Indonesian Journal of Electrical Engineering and Computer Science
Vol. 2, No. 1, April 2016, pp. 107 ~ 114
DOI: 10.11591/ijeecs.v2.i1.pp107-114

Synchronverter Control for Parallel Operation of Cascaded H-Bridge Inverter

Amar Hamza*[1], Sara Altahir*[2], Xiangwu Yan[3]
State Key Laboratory of Alternate Electrical Power System with Renewable Energy Sources (North China Electric Power University), Changping District, Beijing 102206, China
*Corresponding author, e-mail: amarhamza2010@hotmail.com[1], sarayaltaher555@yahoo.com[2], xiangwuy@hotmail.com[3]

Abstract

A 21-levels cascaded H-bridge multilevel inverter topology based on three-phase voltage source inverter has been proposed as a superior replacement for conventional two-level in high voltage applications. In this work we have presented the usage of the new technique called virtual synchronous generator based synchron verter model to operate the multilevel inverter as synchronous generator, and to share active and reactive power automatically in case of parallel operated inverters of the same type. Carrier-based PWM is used to control each phase leg of the cascaded H-bridge multilevel inverter. This carrier-based PWM scheme is derived from the carrier phase disposition pulse width modulation strategy. By aid of MATLAB/Simulink package a simulation experiment is established to verify the performance of the proposed technique.

Keywords: *distributed generation, cascaded H-Bridge inverter, synchronverter, phase disposition pulse width modulation, parallel operation*

1. Introduction

For the fossil fuel cost, pollution, and other environmental effects, the Distributed Generators (DG) based on renewable energy sources are connected to the power system via power electronic inverter [1]. Although, the 2-level inverter offers fast and accurate control of the output power, it requires a DC voltage higher than the peak AC voltage which is not always directly available. In addition, with just two levels, the inverter output voltage can have high Total Harmonic Distortion (THD). This is undesirable because it requires high frequencies about (3 kHz- 10 kHz) and the addition of expensive AC filters to obtain high quality output voltage and current, thus, it has limited used mainly due to switching losses, switching device voltage rating constrains, and high ElectroMagnetic Interference (EMI) [2, 3]. On the other hand, multilevel power inverters present the advantages of producing better quality waveform at the point of connection to the grid and facilitating the large scale integration of DG due to their modularity.thus, multilevel inverters are used as a superior replacement for conventional two-level in high voltage applications. However, the large number of switches substantially increases the requirement of the converter controller [4-9]. One of the most commonly used way of generating the gate signals for the switches is the carrier based pulse width modulation. Among different methods of carrier base pulse width modulation (PWM), the most common types are: a) phase disposition (PD-PWM); b) phase opposition disposition (POD-PWM), and c) alternate phase opposition disposition (APOD-PWM). PD-PWM technique is based on a comparison of a sinusoidal signal at the fundamental frequency reference and triangular high frequency carrier signals to determine levels of output voltages. The carrier signals are in phase and have amplitude offset. This technique generated lower THD with higher modulation indices, see Figure 10 [10, 11].

Generally, the DG can operate in island mode or grid connected mode. In case of island mode, how to share active and reactive power among parallel connected inverter become a challenge [1]. Under islanding mode, voltage magnitude and frequency are drift at the point of common coupling therefore islanding protection is important issues.

In order to make parallel connection, the most important point is that the load sharing among inverters. Usually there are two types of control schemes. First one based on the

Received December 27, 2015; Revised March 17, 2016; Accepted March 28, 2016

communication system, which limit the system reliability, and expandability. The second one is based on droop method which operate through tight adjustment over the output voltage frequency and amplitude of the inverter to compensate the active and reactive power unbalance [1, 12].

In [5], the integration of a large scale PV plant was presented and a study on the use of a novel converter topology for the realization of the VSG: a cascaded H-bridge topology based on single phase current source inverters (CHB-CSI) was investigated.

In [13], carrier-based PWM is used to separately control each phase leg of the modular multilevel inverter and to allow the line-to-line voltage to be developed implicitly. These carrier-based PWM schemes are derived from the carrier disposition strategy.

In order to mimic a synchronous generator characteristic, the main function of VSG is to control the injected power at AC side inverter of a DG.

