International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 6, Number 4 (2013), pp. 447-457

http://www.irphouse.com

Comparative Study of Harmonic Analysis in Different Levels of Symmetrical Cascaded H-bridge Multilevel Inverter for Photovoltaic System

M.S. Sivagamasundari[*] and Dr. P. Melba Mary[**]

[*]Assistant Professor, Department of EEE, V.V. College of Engineering, Tisaiyanvilai, TamilNadu, India.
E-mail: sreenithin@vvcoe.org
[**]Principal, Department of EEE, V.V. College of Engineering, Tisaiyanvilai, TamilNadu, India.

Abstract

Photovoltaic energy conversion becomes main focus of many researches due to its promising potential as source for future electricity and has many advantages than the other alternative energy sources like wind, solar, ocean, biomass, geothermal etc. In Photovoltaic power generation system multi level inverters can be used as an alternative configuration for the dc to ac inverter. Diode clamped inverter, Cascaded H-bridge inverter and Flying capacitor inverter are the three widely used configurations of multilevel inverters .Among these three configurations, Cascaded H –bridge multilevel inverter is mostly used for photovoltaic system because each cell of Cascaded H –bridge multilevel inverter requires separate DC sources which can be easily supplied by individual PV arrays and each H-Bridge cell will be available in a single module . This research paper deals with a comparative study of harmonic analysis in different levels of Symmetrical Cascaded H –bridge multilevel inverter employing multicarrier pulse width modulation technique for photovoltaic system. From this study it is found that the total harmonic distortion is low for higher levels of Symmetrical Cascaded H –bridge multilevel inverter and hence the efficiency of the system will be improved . The harmonic contents in output voltage and load current has been analyzed upto 7th harmonics in different levels of symmetrical cascaded h-bridge multilevel inverter and has been studied by the MATLAB/Simulink. The simulated output shows very favorable results.

Keywords: Multilevel inverter, Cascaded H-Bridge multilevel inverter, Total Harmonic Distortion, Photovoltaic cell, Multicarrier pulse width modulation.

Introduction

The demand for renewable energy has increased significantly over the years because of shortage of fossil fuels and greenhouse effect. Among various types of renewable energy sources, solar energy and wind energy have become very popular and demanding due to advancement in power electronics techniques. Photo-Voltaic (PV) sources are used today in many applications as they have the advantages of being maintenance and pollution free. Solar-electric-energy demand has grown consistently by 20%–25% per annum over the past 20 years, which is mainly due to the decreasing costs and prices. This decline has been driven by the following factors: 1) an increasing efficiency of solar cells 2) manufacturing technology improvements and 3) economics of scale [1].

Multilevel inverter, which is the heart of a PV system, is used to convert dc power obtained from PV modules into ac power to be fed into the grid. Improving the output waveform of the inverter reduces its respective harmonic content and, hence, the size of the filter used and the level of electromagnetic interference (EMI) generated by switching operation of the inverter. In recent years, multilevel inverters have become more attractive for researchers and manufacturers due to their advantages over conventional three-level inverters. They offer improved output waveforms, smaller filter size, lower EMI and lower total harmonic distortion (THD) [2].

The three common topologies for multilevel inverters are as follows: 1) Diode clamped (neutral clamped), 2) Capacitor clamped (flying capacitors), 3) Cascaded H-bridge inverter but the one considered in this paper is the symmetrical Cascaded h-bridge multilevel inverter. This topology has many advantages not only in terms of its simple structure but also allows the use of a single dc source as the first dc source with the remaining (n-1) dc sources being capacitors[3]. The voltage regulation of the capacitor is the key issue and this is achieved by the switching state redundancy of the proposed modulation strategy. This scheme also provides the ability to produce higher voltages at higher speeds with low switching losses and high conversion efficiency.

A cascaded multilevel inverter may have more potential than others since input SDCS (Photovoltaic and Fuel cell) could be naturally interfaced to the multilevel inverter to provide higher output voltages: this may offer a high transformer less multilevel inverter in a grid connected application. Moreover, a cascaded configuration would provide a possibility to connect a higher SDCS (> 600 VDC) for getting higher output voltages which do not exceed the 600 VDC to ground as NEC limits. The cascaded multilevel control method is very easy when compared to other multilevel inverter because it doesn’t require any clamping diode and flying capacitor. [4]

The diode-clamped inverter (neutral-point clamped), capacitor-clamped (flying capacitor) requiring only one dc source and the cascaded bridge inverter requiring separate dc sources. The latter characteristic, which is a drawback when a single dc source is available, becomes a very attractive feature in the case of PV systems, because solar cells can be assembled in a number of separate generators. In this way, they satisfy the requirements of the CHB-MLI, obtaining additional advantages such as a possible elimination of the dc/dc booster (needed in order to adapt voltage levels), a significant reduction of the power drops caused by sun darkening (usually, it influences only a fraction of the overall PV field), and, therefore, a potential increase of efficiency and reliability.[5].

