International Journal of Electronic Engineering and Computer Science
Vol. 6, No. 3, 2021, pp. 31-36
http://www.aiscience.org/journal/ijeecs

Design and Simulation of a Control System for Investors in Wind Turbines

Armin Hassanzadeh Hassanabad*, **Daniel Nazeipur**

Department of Electrical Engineering, Kamal Institute of Technology, Urmia, Iran

Abstract

Wind power is one of the main sources of renewable energies, and wind turbines are widely installed in power distribution grids and are connected directly to power transmission grids. As its level of network penetration has begun to increase, wind power has a pivotal impact on the operation of the modern network system. Direct current (DC) input voltage of inverters fluctuates dramatically in distributed generation applications such as in a wind turbine system. Moreover, a high quality ac output is required for grid interconnection under variable source conditions. Voltage and current converters generate discrete output waveforms, harmonic contamination, additional power losses, and high frequency noise, which need large inductances connected in series with the respective load to obtain the desired current waveform. In order to address this issue, various types of multilevel inverters have been used in the literature. In this work, a neutral point clamped three-level inverter (NPCTLI) is used to evaluate its performance for wind turbines. In this paper a closed loop sinusoidal pulse width modulation (SPWM) control system proposes with real time waveform feedback techniques for a network-connected multilevel inverter in a wind turbine. Additionally, to cope with the high-resonant peak of the inverter that may cause instability, low-pass passive filters with two series inductor and capacitor known as (T) filters are employed. The simulation results demonstrated that the proposed system has better harmonic rejection potency.

Keywords

Wind Turbine, Harmonics, Filters, Three-level Inverter, SPWM

Received: October 18, 2021 / Accepted: November 23, 2021 / Published online: December 6, 2021

1. Introduction

The kinetic energy of wind can be converted to electrical energy to meet our requirements using a wind turbine. To further make it economically viable, improvements in the electrical system efficiency [1] mainly in the power electronic converter control is crucial.

Inverters have found their way into many fields of power system research works, particularly in the area of the applications of power electronics for power system applications, such as energy storage systems, and wind and solar energy systems. Multilevel inverters [2] are a class of inverters in which stepped AC signals are generated using many switches so as to minimize dv/dt and total harmonic distortion (THD). Previously developed control strategies mainly focused on improvements under load variations, relatively small ripples, etc. At the moment, high-quality output voltage is required for these inverters [3].

Myriads of voltage and current strategies have been devoted to the control of inverters in power electronics. Such as multi-loop control [4], and deadbeat control [5]. With these proposed methods, both high-quality output voltage and fast dynamic response can be obtained. The disadvantages are more variables need to be sensed; high-speed control is required to reject the disturbance. These inevitably increase cost and make these methods less suitable. SPWM technique

* Corresponding author
E-mail address: armin.power1993@gmail.com (A. H. Hassanabad)

can greatly improve the output voltage, and has enjoyed extensive applications because of easy implementation, low-cost, and reliable operation. However, the main drawback of an SPWM inverter is large THD with nonlinear loads as well as other nonlinearities within the inverter (dead time, non-ideal switching, etc). High-quality output voltage can be achieved at much lower costs if a repetitive controller is directly combined with an SPWM inverter. This seems more attractive for common products for which fast response is not the chief consideration. Designing a good repetitive controller for an open-loop SPWM inverter is no easy work due to bad dynamics of the inverter, especially at no load. If the parameters of the inverter are precisely known, the inverse transfer function of the inverter can be synthesized in the repetitive controller, which provides fast and precise compensation of the distortion [6-7]. However, this requires perfect modelling of the inverter, which is difficult in practice.

The objective of this paper is to propose a new power conditioning scheme for permanent magnet synchronous generator based wind energy converter systems. A new direct repetitive SPWM control scheme for inverter is proposed in which magnitude and frequency controlled by the reference voltage and a T filter is employed to cancel out the resonant peak of the inverter. The T filter provides larger tolerance to parameter variations, compared with the inverse transfer function of the filter; and better harmonic rejection, compared with other strategies.

2. Numerical Method

In this section, a control strategy of wind turbine is presented along with different components of the proposed control system.

