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Improving Electromagnetic Compatibility and Better Harmonic Performance by Using CHB Converter Based PV-Battery Hybrid System

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Abstract

Now-a-days, photovoltaic (PV) power systems are getting more and more widespread with the increase in the energy demand and the concern for the environmental pollution around the world. A seven level CHB inverter with Phase shifted PWM technique used for PV-battery hybrid system which makes the irregular PV power smoother and also limits the grid current under grid voltage dips. For improve electromagnetic compatibility (EMC) and better harmonic performance in this paper proposed a configuration which different from the conventional configuration where the PV and the battery inverters are paralleled on the grid side, the proposed seven level CHB based hybrid system connects the AC sides of the PV inverter and the battery inverter in cascade Compare to proposed seven level hybrid system THD is 21.58% where as conventional parallel inverter system THD is 52.39%. The seven level inverter output voltages, harmonic performance of grid current and THD is available by using simulation of MATLAB/SIMULINK software.

1. Introduction

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. Power electronic circuits with pulse width modulation (PWM) are mostly used in energy conversion systems to achieve closed loop control. So, there is fluctuation in the PV output power due to the stochastic climatic conditions. To compensate the inherent fluctuation of PV output power and provide the electricity with high quality, the energy storage system such as the battery system must be used in the proposed system. They regulate the output currents of the inverter to meet the requirement by grid code, and implement the maximum power point tracking (MPPT) for the PV modules, the power converters are the vital components in the PV energy system. Unfortunately, the fast-switching power converters which produces the electromagnetic interference (EMI) issues [3], [4]due to high-voltage slew rates (dv/dt). The grid inverter may generate the common-mode (CM) voltage between the PV module and the ground, which in turn results in the CM leakage current through the parasitic capacitors [5]. The differential-mode (DM) noise is also induced by the high-frequency switched phase-to-phase voltages of inverters [6]. Various solutions such as the variable frequency PWM, the soft switching, and the multilevel converter are proposed to reduce the EMI source of power converters [6].

The key is to adopt the seven level cascaded-H bridge (CHB) topology to connect the PV and battery in series, and design the proper control strategy to let them operate both efficiently. The PWM scheme of the proposed CHB based system is similar to the uni-polar SPWM, to improve the EMC, and reduce the harmonics in the output voltage.

2. Proposed Concept

2.1 System Configuration

The PV-battery hybrid system, where two PV arrays and one battery are integrated as Fig. 1 shows four configurations. The battery benefits smoothing the irregular PV output power, and can supply the stable output power under the islanding mode. In Figure 1(a), the PV and battery systems are connected to one centralized inverter with separate DC/DC converters.

By mounting the battery in DC link of the centralized inverter, the DC/DC converter for battery can be saved as shown in Figure 1(b) [1], [2]. Different from the centralized inverters in Figure 1(a) and (b), the separate grid inverters are used by the two PV systems in Figure 1(c). Thus, the power rating of each inverter becomes smaller, and the inverter is intended to be modular design as well as mass production.