Performance of the multilevel inverter (such as THD) is mainly decided by the modulation strategies. For the cascaded multilevel inverter there are several well known pulse width modulation strategies. [6]. Compared to the conventional method, the proposed method is subjected to a new modulation scheme adopting the multicarrier pulse width modulation concept which uses multiple modulating signals with a single carrier reduces the total harmonic distortion .[7]

This research paper deals with a comparative study of harmonic analysis in different levels of Symmetrical Cascaded H –bridge multilevel inverter employing multicarrier pulse width modulation technique for photovoltaic system. From this study it is found that the total harmonic distortion is low for higher levels of Symmetrical Cascaded H –bridge multilevel inverter and hence the efficiency of the system will be improved . The harmonic contents in output voltage and load current has been analyzed upto 7^{th} harmonics in different levels of symmetrical cascaded h-bridge multilevel inverter and has been studied by the MATLAB/Simulink

Photovoltaic System

A Photovoltaic (PV) system directly converts solar energy into electrical energy. The basic device of a PV system is the PV cell. Cells may be grouped to form arrays . The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and DC motors or connect to a grid by using proper energy conversion devices. This photovoltaic system consists of main parts such as PV module, charger, battery, inverter and load.[8]

Equivalent model

A Photovoltaic cell is a device used to convert solar radiation directly into electricity. It consists of two or more thin layers of semiconducting material, most commonly silicon. When the silicon is exposed to light, electrical charges are generated.

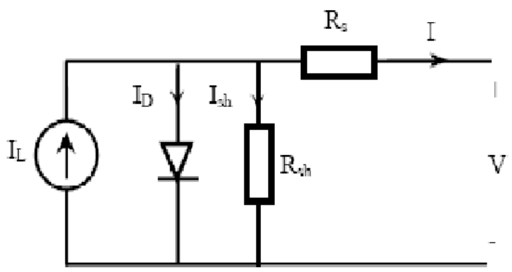

Figure 1: Single PV cell model.

A PV cell is usually represented by an electrical equivalent one-diode model shown in Figure 1.

The model contains a current source, one diode, internal shunt resistance and a series resistance which represents the resistance inside each cell. The net current is the difference between the photo current and the normal diode current is given by the equation.[9].

$$ID = IO\left[e^{\frac{q(V+IRs)}{KT}} - 1\right] \quad (1)$$

$$I = I_L - I_O\left[e^{\frac{q(V+IRs)}{KT}} - 1\right] - \frac{V+IRs}{Rsh} \quad (2)$$

where
I is the cell current (A).
q is the charge of electron (coul).
K is the Boltzmann's constant (j/K).
T is the cell temperature (K).
I_L is the photo current (A).
Io is the diode saturation current.(A)
Rs , Rsh are cell series and shunt resistances (ohms). V is the cell output voltage (V).

Cascaded H-bridge Multilevel Inverter

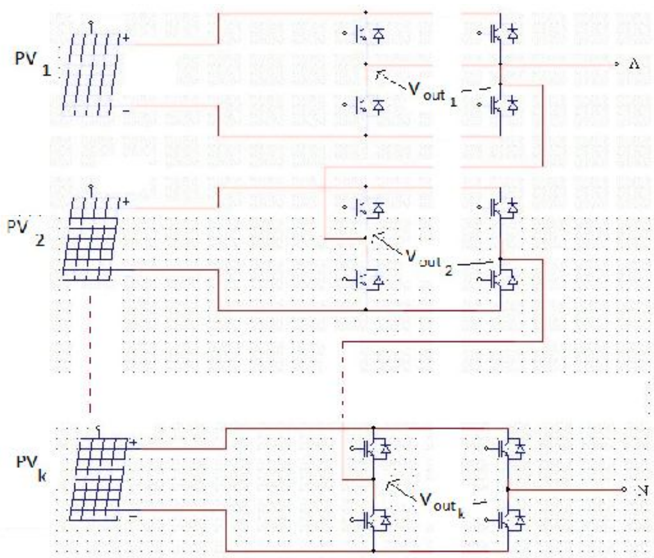

Figure 2: Single Phase n - level Structure of Cascaded H-Bridge Inverter for pv applications.

