulated in MATLAB/Simulink with proposed control technique.

II. MODULAR CASCADED H-BRIDGE MULTILEVEL INVERTER

To show the necessity of individual MPPT control, a nine-level H-bridge three-phase inverter is simulated in MATLAB/SIMULINK. 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. Consider an operating condition that each panel has a different irradiation from the sun; in R-phase panel1, panel2, panel3 have different irradiation from the sun and panel4 has perfect sun irradiation.

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.

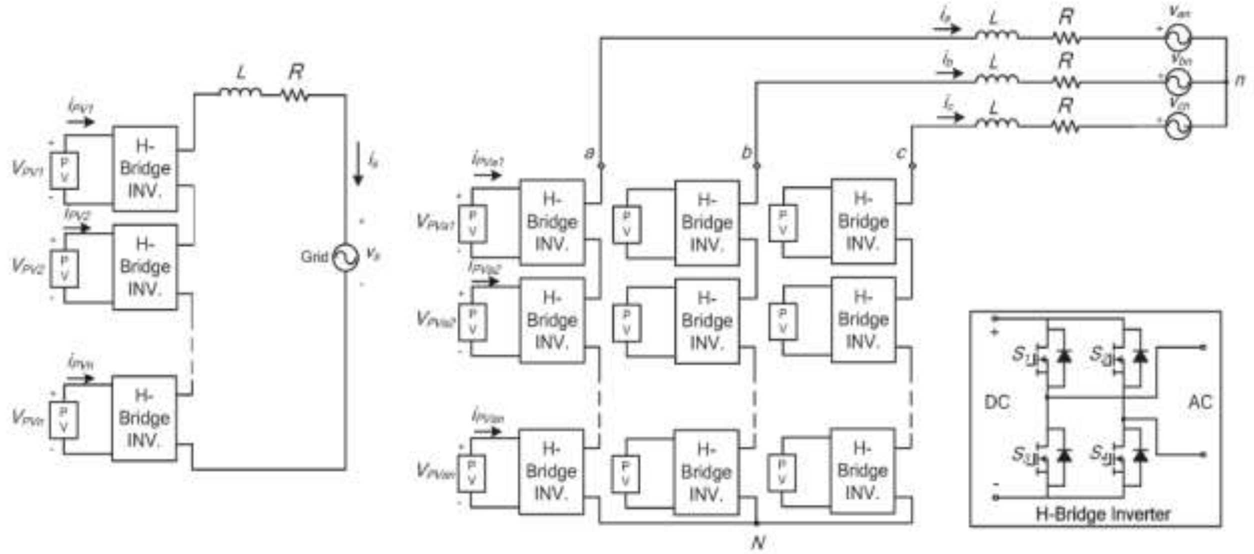


Fig.1. The topology of the modular cascaded H-bridge multilevel inverter for grid-connected PV systems.

III. CONTROL SCHEME

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 in [9] is updated for this application.

The distributed MPPT control of the three-phase cascaded H-bridge inverter is shown in Fig. 2. 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 [15]. The synchronous reference frame phase-locked loop (PLL) has been used to find the phase angle of the grid voltage [12]. As the classic control scheme in three-phase systems, the grid currents in *abc* coordinates are converted to *dq* coordinates and regulated through proportional-integral (PI) controllers to generate the modulation index in the *dq* 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.

Modulation Compensation

The modulation compensation block, as shown in Fig. 3, 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 complexity of the controlsystem.