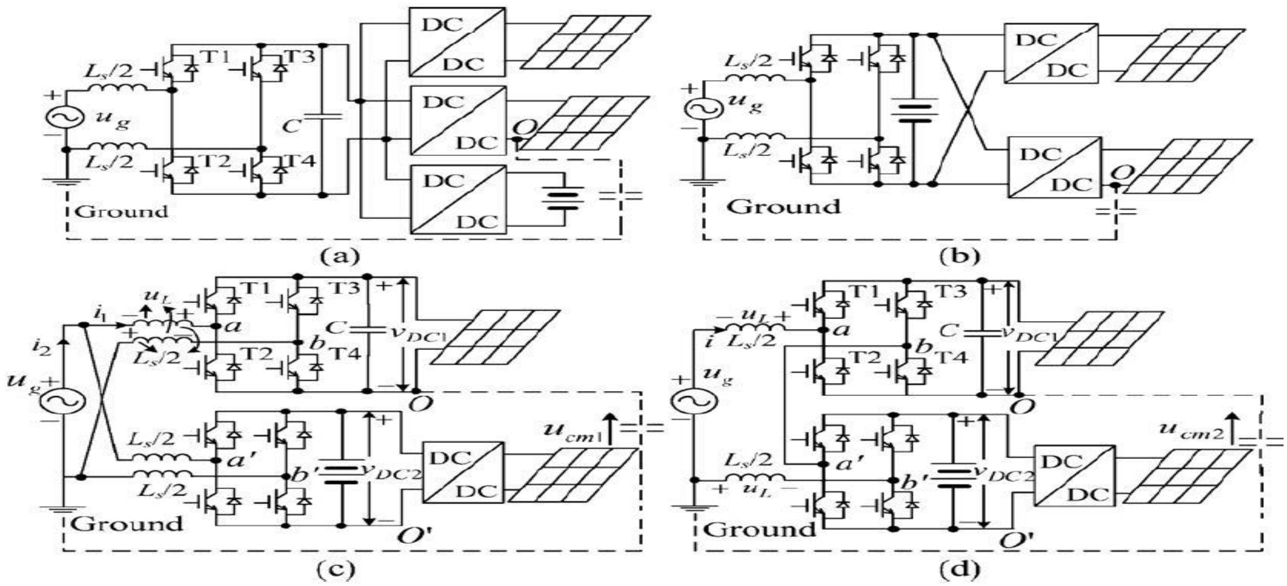

Figure 1 System configuration of PV-battery hybrid system: (a) centralized inverter based system with separate DC/DC converters; (b) centralized inverter based system with battery in DC link; (c) conventional paralleled inverters based system; (d) proposed five level CHB inverter based system.

Furthermore, one PV array can be directly connected to the inverter, and this single-stage configuration saves the DC/DC converter for the PV array.It is noted that the interleaved operation for the paralleled inverters in Figure 1(c). can make the THD of grid current lower compared to the centralized inverters in Figure 1(a). and (b).

Based on the CHB inverter, this paper proposes a new PV-battery hybrid system, which is shown in Figure 1(d). Compared to the configuration in Figure 1(c), the two grid inverters are connected in cascade, and provide a common output voltage in Figure 1(d). The grid-side impedance is shared the two inverters.

. In the four topologies in Figure 1, the CM voltage induced at point generates the leakage current through the parasitic capacitor between the PV array and the ground, while the DM voltage produces the interference in the grid current. The CM and DM voltages caused by the inverters in Figure 1(a) and (b). are similar to those in Figure 1(c). But the paralleled inverters in Figure 1(c) have the lower grid current interference by using the interleaved operation, and their modular design makes it easy to enlarge the system. So, the topology seven level CHB inverter as shown in Figure 2 will be analyzed and compared with the Figure 1(c), 1(d).

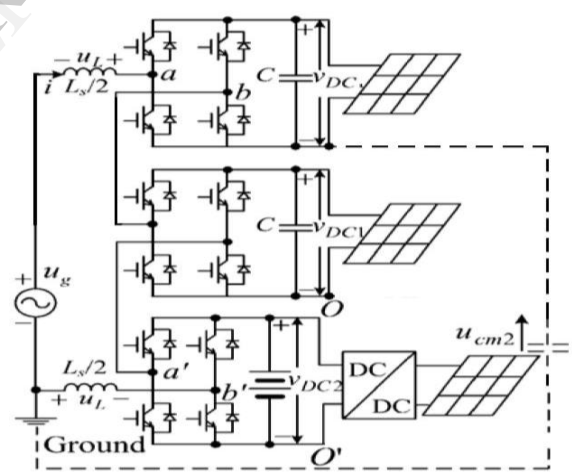

Figure 2. Proposed Seven Level CHB Inverter based system.

2.2 Control Scheme

Figure 3 shows the control scheme of the system in Figure 1(c). By using the PI controller to regulate the PV output voltage v_{DC1}, the output current reference of PV inverter, namely i^*_{ref1} is generated. By using the P controller to track i^*_{ref1}, the output voltage reference v^*_{DC1} is produced. For the battery, the total output current of the PV inverter and the battery inverter, namely v^*_{ref2} is tracked by the P controller, and the output voltage reference of the battery inverter, namely i^*_{ref2} is produced. The normalized grid voltage v_{in_norm} is used to provide the grid angle for synchronization.