Figure 6. shows the Single Phase n - level Structure of Cascaded H-Bridge Inverter for pv applications, consisting of *k* dc generators and *k* cascaded H-bridges arranged in a single-phase multilevel inverter topology. Each dc generator consists of PV cell arrays connected in series and in parallel, thus obtaining the desired output

voltage and current. Hbridges basically consist of four metal oxide semiconductor field-effect transistors (MOSFETs) embedding an antiparallel diode and a driver circuit. The number *k* of H-bridges depends on the number n = 2*k*+1 of desired levels, which has to be chosen by taking into account both the available PV fields and design considerations.[10] The circuit has many advantages like simple, modular, improved waveform which results in reduced total harmonic distortion. The Cascaded h-bridge multi-level inverter circuit provides high quality output when the number of levels in the output increases and also this reduces the filter components size and cost.[11].

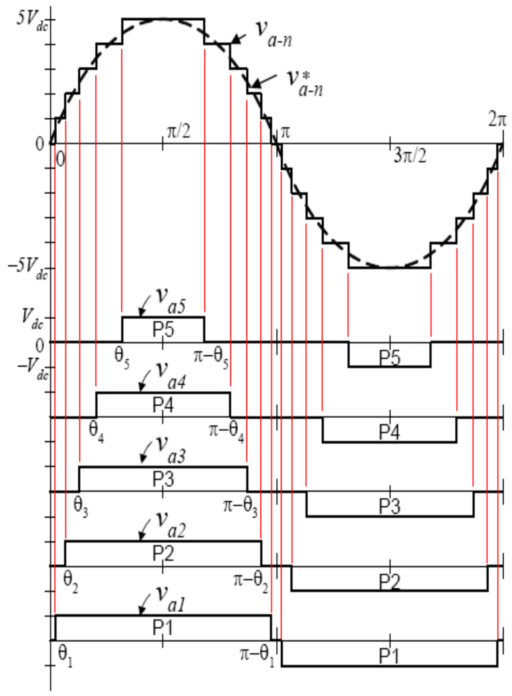

Figure 3: Output phase voltage waveform of an n-level cascaded h-bridge inverter.

Figure.3 shows the output phase voltage waveform for an n-level cascaded H-bridge inverter. The phase voltage $v_{an} = v_{a1} + v_{a2} + v_{a3} + v_{a4} + v_{a5}$.

For a stepped waveform such as the one depicted in Figure 3 with s steps, the Fourier Transform for this waveform follows [12]:

V (ωt) = ($\frac{4VDC}{\pi}$) Σ [cos (n θ1)+ cos (n θ2)+--------+ cos (n θn)] ………………

where n = 1, 3, 5, 7,

The conducting angles, θ_1, θ_2, ..., θ_s, can be chosen such that the voltage total harmonic distortion is a minimum. Generally, these angles are chosen so that predominant lower frequency harmonics, 5th, 7th, 11th, and 13^{th}, harmonics are eliminated.

Multicarrier PWM Technique

Several modulation strategies have been developed for multilevel inverters. The most commonly used is the multi carrier PWM technique. The principle of the multicarrier PWM is based on a comparison of a sinusoidal reference waveform with triangular carrier waveforms. m-1 carriers are required to generate m levels. The carriers are in continuous bands around the reference zero. They have the same amplitude Ac and the same frequency fc. The sine reference waveform has a frequency fr and Ar is the peak to peak value of the reference waveform. At each instant, the result of the comparison is 1 if the triangular carrier is greater than the reference signal and 0 otherwise. The output of the modulator is the sum of the different comparisons which represents the voltage level. The strategy is therefore characterized by the two following parameters called amplitude modulation index ma and frequency modulation index mf . [13]

Frequency modulation ratio is defined as the ratio of carrier frequency and modulating frequency.

Amplitude modulation ratio is defined as the ratio of amplitude of modulating signal and amplitude of carrier signal.[14]

Using this technique THD value can be reduced with reduction in output voltage.