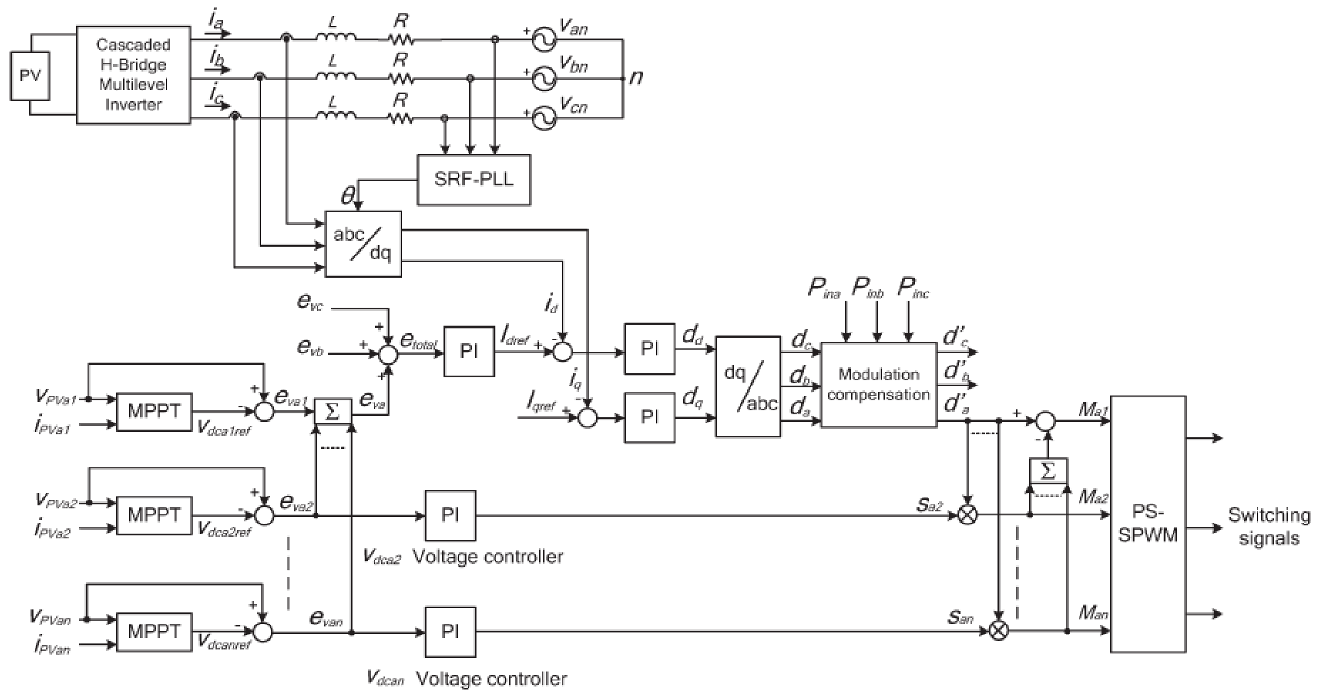


Fig.2. The control scheme of Proposed topology.

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. If the updated inverter output phase voltage is proportional to the unbalanced power, the current will be balanced. The key is how to update the modulation index of each phase without increasing the complexity of the control system.

$$r_j = \frac{P_{\text{inav}}}{P_{\text{inj}}}$$

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

$$d'_j = d_j - d_0.$$

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

Table 1 System Parameters

S.No	***Parameters***	***Values***
1	Grid Resistance	0.1 ohm
2	Inductance	5m H
3	Switching Frequency	2K Hz
4	Grid per phase voltage	80 V
5	DC link Capacitor	3600 μF

IV. Simulation Results

To verify the proposed control scheme, the three-phase grid connected PV inverter is simulated the solar irradiance on the first, second, third and fourth panels of phase *a* decreases and that for the other panels stay the same. The dc-link voltages of phase *a* are shown in Fig. 5. At the beginning, all PV panels are operated at an MPP voltage of 36.4 V. As the irradiance changes, the first, second, third panels dc- link voltages decrease and track the new MPP voltage of 36 V, while the fourth panel is still operated at 36.4 V. The PV current waveforms of phase *a* are shown in Fig. 4. After $t = 0.8$ s, the currents of the first, second, third PV panels are much smaller due to the low irradiance, and the lower ripple of the dc-link voltage can be found. The dc-link voltages of phase *b* are shown in Fig. 6. All phase-*b* panels track the MPP voltage of 36.4 V, which shows that 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.