In this paper, a twenty one-level voltage source inverter cascaded H-bridge topology based is presented as a case study in order to study the impact of different converter topologies on the design and operation of the Virtual Synchronous Generators (VSGs). The VSG benefits its inherent operation frequency and voltage drooping mechanism for load sharing.

The rest of this paper is organized as follows: section II represents the mathematical model of SG. Details of used cascaded H-bridges inverter and the VSG control are presented in section III. In section IV the simulation results are discussed. All the simulations are performed in MATLAB/SIMULINK. Finally, conclusions are mentioned in section V.

2. Mathematical Model of Synchronoverter

The mathematical model of the three-phase cylindrical-rotor SG that described by equation (1-13) is used in this paper as controller [4, 5, 14].

$$V_{abc} = -R_s i_{abc} - L_s \frac{di_{abc}}{dt} + e_{abc} \tag{1}$$

$$\left.\begin{aligned} i_{abc} &= [i_a \quad i_b \quad i_c]^T \\ e_{abc} &= [e_a \quad e_b \quad e_c]^T \\ V_{abc} &= [V_a \quad V_b \quad V_c]^T \end{aligned}\right\} \tag{2}$$

Where V_{abc} is the phase terminal voltage. i_{abc} is the stator phase current. e_{abc} is the three-phase generated voltage. R_s and L_s are the resistance and inductance of the stator windings, respectively.

$$2H\ddot{\theta} = T_m - T_e - D_p\dot{\theta} \tag{3}$$

$$T_e = M < i_{abc}, \widetilde{sin}\,\theta > \tag{4}$$

$$e_{abc} = Ms\theta\,\widetilde{sin}\,\theta \tag{5}$$

$$P_s = Ms\theta < i_{abc}, \widetilde{sin}\,\theta > \tag{6}$$

$$Q_s = -Ms\theta < i_{abc}, \widetilde{cos}\,\theta > \tag{7}$$

$$\left.\begin{aligned} \widetilde{sin}\theta &= \left[sin\,\theta \quad sin\left(\theta - \frac{2\pi}{3}\right) \quad sin\left(\theta + \frac{2\pi}{3}\right)\right]^T \\ \widetilde{cos}\theta &= \left[cos\,\theta \quad cos\left(\theta - \frac{2\pi}{3}\right) \quad cos\left(\theta + \frac{2\pi}{3}\right)\right]^T \end{aligned}\right\} \tag{8}$$

$$T_m = T_{m_{-ref}} + D_p(\omega_n - s\theta) \tag{9}$$

$$T_{m_{-ref}} = \frac{P_{ref}}{\omega_n} \tag{10}$$

$$M = \frac{1}{ks}(Q_m - Q_s) \tag{11}$$

$$Q_m = Q_{ref} + D_q(V_{ref} - V_m) \tag{12}$$

$$V_m = \frac{2}{\sqrt{3}}\sqrt{(v_a v_b + v_b v_c + v_c v_a)} \tag{13}$$

Where T_m is the mechanical torque applied to the rotor. T_e is the electromagnetic torque. θ is the rotor angle. P and Q are the active and reactive power respectively. H is the inertia constant. M is the field excitation. $\dot{\theta}$ is the angular speed. ω_n is the nominal mechanical speed. D_p is the frequency droop coefficient. D_q is the voltage droop coefficient. V_m is the output voltage amplitude.

3. Inverter Description and VSG Control

Figure 1 depicts the three-phase inverter which consists of cascaded connection of 10 cells of H-bridge in each phase of the inverter. Each bridge consists of four insulated-gate bipolar transistor (IGBT) switches driven by pulse width-modulated (PWM) gate circuits, and isolated DC source. The VSC used to perform the functions of the DC/AC conversion and to interface with the grid if deeded.

Figure 2 shows the power circuit for one phase leg of a three-level cascaded inverter. The circuit generates three voltages at the output (+Vdc, 0, -Vdc) as in table 1. We assume that the DC bus of the VSC is constant. Then, The AC output phase voltage is constructed by adding the voltages generated by the different cells. One advantage of this structure is that the output waveform is nearly sinusoidal [15,16].

The overall structure as depicted in Figure 3 is shown to be equivalent to a SG with capacitor bank connected in parallel with the stator terminal. Figure 4 and 5 depicts the block diagram of the VSG control and two VSGs suppling a common load, respectively [14].