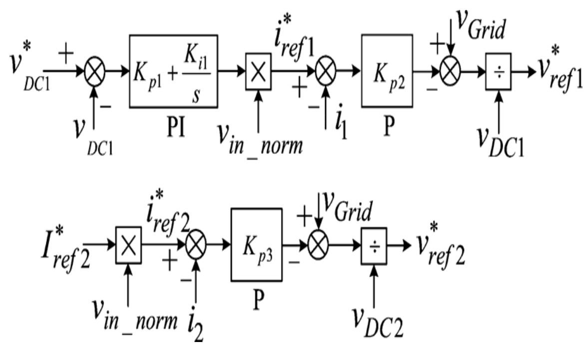

Figure 3. Control scheme of conventional paralleled inverters configuration

Fig. 4 shows the control scheme of the proposed CHB based PV-battery hybrid system. The closed-loop DC voltage controller generates the output voltage reference of PV inverter v^*_{ref1}. For the battery system, the total grid current is controlled with the P controller. Since the output voltages of PV and battery inverters are connected in cascade, the output voltage of the PV inverter namely $v^*_{ref1} \cdot v^*_{DC1}$ is subtracted from the total inverter output voltage.

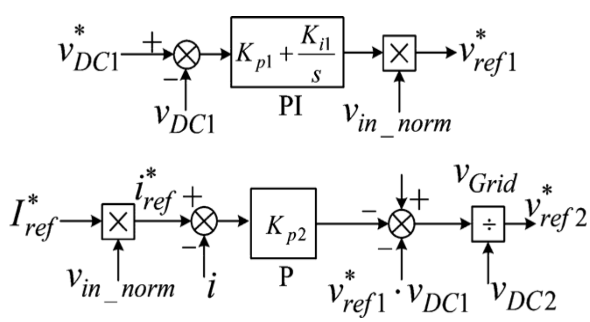

Figure 4. Control scheme of the proposed CHB based hybrid system.

2.3 SPWM Switching Strategy

The unipolar sinusoidal PWM (SPWM) and the bipolar SPWM are the two well-known modulation strategies for the single-phase inverter [8]. Figure 4(a) and (b) show the bipolar SPWM and the unipolar SPWM, respectively. The bipolar SPWM suffers from poor grid harmonics although it could offer almost constant CM voltage and low leakage current of PV.

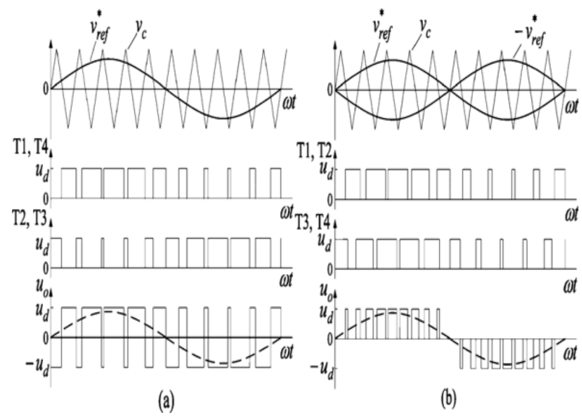

Figure 5. Switching strategy: (a) bipolar SPWM; (b) unipolar SPWM

Compared to that, the unipolar SPWM offers better current harmonic performance, and is widely used in grid inverters [7]. The PWM scheme of the proposed CHB based system is similar to the unipolar SPWM. The difference is that there is π/3 phase shift between the carries of PV inverter and battery inverter.

3. Circuit Parameters

For the unipolar SPWM based inverter, the grid-side inductance L_S can be designed according to the grid current ripple Δi at the peak of grid voltage as follows:

$$Ls = \frac{(Ud-Ugm)}{(2fs\Delta i)} D \quad \left(D = \left(u_{gm} \middle| u_d\right)\right) \quad \text{- (1)}$$

Where f_s is the switching frequency, D is the duty-ratio, u_{gm} is the peak value of grid voltage, and u_d is the DC link voltage. Based on the DC link voltage rippleΔUd, the DC link capacitance C is designed as [9]:

$$C = \frac{\sqrt{\left(u_{gm}\, i_{gm}\right)^2/4 + \left(2\pi f L_s\, i_{gm}^2\right)^2/4}}{4u_d \pi f \Delta u_d} \quad \text{- (2)}$$

Where f is the grid frequency, and i_{gm} is the peak value of grid current, Equation (2) is obtained by considering the DC link voltage ripple is caused by the $2f$ oscillations in grid power.