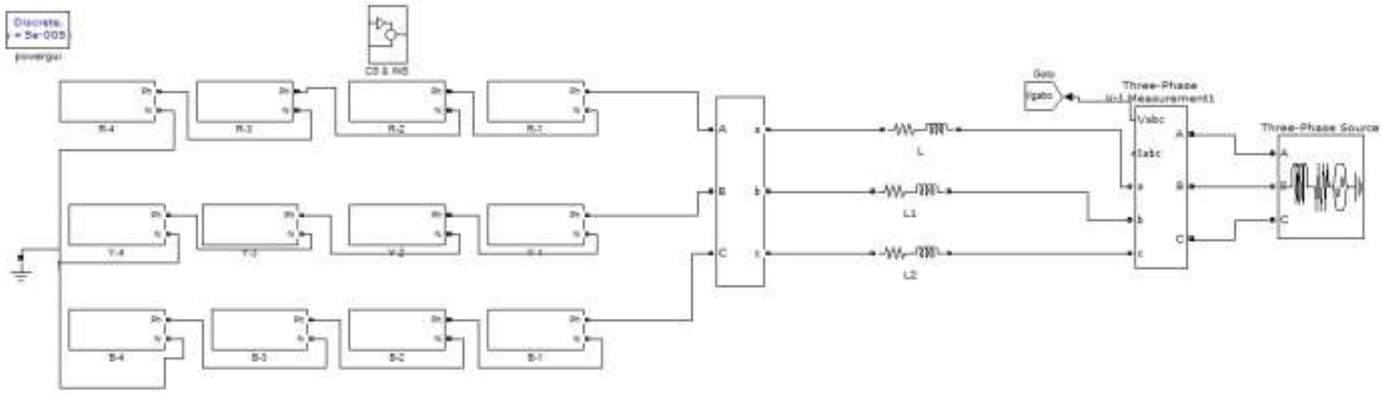


Fig.3. Simulation model of Grid connected a nine level modular cascaded H-Bridge Multilevel PV inverter.

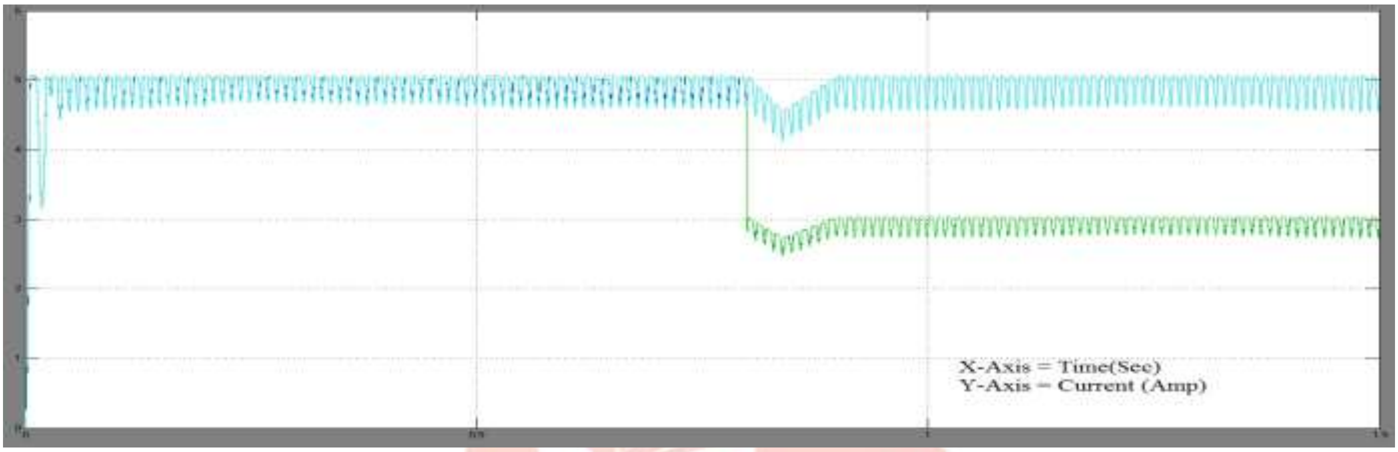


Fig.4. PV panel A Currents with Distributed MPPT.