2.1. Control Strategy

The entire wind energy conversion system is as shown in figure 1. The blades of the turbine interact with wind and transfer energy to the turbine rotor [8] which is connected to a common shaft connecting the PMSG. PMSG converts this mechanical energy to three phase ac voltage which fluctuates according to the wind speed. This three phase ac voltage is converted into dc by a three phase rectifier. Output dc voltage is fed to a boost converter which boosts the input signal voltage and feeds an amplified dc voltage to the MLI. The NPC topology of the MLI blocks the dc component from entering the grid and provides a feasible application of control technique for the switches.

SPWM technique uses redundant switching states. It is highly efficient and it reduces THD in the output. The inverter output is a three level stepped wave which is converted to a sinusoid by using T filter. T filters decrease the harmonic distortion levels at lower switching frequencies. They omit the need for a transformer and reduce the circuit complexity, size, cost, and accurately synchronize the inverter to the grid. The output waveform obtained is a pure three phase sinusoid with negligible THD.

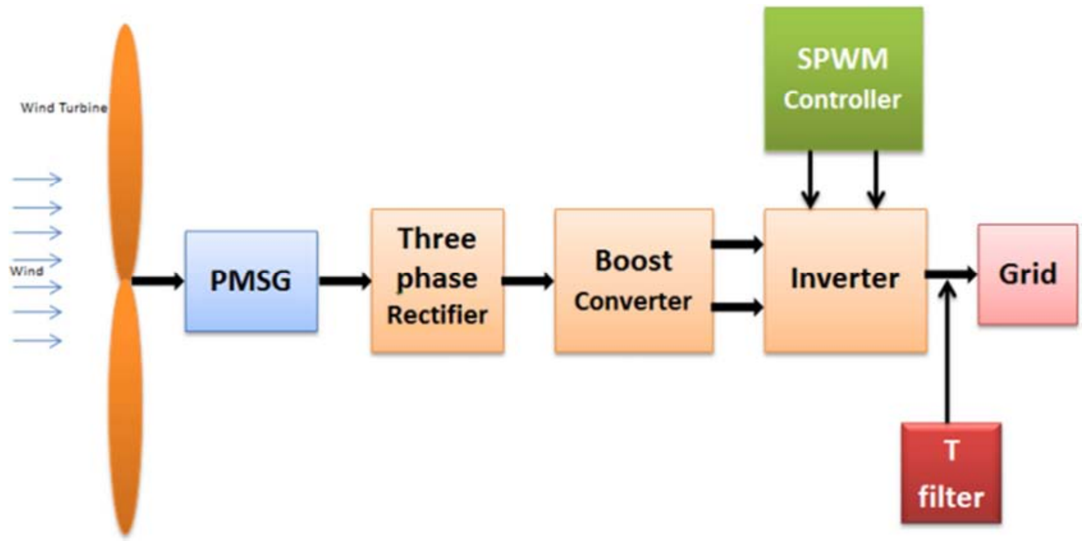

Figure 1. Block diagram of the wind turbine system.

2.2. NPC Three-level Inverter

One of the multilevel arrangements that has gained much notice and widely used is the Neutral-Point-Clamped multilevel inverter or also known as Diode Clamped multilevel inverter [9]. Figure 2 shows the three-level NPC inverter. Fundamentally, NPC multilevel inverters combine the small step of staircase output voltage from several levels of DC capacitor voltages. A k-level NPC inverter consists of (k-1) capacitors on the DC bus, 2(k-1) switching devices per phase and 2(k-2) clamping diodes per phase. The DC bus voltage is split into three-levels by using 2 DC capacitors, C1 and C2. Each capacitor has Vdc/2 volts and each voltage stress will be limited to one capacitor level through clamping diodes.

The number of levels can be comprehensive to a higher level by additional switching devices and with these additions, the inverter will be able to achieve higher AC voltage, producing more voltage steps that will be approaching sinusoidal with minimum harmonics distortion. During inverter operations, the switches near the center tap are switched on for a longer period compared to the switches further away from the center tap as given in the switching states in Table. As the switch is further away from the center tap the switching time is shorter. Another difference between the conventional 2-level and multilevel NPC is the clamping diode [10-11]. In case of three-level NPC inverter, clamping diode, D1 and D4 clamped the DC bus voltage into three voltage level, +Vdc/2, 0 and -Vdc/2. The number of freewheeling diodes (df) per phase, the number of clamping diodes (dc) and number of DC capacitance can be calculated by using equations (1) and (2) respectively.