Table 1. the switching states corresponding to Figure 2

S1	S2	S3	S4	Vo
1	0	1	0	+Vdc
1	0	1	0	0
0	1	0	1	0
0	1	1	0	-Vdc

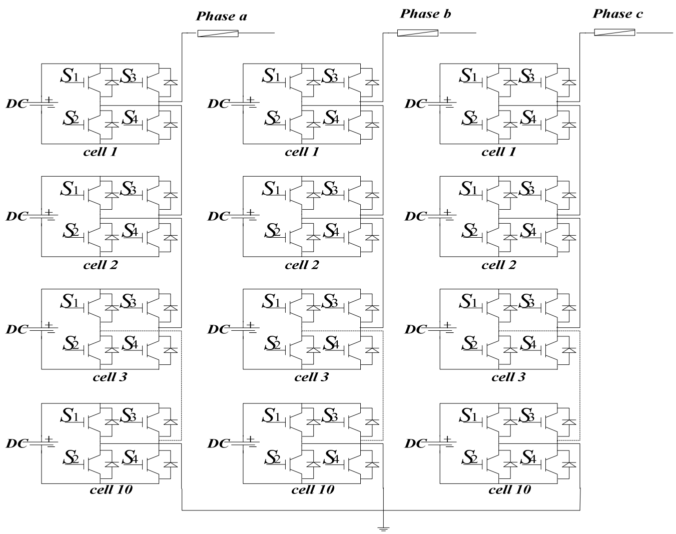

Figure 1. Three phase 21-level cascaded H-Bridge multilevel inverter (Y- connected)

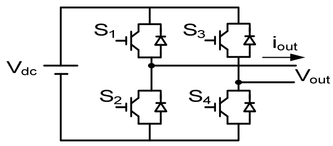

Figure 2. One cell structure of cascaded inverter

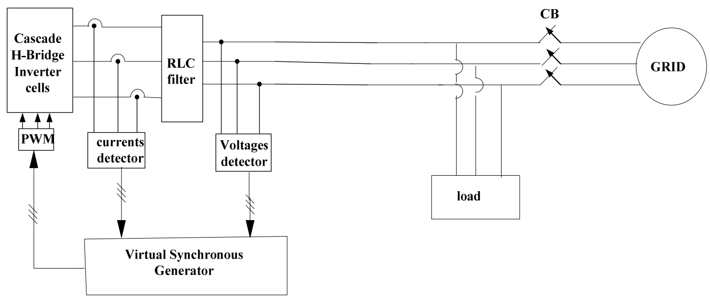

Figure 3. The main circuit of three phase inverter with load and grid

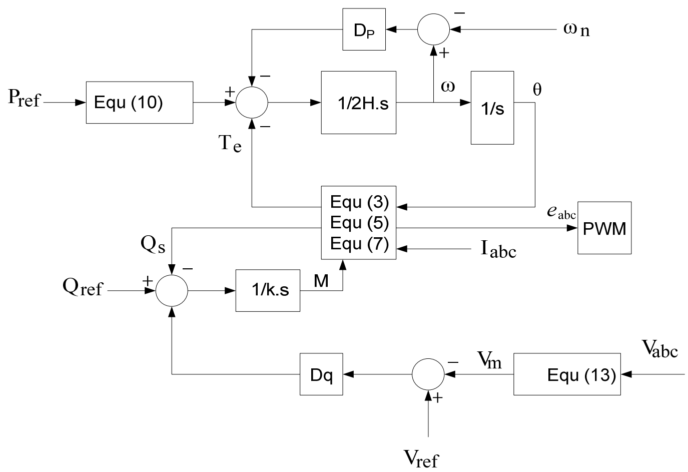

Figure 4. Block diagram of VSG control

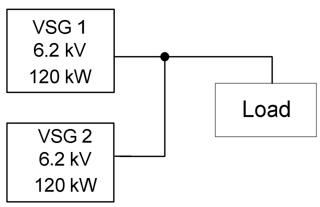

Figure 5. Isolated system including two VSGs

4. Results and Analysis

To examine the proposed method, the mathematical model described by equations (1-13) is applied to the cascaded H-bridge inverter that shown in Figure 1 and the isolated system of figure 5 is simulated in MATLAB/Simulink. The parameters for simulation are presented in table II. As a result, the inverter behaves as a synchronous generator. Since, it's important for large scale inverters to share the load in proportional to their capacities to improve the system reliability and redundancy, the real and reactive power delivered by synchronverters connected in parallel can be automatically shared. From Figures 6 and 7 it can be observe that, the output active and reactive power for two similar inverters most be same, so it is not necessary to repeat the same result. Also both active and reactive power track their references very well.