Simulation Results

In this paper, the simulation model is developed with MATLAB/SIMULINK. The simulation results of the proposed cascaded h-bridge eleven level inverter is shown in figure.4 and the switching scheme is shown in figure.5

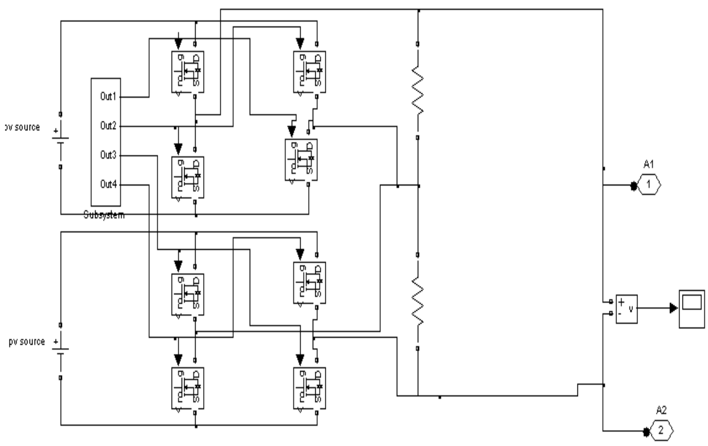

Figure 4: Proposed cascaded h-bridge multilevel inverter topology.

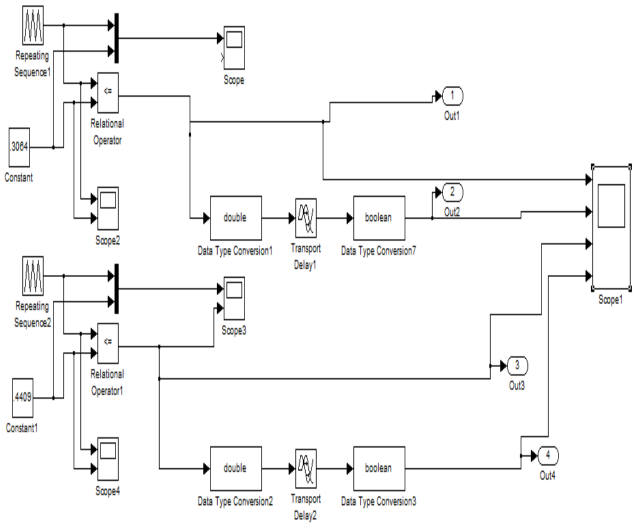

Figure 5: Switching scheme.

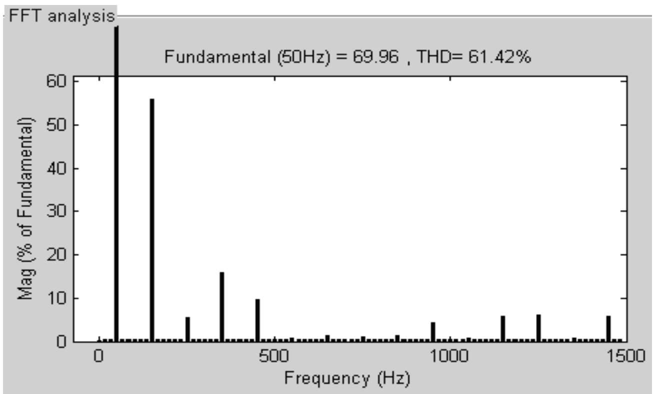

Figure 6: FFT Analysis for five level inverter.

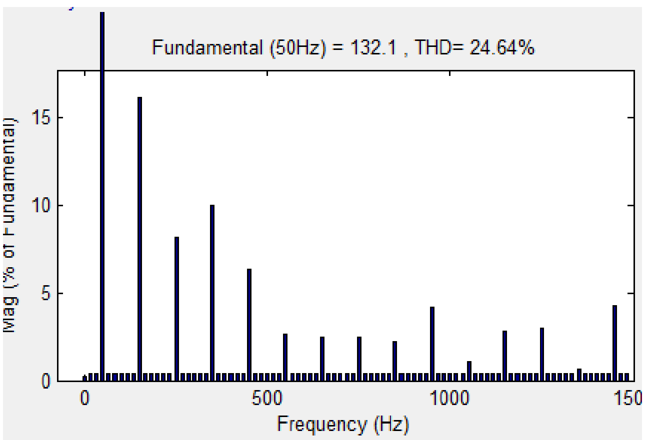

Figure 7: FFT Analysis for seven level inverter.