$$d_f = 2(k-1) \quad (1)$$

$$d_c = (k-1)(k-2) \quad (2)$$

$$c = k-1 \quad (3)$$

Assuming $v^{(1)}$; $v^{(2)}$; $v^{(3)}$ stand for the 3 phase voltages and $i^{(1)}$; $i^{(2)}$; $i^{(3)}$ stand for the 3 phase currents, where the positive current is defined as flowing from the inverter to the grid. The phase voltages and currents can be normalized as [11]:

$$v^k = \frac{mv_{dc}}{2}\cos\left[\omega t - \frac{2\pi(k-1)}{N}\right] \quad (4)$$

$$i^k = I_m \cos\left[\omega t - \frac{2\pi(k-1)}{N} - \varphi\right] \quad (5)$$

K=1, 2, 3

Where I_m, φ, ωt are peak value of phase current, power factor angle of load, and phase angle, respectively.

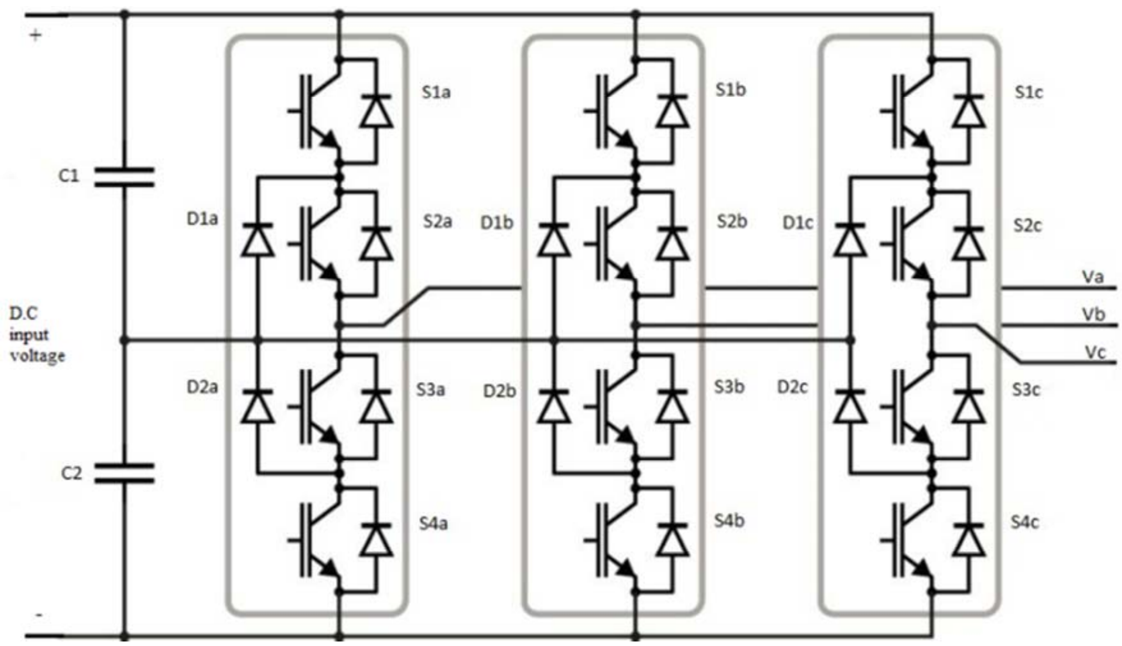

Figure 2. Three level NPC inverter.

2.3. Sinusoidal Pulse Width Modulation

For an MLI to operate properly, proper selection of switching states and their sequence is essential. In the Novel SPWM technique proposed, first a signal is obtained by comparing a reference sine wave with a triangular carrier wave, then the pulse trains are steered into the respective switches at appropriate time intervals using logic combinations as depicted [12, 13]. It is shown the scheme of generation of the SPWM signal in figure 3. It can be seen the pulse steering logic scheme to apply gating signals to a particular switch. Thus generating gating signals for any switch involves logical ANDing of the parent signal with a pulse of duration equal to the conduction period of that switch.

In this type of control a generalized gating signal generation method use only one modulating and one carrier signal. The signal so generated is steered into various switches through pulse steering circuit developed in the present work. The presented method makes use of only one sine and one carrier signal and is generic in nature. As a result the method can be extended to any types of multilevel inverter by generating a parent train of pulses and then steering them to appropriate switches to generate required step signal.