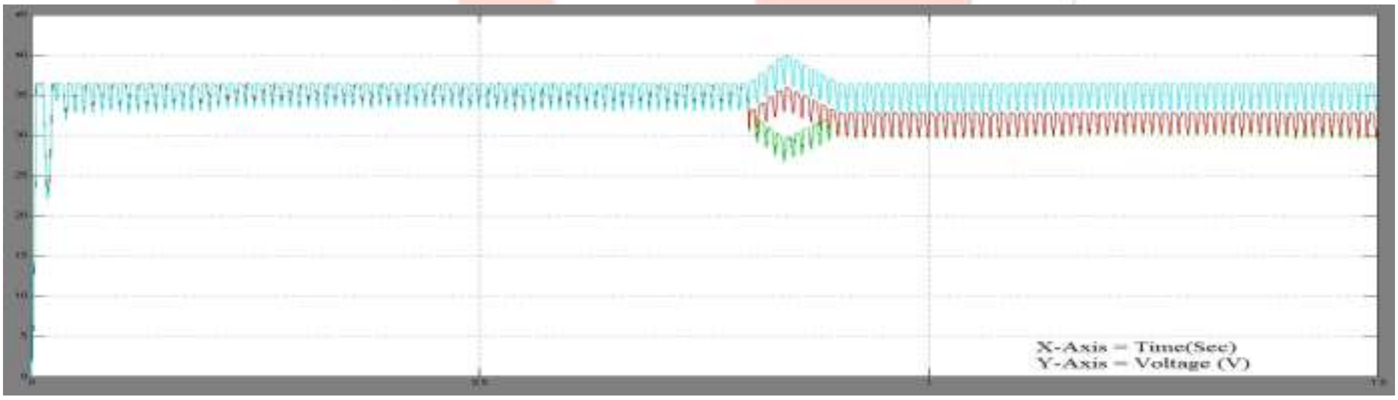


Fig.5. PV Panel A Voltages with Distributed MPPT .

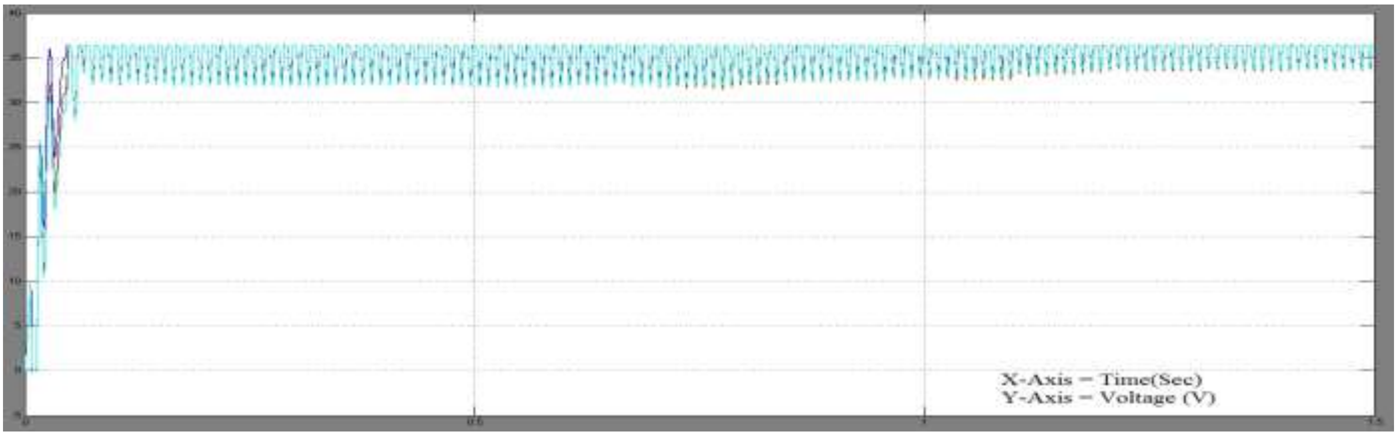


Fig.6. DC-Link Voltage of Phase ‘b’ with Distributed MPPT.

Fig. 7 shows the power extracted from each phase. At the beginning, all panels are operated under irradiance and every phase is generating a maximum power of 609 W. After t = 0.8 s, the power harvested from phase a decreases to 395 W, and those from the other two phases stay the same. Obviously, the power supplied to the three-phase grid-connected inverter is unbalanced.