4. Performance Evaluation with Simulation Results

To compare the performance of the proposed CHB based system with the conventional paralleled inverters configuration, the MATLAB/SIMULINK is used to simulate the two systems. The DC link voltages of the PV inverter and the battery inverter are both set to be 400 V in the conventional paralleled inverters configuration. For the proposed system, the DC link voltages of the PV and battery inverters are decreased to be 135 V since their output voltages are connected in series at grid side. The rated grid voltage is 200 V, the rated grid current is 50 A, and the grid frequency is 50 Hz. The switching frequencies of the inverters are all set as 3 kHz. Based on (1) and (2), the grid-side inductance Ls is designed as 5 mH, and the DC link capacitance C is 5000 μF. Thus, the ripples in the grid current and the DC link voltage are around 8.6 A and 10.5 V for the unipolar SPWM based inverter without the interleaved operation

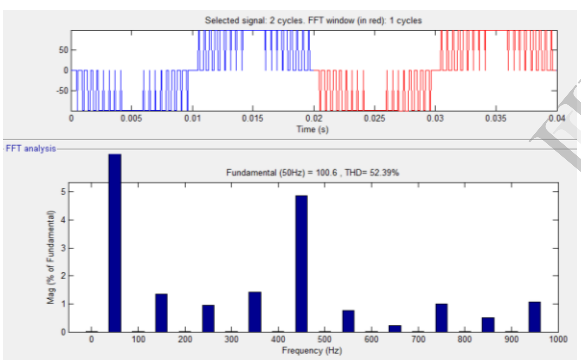

Figure 6(a). Harmonic Performance: (a) inverter voltage and THD with Unipolar SPWM

. The control parameters are designed as $k_{p1} = 1$, $k_{s1} = 1, k_{p2} = 15, and\ k_{p3} = 15$ and for the paralleled inverters system in Fig. 3 and the control parameters $k_{p1} = 0.05, k_{s1} = 0.05\ and\ k_{p2} = 15$, for the CHB based hybrid system in Figure 4.

First, the harmonic performance of the conventional paralleled inverters with bipolar SPWM, unipolar SPWM, and the proposed system are compared in Figure 6, figure 9, and figure10. It can be observed that two voltage steps, namely 400 V and -400V appear in the bipolar SPWM inverter.

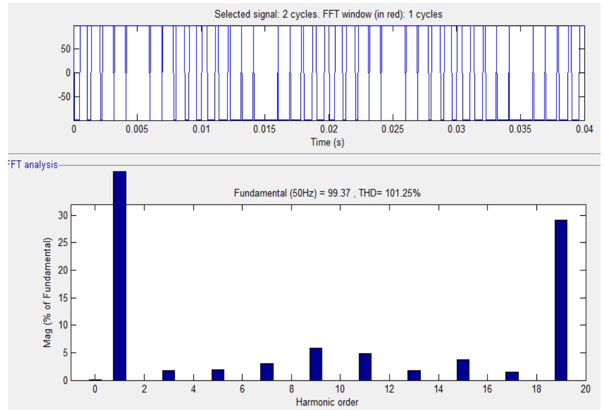

Figure 6(b). Harmonic Performance inverter voltage and THD with Bipolar SPWM

Three voltage steps, namely 400 V, 0 V and -400V are available in the unipolar SPWM of Figure 9. Compared to those, five voltage steps 400 V, 200 V, 0 V, -200V and -400V are given with the proposed system. Their THD values are 101.25%, 52.39%, and 38.56% respectively. The proposed system offers the best grid current waveform with the lowest THD of 2.85%.

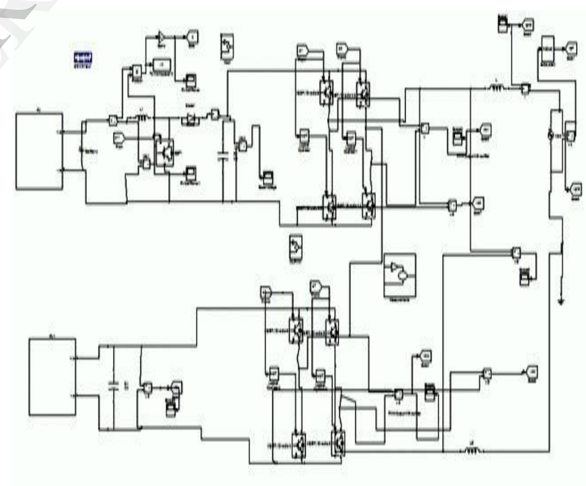

Figure 7. Simulation model of Proposed Five Level CHB inverter based Hybrid System

The grid current of bipolar SPWM has the highest THD of 16.63%, and thus suffers from the shortcomings of higher loss, lower efficiency, and larger inductance for smoothing the current ripples. Although the bipolar SPWM provides almost constant CM voltage, it will not be further investigated here.