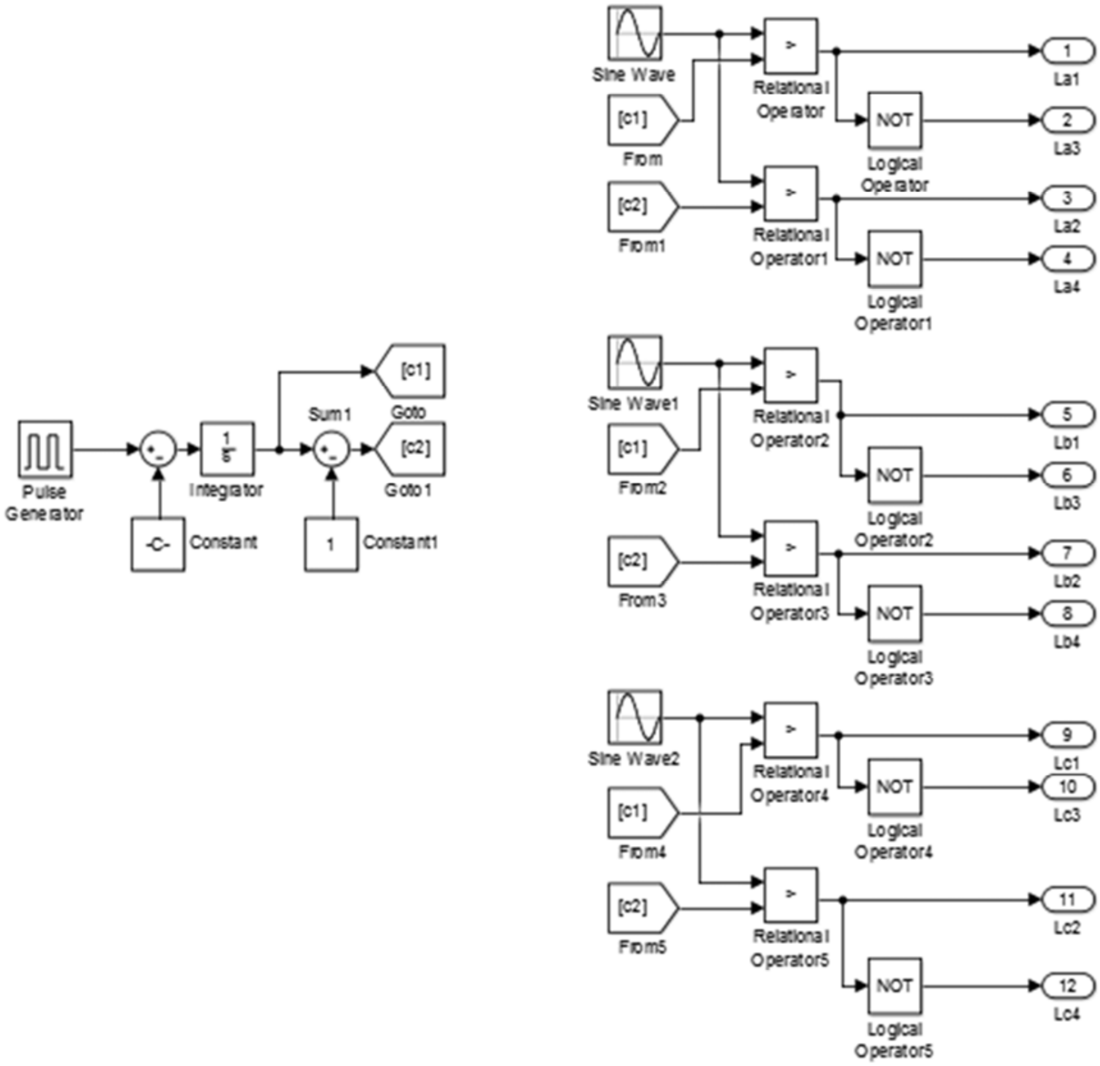

Figure 3. SPWM model of signal generation in MATLAB/SIMULINK.