Two cases are simulated to evaluate the performance of the proposed method under different inertia constant. We note that the overshoots in the active and reactive power are limited in case of small inertia. As a result, for a given frequency droop coefficient D_p, J should be made small.

The results obtained for the load can be seen in Figure 8 and 9, which show the load power and output frequency, respectively. When an active load increase from 220kW to 240kW, at t = 0.2 s, the system responded very fast. Figures 11 and 12 depict the inverter output phase voltage which comprise 21-level and its reduced order THD. The measured output voltage THD was 2.02%. Figures 13 and 14 show the purely sinusoidal load voltages and currents which are in phase.

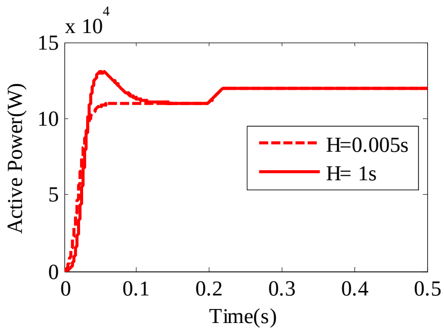

Figure 6. Output active power of one inverter with: (H=1s& H=0.005s)

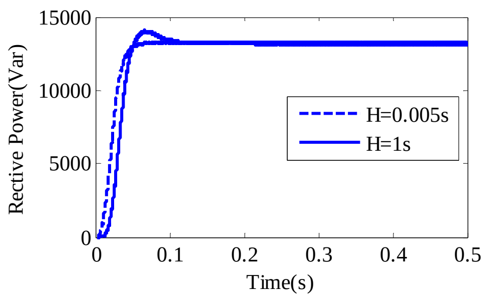

Figure 7. Output reactive power of one inverter with: (H=1s& H=0.005s)

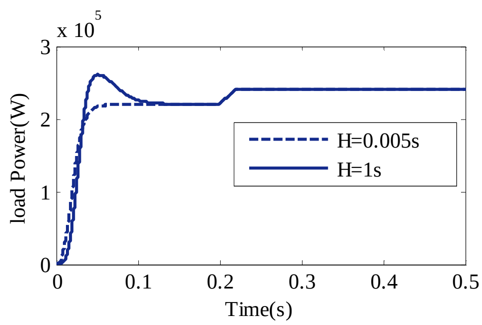

Figure 8. Load active for two parallel inverters with: (H=1s& H=0.005s)

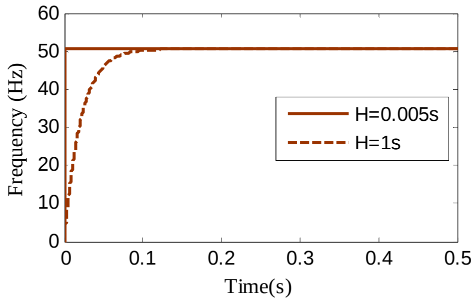

Figure 9. The system frequency with (H=1s & H=0.005s)