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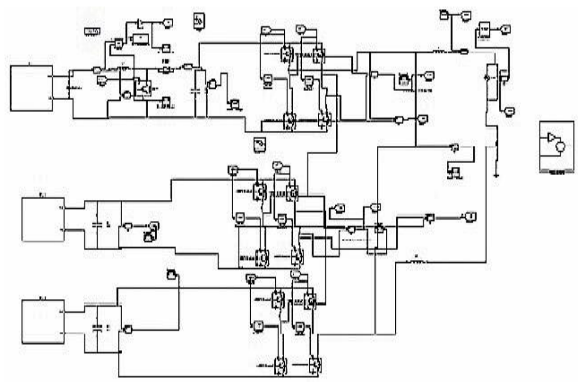


Figure 8. Simulation Model of Proposed Seven Level CHB inverter based Hybrid system

Compared to proposed seven level inverter voltage steps 400V, 267V, 133V, 0, -133V, -267V, -400V are given with proposed seven level hybrid system and THD is 21.58% in Figure 10.

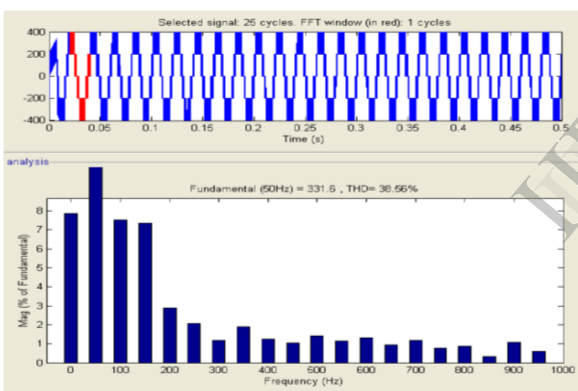


Figure 9. Harmonic performance Inverter voltage and THD with proposed five level CHB hybrid system

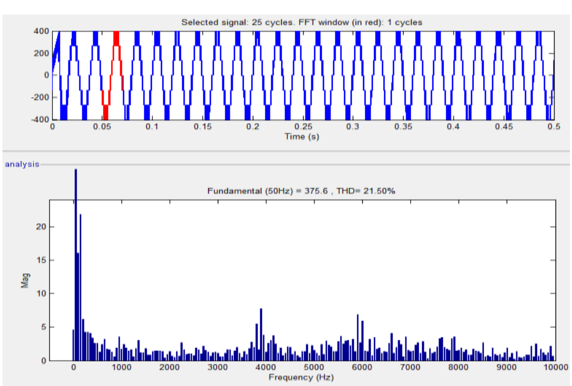


Fig. 10 Harmonic performance Inverter voltage and THD with proposed seven level CHB hybrid system

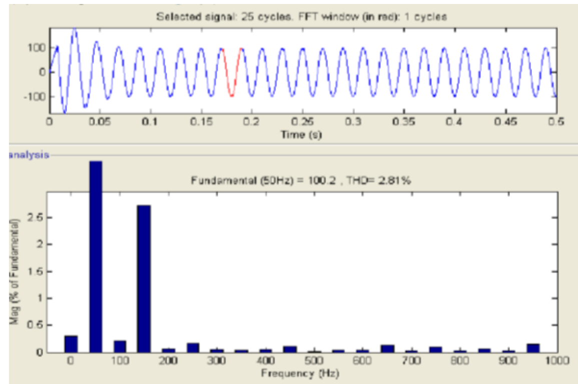
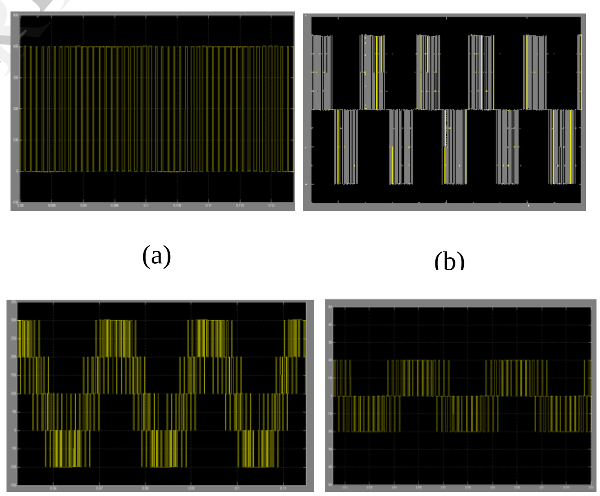