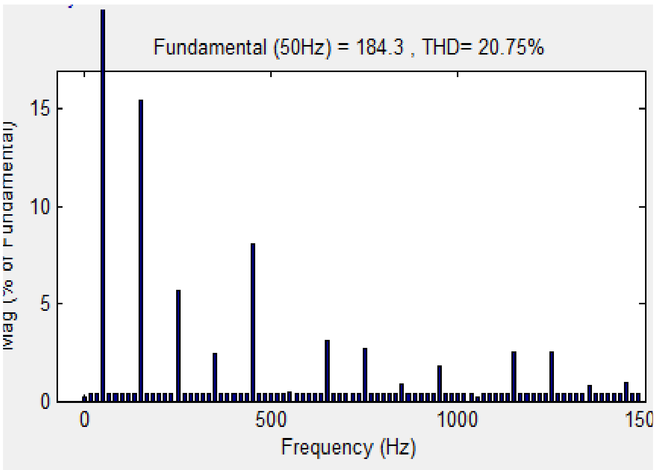

Figure 8: FFT Analysis for nine level inverter.

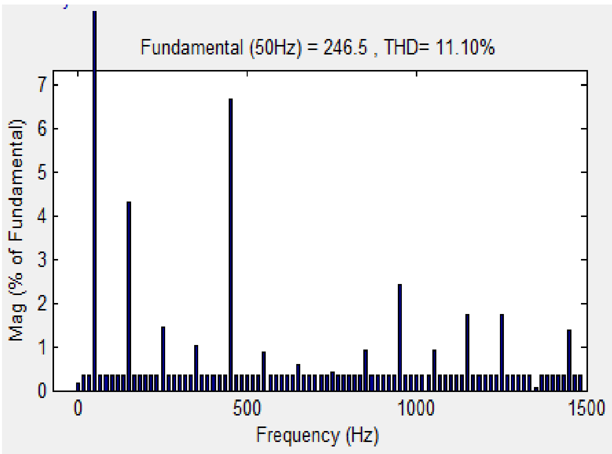

Figure 9: FFT Analysis for eleven level inverter.

Table 1: Harmonics in output voltage for different levels of symmetrical cascaded h-bridge multilevel inverter.

Levels	THD%	Harmonic Contents(%)		
		3rd	5th	7th
5	61.42	1.11	0.18	0.02
7	24.64	1.80	0.19	0.28
9	20.75	2.22	0.20	0.47
11	11.10	1.15	1.40	1.25

Table 2: Harmonics in load current for different levels of symmetrical cascaded h-bridge multilevel inverter.

Levels	THD%	Harmonic Contents(%)		
		3rd	5th	7th
5	5.42	0.88	0.12	0.02
7	4.73	1.45	0.13	0.15
9	3.65	2.09	0.14	0.29
11	3.02	1.12	1.11	0.38

Table 3: Symmetrical Topology.

Levels	DC Sources	Bridges	Switches	THD%
5	2	2	8	61.42
7	3	3	12	24.64
9	4	4	16	20.75
11	5	5	20	11.10

The proposed circuit needs independent dc source which is supplied from photovoltaic cell. For each of the H-bridges in the Cascaded multilevel inverter, 50V photovoltaic power source is used. The switching device used is 400V, 10A MOSFET. Figure.6 ,7,8 and 9 shows the FFT analysis for five level, seven level, nine level and eleven level inverter. Here load is taken as R load and a comparative study of harmonic analysis is done from 5^{th} level to 11^{th} level for output voltage and load current are shown in table.1 and table.2. Table.3 shows the symmetrical topology of various levels.

From the above simulated analysis it is found that the total harmonic distortion of the system will be reduced by increasing the number of levels in the output waveform and hence the efficiency of the system will be improved .

Conclusion

In the present work , this research focus on the comparative study of harmonic analysis in 5,7,9 and 11 levels of Symmetrical Cascaded H-Bridge Multilevel Inverter for photovoltaic power system. Multicarrier pwm technique is being used in this h-bridge multilevel inverter topology. It has been found that the total harmonic distortion of the system will be reduced by increasing the number of levels .Hence we could achieve improved efficiency of the system. The harmonic contents has been analyzed upto 7^{th} harmonics in various levels of outputs and has been studied by the MATLAB/Simulink.

References

[1] Juan Manuel Carrasco, Leopoldo Garcia Franquelo, 2006, “Power-Electronic Systems for the Grid Integration of Renewable Energy Sources: A Survey”, *IEEE Transactions on Power Electronics,* Vol.53, No.4, pp 1002-1016.

