# Electromagnetic Compatibility and Better Harmonic Performance with Seven Level CHB Converter Based PV-Battery Hybrid System

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Abstract: The objective of this paper is to develop for improve electromagnetic compatibility (EMC) and better harmonic performance, with help of seven level CHB Phase shifted PWM technique inverter used for PV-battery hybrid system which makes the irregular PV power smoother and also limits the grid current under grid voltage dips. Proposed 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 21.50% 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.

Keywords: Battery, cascaded H-bridge inverter, electromagnetic compatibility (EMC), photovoltaic (PV) inverter.

### 1. Introduction

In recent years, research on the use of photovoltaic as an alternative source of energy has become prominence in the field of electrical engineering. 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 highfrequency 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 following are past proposed System configurations of PVbattery hybrid system for electromagnetic compatibility and better harmonic performance [10].

- Centralized Inverter: This system with separate DC/DC converters, the power rating of each inverter becomes smaller, and each PV panel required DC/DC converter.
- Conventional Paralleled Inverter: 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, which can make the THD of grid current lower compared to the centralized inverters.

The CM and DM voltages caused in centralized inverters and conventional parallel inverters. 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



Based on the seven levels CHB Phase shifted PWM technique inverter, this paper proposes a new PV-battery hybrid system, which is shown in Figure 1. Compared to the

Volume 3 Issue 11, November 2014 <u>www.ijsr.net</u> Licensed Under Creative Commons Attribution CC BY conventional parallel inverter, the two grid inverters are connected in cascade, and provide a common output voltage in Figure 1. The grid-side impedance is shared the two inverters.

#### 2.1 Control Method

Figure 2 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  $v*_{refl}$ . 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  $v*_{refl}$ .  $v*_{DC1}$  is subtracted from the total inverter output voltage.



Figure 2: Control scheme of the proposed CHB based hybrid system.

#### 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.



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  $\pi/3$  phase shift between the carries of PV inverter and battery inverter.

# 4. Circuit Parameters

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

$$Ls = \frac{(ud - v_{gm})}{(u_{fs}u_{f})} D \quad \left(D = \left(u_{gm} \mid u_{d}\right)\right) - (1)$$

Where  $f_{\overline{s}}$  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 ripple  $\Delta Ud$ , the DC link capacitance C is designed as [9]:

$$C = \frac{\sqrt{(u_{gm} l_{gm})^2 / 4 + (2\pi f l_s (\tilde{g}_m)^2 / 4}}{4u_d \pi f \tilde{u}_d} - (2)$$

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.

#### 5. Simulink 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 gridside inductance Ls is designed as 5 mH, and the DC link capacitance C is 5000  $\mu$ F. 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.

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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.



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 21.50% in Figure 10.



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



**Figure 10:** Harmonic performance Inverter voltage and THD with proposed seven level CHB hybrid system.



Figure 11: Harmonic performance Grid current with proposed hybrid system.

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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.







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.

## 6. Conclusion

By using the PV array and the battery as the separate 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.

## References

- [1]Zheng Wang, Shouting Fan, Yang Zheng, and Ming Cheng, "Design and analysis of a CHB converter based PV-battery hybrid system for better electromagnetic compatibility," *IEEE Trans. Magnetics*, vol.48, no. 11, November 2012.
- [2]H. Fakham, D. Lu, and B. Francois, "Power control design of a battery charger in a hybrid active PV generator for load-following applications," *IEEE Trans. Ind. Electron.*, vol. 58, no. 1, pp. 85–94, Jan. 2011.
- [3]Y. K. Lo, T. P. Lee, and K. H. Wu, "Grid-connected photovoltaic system with power factor correction," *IEEE Trans. Ind. Electron.*, vol.55, no. 5, pp. 2224–2227, May 2008.
- [4]A. M. Sitzia, A. E. Baker, and T. W. Preston, "Finiteelement analysis for power electronics EMC applications," *IEEE Trans. Magn.*, vol. 32, no. 3, pp. 1517–1520, May 1996.
- [5]G. Ala, M. C. Di Piazza, G. Tinè, F. Viola, and G. Vitale, "Numerical simulation of radiated EMI in 42 V electrical automotive architectures, *IEEE Trans. Magn.*, vol. 42, no. 4, pp. 879–882, Apr. 2006.
- [6]H. Xiao and S. Xie, "Leakage current analytical model and application in single-phase transformerless photovoltaic grid-connected inverter," *IEEE Trans. Electromagn. Compat.*, vol. 52, no. 4, pp. 902–913, Nov. 2010.
- [7]Z. Wang, K. T. Chau, and C. Liu, "Improvement of electromagnetic compatibility of motor drives using

chaotic PWM," *IEEE Trans. Magn.*, vol. 43, no. 6, pp. 2612–2614, Jun. 2007.

[8]R. Araneo, S. Lammens, M. Grossi, and S. Bertone, "EMC issues in high-power grid-connected photovoltaic plants," *IEEE Trans. Electromagn. Compat.*, vol. 51, no. 3, pp. 630–648, Aug. 2009.