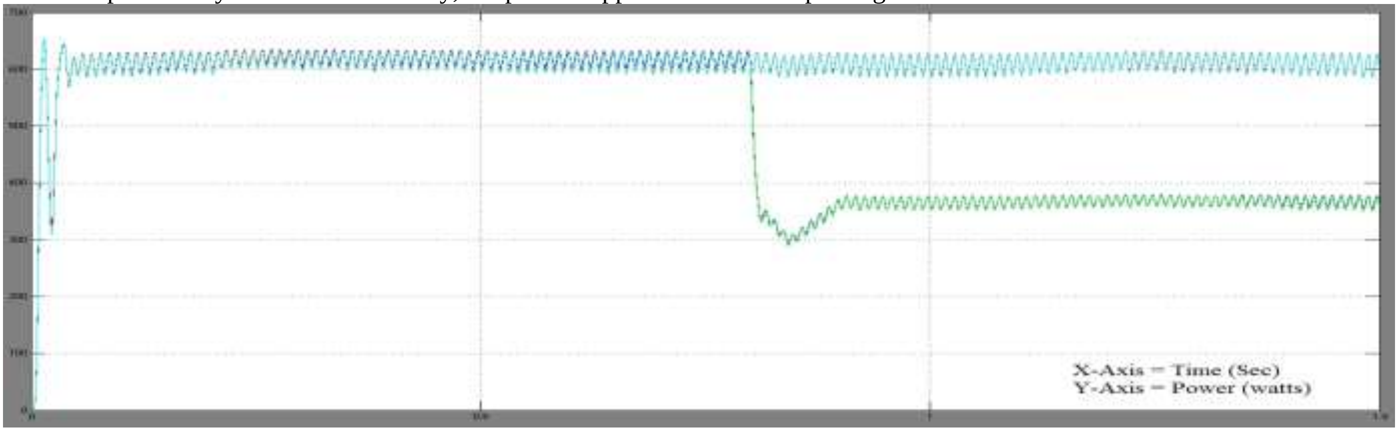


Fig.7. Power Extracted from PV panels with distribution MPPT.

Fig.8. Power Injected to frid with modulation compensation.

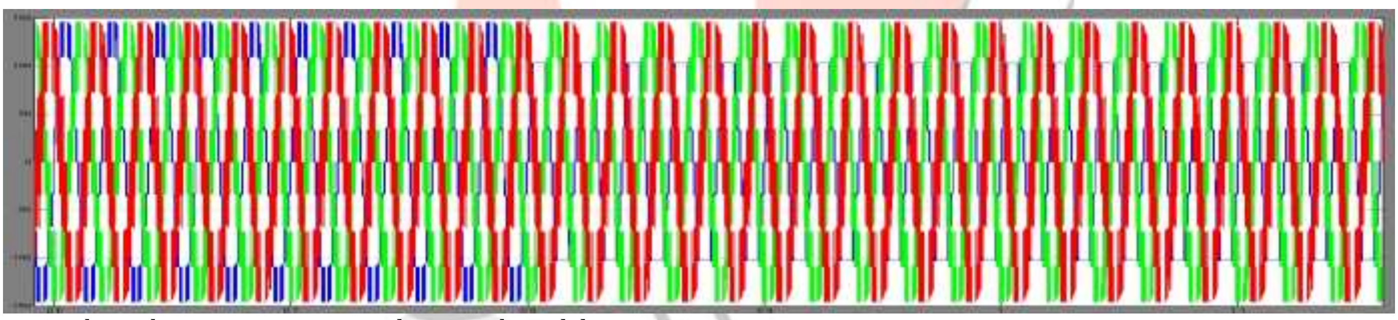


Fig.9. Three phase Inverter output voltages with modulation compensation.