2.4. LCL (T) Filter

In the case of L filter, the attenuation is -20dB/decade in the whole range of frequency. This makes the higher switching frequency of the inverter. On the other hand, second order filter i.e LC filter the attenuation is around -40 dB/decade. This shunt component of LC will further attenuate the operating switching frequency elements. Hence it must be designed in such a way to produce lower reactance but higher impedance magnitude within the prescribed limits [14]. Also, the load impedance across the filter capacitor must be high enough. LCL Filter: This represents a third order filter giving -60 dB/ decade attenuation. This type of filter can reduce the harmonic distortion levels at lower switching frequencies.

The abandoned use of power electronic converters in the application of grid connected system paves a way for critical injected harmonics. A filter with two series inductors and a capacitor (an LCL filter) is usually applied to reduce the current harmonics around the switching frequency, because it can achieve good attenuation of the high frequency switching noise. Hence the use of filter becomes a significant play among the present scenario. Higher order passive filter is mostly preferred in this application because of its reduced cost and size [15]. This paper focuses on the design of LCL filter for the reduction of injected harmonics [16]. The reason behind choosing LCL filter is inductor sizing and good ripple component attenuation over the other conventional filters [17].

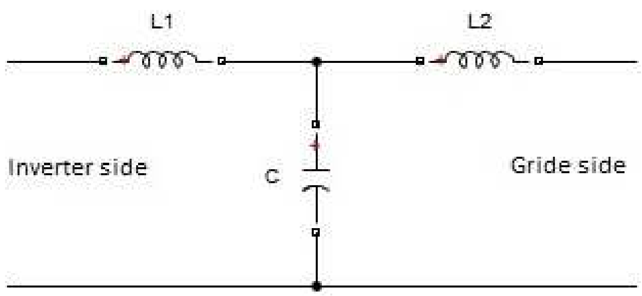

Figure 4. Per phase T filter.

3. Results and Discussion

In this section, the result from the proposed system which was implemented using the MATLAB/SIMULINK is presented. Three level step voltage of the NPC inverter with 600V is as obtained in figure 5. Each phase is at an angle of 120 degrees from the other. Once the T filter introduced to the system, it affects the output results considerably. The Figure 6 demonstrates grid side voltage of three-phase three-level NPC inverter coupled with T filter. It is shown the inverter output voltage with 600V is nearly sinusoidal voltage. Simulation result shows that filtering effect is very effective in reducing harmonics. Therefore, the T filter has a high capability to be used for wind turbine applications.

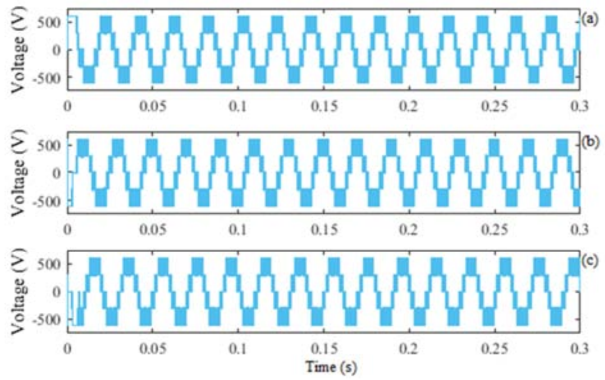

Figure 5. Output voltage of NPC inverter (a) phase A (b) phase B (c) phase C.

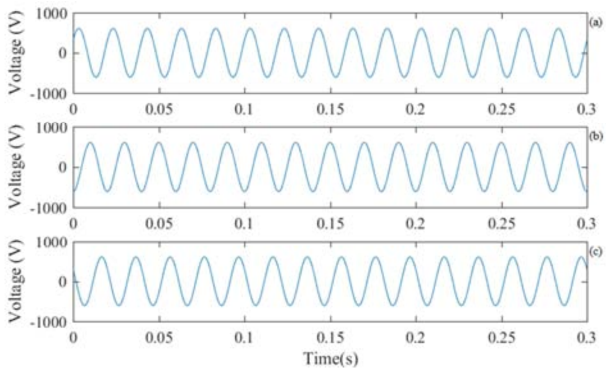

Figure 6. Output grid voltage (a) phase A (b) phase B (c) phase C.

The three phase grid current waveform is shown in figure 7. The current for all three phases changes between -5 A and 5 A for the duration of the simulation which is 0.3 s. It can be seen that the current ripple of the grid side is sinusoidal and there is no resonant phenomenon. This is another proof for the effectiveness of the T filter for the wind turbines system.