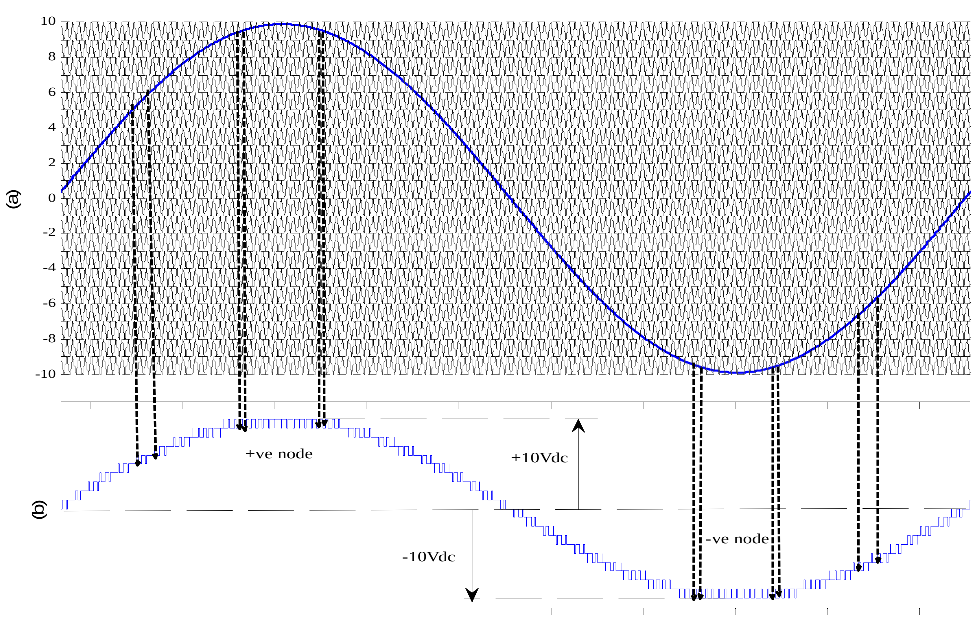

Figure 10. Simulation of carrier-based PWM scheme using the in phase disposition (IPD), (a) Modulation signal and in-phase carrier waveforms (b) Phase “a” output voltage

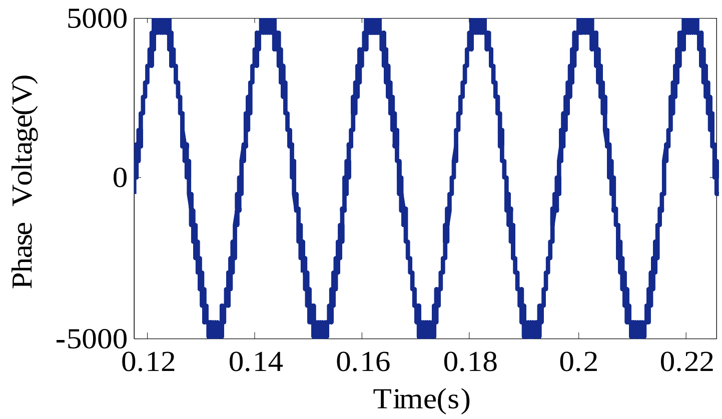

Figure 11. Inverter output phase voltage 21-levels

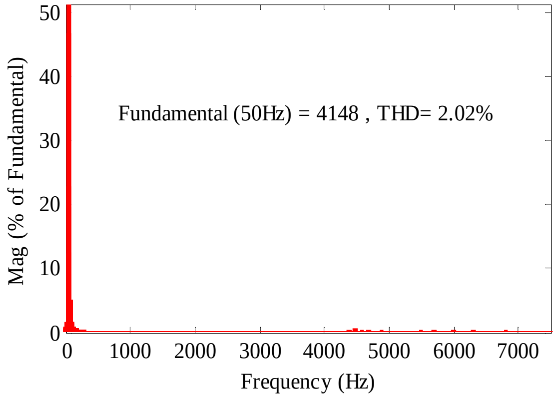

Figure 12. Harmonic Spectrum of 21-level Phase Voltage at modulation index=0.98

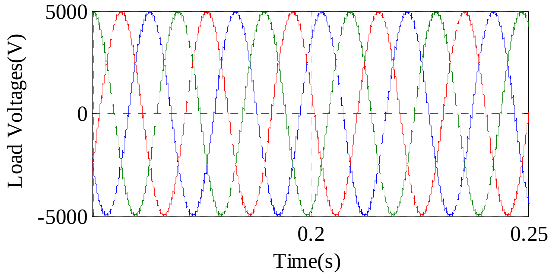

Figure 13. Three-phase load voltages

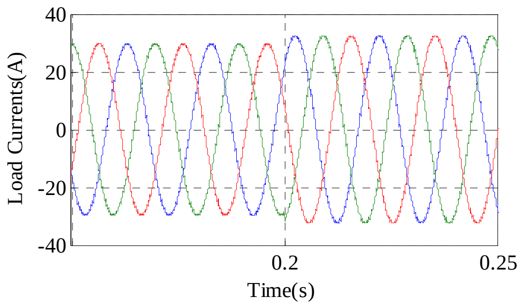

Figure 14. Three-phase load currents

Table 2. simulation parameters

Parameters	Values	Parameters	Values
V_{dc}	500 V	H	0.005s
V_{L-L}(RMS)	6.2 kV	K	150000
P_{ref}	120 kW	R_s	0.13 Ω
Q_{ref}	12.9 kVar	L_s	2.02 mH
D_p	94	C	1.15 μF
D_q	117	P_{load}	240 kW
V_{ref}	5058	f_{sw}	7.5 kHz
ω_n	314 rad/sec	f_n	50 Hz