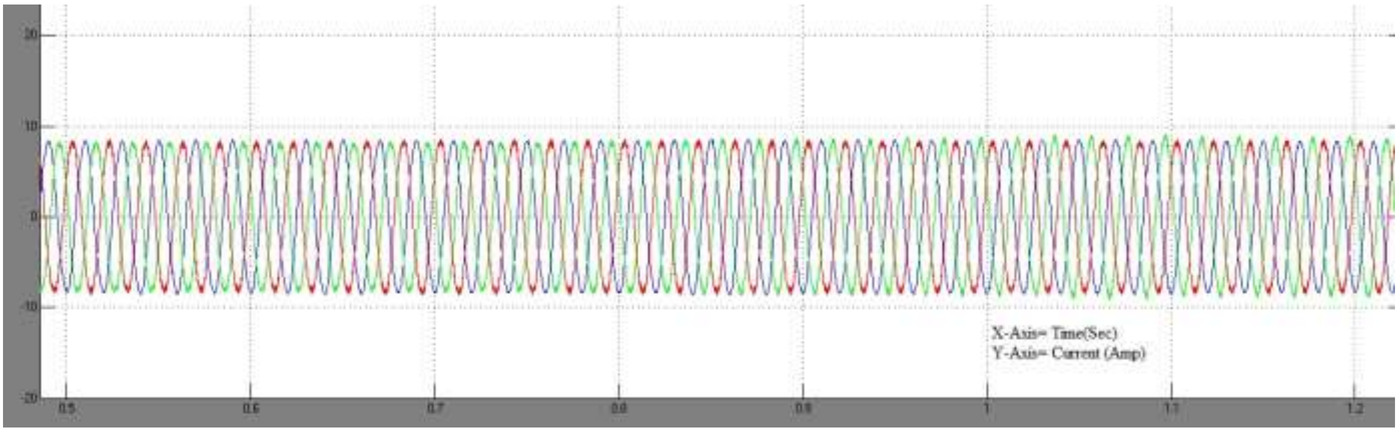
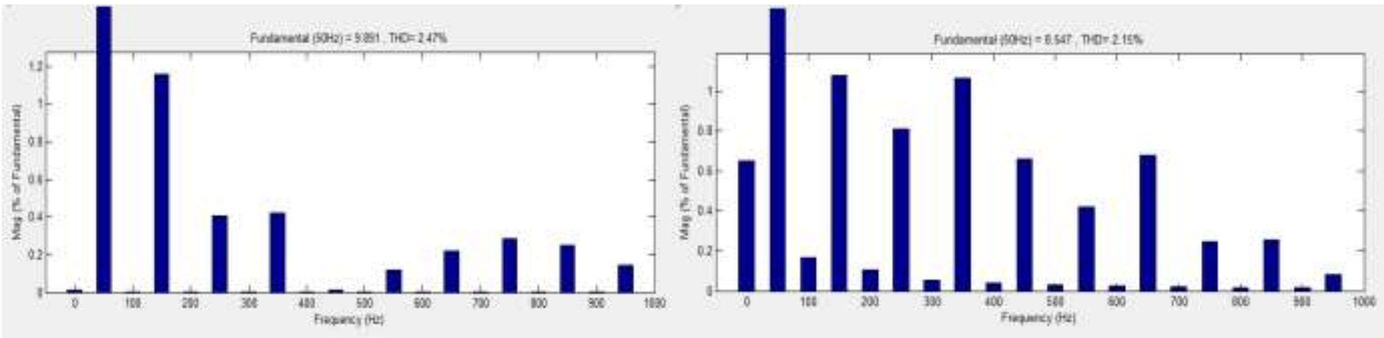


Fig.10. Three phase grid current waveform with modulation compensation.



(a) (b)

Fig.11. THD% of grid Current under: a) Seven Level inverter, b) Nine level inverter.

However, by applying the modulation compensation scheme, the power injected to the grid is still balanced, as shown in Fig. 10. 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.11 (a) and (b) shows the THD% of grid current under seven level inverter with 2.47% and nine level inverter with 2.15%.

V. CONCLUSION

This paper presented a nine level modular cascaded PV inverter for grid applications. The multilevel inverter topology will help to improve the utilization of connected PV modules if the voltages of the separate dc links are controlled independently. 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. 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. Finally, this proposed nine level inverter THD% is low as compare to seven level inverter, high power generation and high voltage applications. Therefore this proposed technique useful to high level inverter applications.

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