The power loss in converter is resulted from conduction loss and the turn-on and turn-off losses. The conduction losses are caused by the conduction resistance and the load currents through semiconductors, while the turn-on and turn-off losses are mainly caused by the non-zero switching time and the load currents. Therefore, under the same load condition, if the switching frequency is stable, the turn-on and turn-off losses are almost constant either. Also the inverter output coupled with T filter that help to decrease low pass harmonics. It can be seen that the stepped voltage is fully converted to sinusoidal waveform and the grid current waveform without resonant phenomenon is also shown. The total harmonic distortion in the output grid voltage waveform is shown in Figure 8 for a range of frequencies between up to 1000 Hz. There is a peak at lower frequencies at 50 Hz, and the magnitude is very low at higher frequencies. The fast fourier transform (FFT) results are also shown in Figure 9 for the output grid current waveform. It can be observed that the total harmonic distortion is about 6.90% in average for the entire frequency spectrum shown in Figure 9.

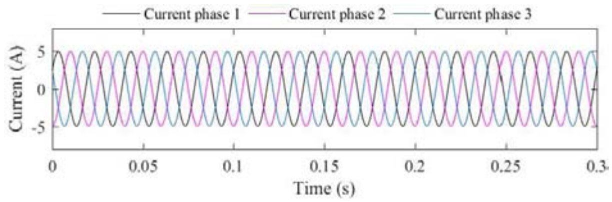

Figure 7. Output grid current.

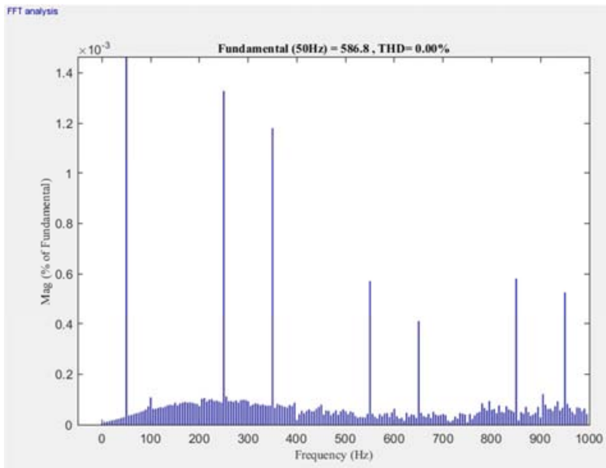

Figure 8. Total Harmonic Distortion in output voltage.

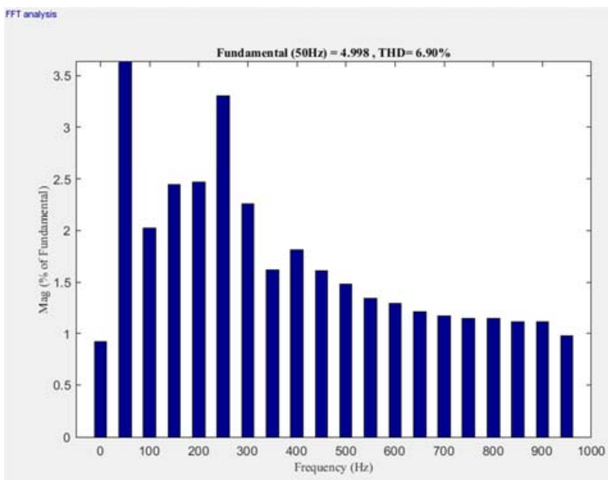

Figure 9. Total Harmonic Distortion in output current.

4. Conclusion

A type of neutral point clamped three-level inverter that it is suitable for a transformer-less grid connected wind energy conversion system was successfully implemented. The results demonstrated that the approach helps to control the leakage currents, common mode voltage and capacitor balancing problems. The new method is very generic in nature and can be applied to any type of MLI irrespective of the level. The main advantage of the proposed control is that only one sine and carrier wave is employed unlike other control methods proposed in the literature, where n-1 number of carrier waves are required. Also the control results in a low THD.

References

[1] Z. Chen, J. M. Guerrero and F. Blaabjerg, "A Review of the State of the Art of Power Electronics for Wind Turbines," in IEEE Transactions on Power Electronics, vol. 24, no. 8, pp. 1859-1875, Aug. 2009, doi: 10.1109/TPEL.2009.2017082.