5. Conclusion

In this paper a control strategy named synchronverter that provide inertial and damping effect was used to control a 21-level cascaded H-bridge inverter topology based on three-phase voltage source inverter in order to emulate the dynamic and transient performance of SGs and to produce better quality waveform at the terminal. Moreover, parallel operation of two large scale DGs with an isolated load was investigated. The overall performance was evaluated for two different cases of inertia constant. The proposed method was verified through simulation results.

To the best of our knowledge, SG popular to give excellent responses when operate with highly inductive system as in case of high voltage power system, thus, this paper confirmed a benefit of using VSG technique for large scale distributed generators in regard of bring the whole performance of SG in high voltage power system. This can open new applications in the future.

6. Acknowledgement

This paper is supported by The Natural Science Fundings of Hebei (E2014502109) and The Fundamental Research Funds for the Centraln Universities (2014ZD30).

The authors would like to thank Omar Busati, for his help.

References

[1] Zhang G et al. *A novel control strategy for parallel-connected converters in low voltage microgrid*, in Transportation Electrification Asia-Pacific (ITEC Asia-Pacific). IEEE Conference and Expo. 2014: 1-6

[2] Adam GP et al. Quasi-two-level and three-level operation of a diode-clamped multilevel inverter using space vector modulation. *Power Electronics, IET*. 2012; 5(5): 542-551.

[3] Rodriguez J, JS Lai and FZ Peng. Multilevel inverters: a survey of topologies, controls, and applications. *IEEE Transactions on Industrial Electronics*. 2002; 49(4): 724-738.

[4] Malinowski M et al. A survey on cascaded multilevel inverters*. IEEE Transactions on Industrial Electronics.* 2010; 57(7): 2197-2206.

[5] Torres M, et al. *Integration of a large-scale photovoltaic plant using a multilevel converter topology and virtual synchronous generator control*, in IEEE 23rd International Symposium on Industrial Electronics (ISIE). 2014: 2620-2624.

[6] Shintai T, Y Miura and T Ise. *Reactive power control for load sharing with virtual synchronous generator contro*l. in 7th International Power Electronics and Motion Control Conference (IPEMC). 2012: 846-853.

[7] Zhong QC and T Hornik. *Control of power inverters in renewable energy and smart grid integration*. John Wiley & Sons. 2012; 97.

[8] Rasheed M, R Omar and M Sulaiman. Harmonic Reduction in Multilevel Inverter Based on Super Capacitor as a Storage. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2015; 16(3).

[9] Murali M. A Cascade Multilevel Z-Source Inverter for Photovoltaic System. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2015; 16(3).

[10] Mc Grath BP and DG Holmes. *Multicarrier PWM strategies for multilevel inverters. IEEE Transactions on Industrial Electronics*. 2002; 49(4): 858-867.

[11] Konstantinou GS and VG Agelidis. *Performance evaluation of half-bridge cascaded multilevel converters operated with multicarrier sinusoidal PWM techniques*. in 4th IEEE Conference on Industrial Electronics and Applications, ICIEA. 2009.

[12] Lazzarin TB, GA Bauer and I Barbi. *A control strategy for parallel operation of single-phase voltage source inverters: analysis, design and experimental results*. *IEEE Transactions* on Industrial Electronics. 2013; 60(6): 2194-2204.

[13] Adam GP et al. Modular multilevel inverter: Pulse width modulation and capacitor balancing technique. *Power Electronics, IET*. 2010; 3(5): 702-715.

[14] Aouini R et al. *Virtual synchronous generators dynamic performances*, in IEEE International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM). 2014: 1-6.

[15] Lin BR, YP Chien and HH Lu. *Multilevel inverter with series connection of H-bridge cells*, in Proceedings of the IEEE 1999 International Conference on Power Electronics and Drive Systems, PEDS'99. 1999: 859-864.

[16] Kouro S et al. *Single DC-link cascaded H-bridge multilevel multistring photovoltaic energy conversion system with inherent balanced operation*. in IECON 2012-38th Annual Conference on IEEE Industrial Electronics Society, IEEE. 2012: 4998-5005.