Figure 11 Harmonic performance Grid current with proposed hybrid system

Second, the CM and DM voltages of the conventional paralleled inverters with unipolar SPWM and the proposed system are compared in figure 12. It can be seen the proposed system offers lower voltage steps in both the CM and the DM voltages. Based on the spectrum comparison, it is verified that the proposed hybrid system can reduce the EMI effectively.



(a) (b)

(c) (d)

Figure 12. CM and DM voltage comparison: (a)CM voltage of paralleled inverters system; (b) DM voltage of paralleled inverters system; (c) CM voltage of proposed hybrid system; (d) DM voltage of proposed hybrid system.

Third, system performance in smoothing the irregular PV power is investigated in figure 11. The PV output power, PV array output voltage and the grid power of the proposed system are shown in figure 13 respectively.

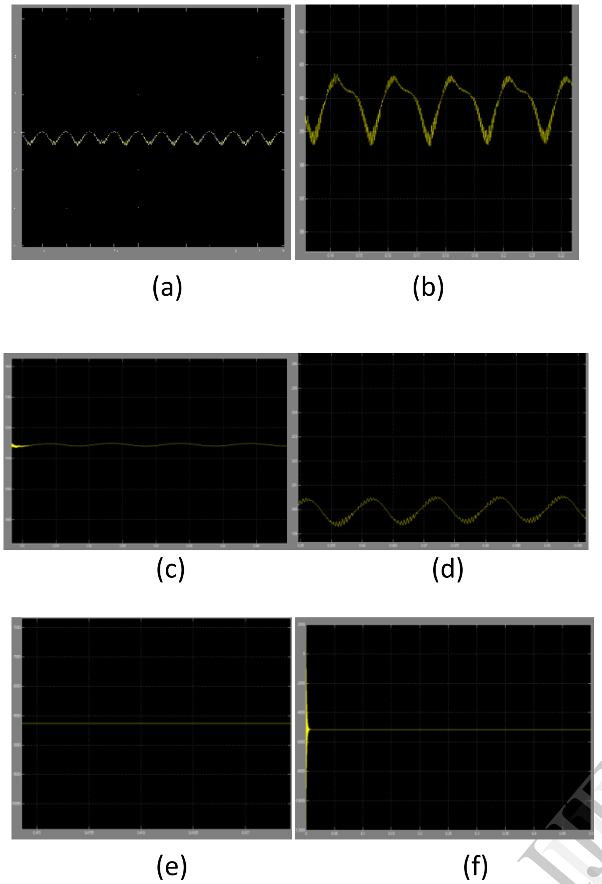


Figure 13. Power smoothing: (a) PV power of paralleled inverters system; (b) PV voltage of paralleled inverters system; (e) grid power of paralleled inverters system; (c) PV power of proposed hybrid system; (d) PV voltage of proposed hybrid system; (f) grid power of proposed hybrid system.

Due to the stochastic nature of climatic condition, the PV output voltage at the maximum power point (MPP) is changed. By controlling the PV output voltage to track the varying MPP as shown in Figure 13, the proposed system can capture the maximum PV power, which is changed irregularly in Figure 13(c). With the power compensation of battery, the smooth grid power is provided by the proposed system, as shown in Fig. 13(f). It is observed that the power smoothing performance of the CHB based system is similar to that of the paralleled inverters system in Fig. 13(a), (c) and (e).

Finally, the performances of the two systems under the 30% grid voltage dip fault are compared. For outputting the power of 3kw through the PV inverter, the paralleled inverters configuration requires higher inverter current compared to the proposed hybrid system, that the proposed system has lower power ripples under this condition.

5. Conclusion

DC links for the CHB inverter, the hybrid system offers the multilevel output voltages and lower steps in the CM and DM voltages. Thus, the better EMC and THD performance are given. The proposed hybrid system can smooth the irregular PV power and limit the grid current under grid voltage dips. The improved operating performance of the proposed seven level inverter output voltages, harmonic performance of grid current and THD has been verified by computer simulation.

6. References

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