[2] Jeyraj Selvaraj and Nasrudin Rahim A,2009, “Multilevel Inverter for Grid-Connected PV System Employing Digital PI Controller”, *IEEE Transactions on Power Electronics,* Vol.56, No.1, pp 149-158.

[3] R.Seyezhai and B.L.Mathur,2010,” Hybrid Multilevel Inverter using ISPWMTechnique for Fuel Cell Ap plicationsnternational Journal of Computer Applic ations 9(1):41–47.

[4] R.Seyezhai and B.L.Mathur, 2008,“Harmonic evaluation of multicarrier PWM techniques for cascaded multi level inverter”, in Proc. 2nd International Confer ence on ElectricalEngineering and its Applications, Algeria, ICEEA, 20-21 May 2008, pp. 3 - 8.

[5] M.G.H.Aghdam, S.H.Fathi, G.B.Gharehpetian,2008, “Analysis of multicarrier PWM methods for asym metric multilevel inverter” in Proc.3rd IEEE Con ference on Industrial Electronics and Applications, ICIEA’08, pp.2057 -2062.

[6] L. M. Tolbert, F. Z. Peng, T. G. Habetler, 1999,“Multilevel convertersfor large electric drives,” IEEE Transactions on Industry Applications, vol. 35, no. 1, pp. 36-44.

[7] Jose Rodriguez, Jin-Sheng Lai and Fang Zheng, 2002, “Multilevel Inverters: A survey of topologies, Control applications,” IEEE transactions on Industrial Electronics, Vol.49, No. 4, pp. 724-738.

[8] Penugonda V. V. N. M. Kumar, P. M. Kishore, R. K. Nema, 2013, “Simulation Of Cascaded H-Bridge Multilevel Inverters For PV Applications” *International Journal of ChemTech Research,*Vol.5, No.2, pp 918-924.

[9] Jose Rodriguez, Jin-Sheng Lai and Fang Zheng, “Multilevel Inverters: A survey of topologies, Control applications,” IEEE transactions on Industrial Electronics, Vol.49, No. 4, pp. 724- 738,August 2002.

[10] F.T. Josh, Jovitha Jerome, and J. Arulwilson,2013,” Fuzzy Logic based nine level Inverter for photovoltaic systems”,*European Journal of Scientific Research,*Vol.78 ,No.3, pp.522-533.

[11] J. S. Lai and F. Z. Peng,1995, “Multilevel converters—a new breed of power converters,” in *Conf. Rec. IEEE-IAS Annu. Meeting,* pp.2348–2356.

[12] L. M. Tolbert, F. Z. Peng, T. G. Habetler,1999, “Multilevel converters for large electric drives,” IEEE Transactions on Industry Applications, vol. 35, no. 1, pp. 36-44.

[13] R.Seyezhai and B.L.Mathur,2008,“Harmonic evaluation of multicarrier PWM techniques for cascaded multi level inverter”, in Proc. 2nd International Conference on Electrical Engineering and its Applications, Algeria, ICEEA 2008, 20-21 ,pp. 3 - 8.

[14] M.G.H.Aghdam, S.H.Fathi, G.B.Gharehpetian, 2008,“Analysis of multicarrier PWM methods for asymmetric multilevel inverter” in Proc. 3rd IEEE

Conference on Industrial Electronics and Applications, ICIEA'08, pp.2057 - 2062

[15] G. Ceglia, V. Guzman, C. Sanchez, F.Ibanez, J. Walter, and M. I. Gimanez, 2006,"A new simplified multilevel inverter topology for DC–AC conversion," *IEEE Trans. Power Electron.*, vol. 21, no. 5, pp. 1311–1319.

[16] Y. Cheng, C. Qian, M. L. Crow, S.Pekarek, and S. Atcitty,2006, "A comparison of diode-clamped and cascaded multilevel converters for a STATCOM with energy storage," *IEEE Trans. Ind. Electron.*, vol. 53, no. 5, pp. 1512–1521.

[17] R. Stala, S. Pirog, M. Baszynski, A.Mondzik, A. Penczek, J. Czekonski, and S. Gasiorek,2009, "Results of investigation of multicell converters with balancing circuit—Part II," *IEEE Trans. Ind. Electron.*, vol. 56, no. 7,pp. 2620–2628.