[2] M. Malinowski, K. Gopakumar, J. Rodriguez and M. A. Pérez, "A Survey on Cascaded Multilevel Inverters," in IEEE Transactions on Industrial Electronics, vol. 57, no. 7, pp. 2197-2206, July 2010, doi: 10.1109/TIE.2009.2030767.

[3] Feel-Soon Kang, Sung-Jun Park, Su Eog Cho, Cheul-U Kim and T. Ise, "Multilevel PWM inverters suitable for the use of stand-alone photovoltaic power systems," in IEEE Transactions on Energy Conversion, vol. 20, no. 4, pp. 906-915, Dec. 2005, doi: 10.1109/TEC.2005.847956.

[4] Q. Lei, S. Yang and F. Z. Peng, "Multi-loop control algorithms for seamless transition of grid-connected inverter," 2010 Twenty-Fifth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), 2010, pp. 844-848, doi: 10.1109/APEC.2010.5433569.

[5] M. Kojima, K. Hirabayashi, Y. Kawabata, E. C. Ejiogu and T. Kawabata, "Novel vector control system using deadbeat-controlled PWM inverter with output LC filter," in IEEE Transactions on Industry Applications, vol. 40, no. 1, pp. 162-169, Jan.-Feb. 2004, doi: 10.1109/TIA.2003.821665.

[6] C. P. Sharma, K. Sapkota, D. B. Tamang, S. Newpaney and J. N. Bhutia, "Harmonic analysis and comparison between single phase three-level pulse width modulation (PWM) inverter and sinusoidal pulse width modulation (SPWM) inverter implementing analog circuits," 2019 Second International Conference on Advanced Computational and Communication Paradigms (ICACCP), 2019, pp. 1-5, doi: 10.1109/ICACCP.2019.8882947.

[7] A. Kouchaki and M. Nymand, "Analytical Design of Passive LCL Filter for Three-Phase Two-Level Power Factor Correction Rectifiers," in IEEE Transactions on Power Electronics, vol. 33, no. 4, pp. 3012-3022, April 2018, doi: 10.1109/TPEL.2017.2705288.

[8] Arash Hassanzadeh, Armin Hassanzadeh Hassanabad, Abdolrahman Dadvand, Aerodynamic shape optimization and analysis of small wind turbine blades employing the Viterna approach for post-stall region, Alexandria Engineering Journal, Volume 55, Issue 3, 2016, Pages 2035-2043, ISSN 1110-0168, https://doi.org/10.1016/j.aej.2016.07.008.

[9] A. Kersten, E. Grunditz and T. Thiringer, "Efficiency of Active Three-Level and Five-Level NPC Inverters Compared to a Two-Level Inverter in a Vehicle," 2018 20th European Conference on Power Electronics and Applications (EPE'18 ECCE Europe), 2018, pp. P. 1-P. 9.

[10] R. Maheshwari, S. Munk-Nielsen and S. Busquets-Monge, "Design of Neutral-Point Voltage Controller of a Three-Level NPC Inverter With Small DC-Link Capacitors," in IEEE Transactions on Industrial Electronics, vol. 60, no. 5, pp. 1861-1871, May 2013, doi: 10.1109/TIE.2012.2202352.

[11] J. Chen, Y. He, S. U. Hasan, and J. Liu, ``A comprehensive study on equivalent modulation waveforms of the SVM sequence for three level inverters," IEEE Trans. Power Electron., vol. 30, no. 12, pp. 71497158, Dec. 2015.

[12] Ilhami Colak, Ersan Kabalci, Developing a novel sinusoidal pulse width modulation (SPWM) technique to eliminate side band harmonics, International Journal of Electrical Power & Energy Systems, Volume 44, Issue 1, 2013, Pages 861-871, ISSN 0142-0615, https://doi.org/10.1016/j.ijepes.2012.08.024.

[13] S. T. Meraj, L. Kah Haw and A. Masaoud, "Simplified Sinusoidal Pulse Width Modulation of Cross-switched Multilevel Inverter," 2019 IEEE 15th International Colloquium on Signal Processing & Its Applications (CSPA), 2019, pp. 1-6, doi: 10.1109/CSPA.2019.8695985.

[14] M. Roth, E. Özkan and F. Gustafsson, "A Student's t filter for heavy tailed process and measurement noise," 2013 IEEE International Conference on Acoustics, Speech and Signal Processing, 2013, pp. 5770-5774, doi: 10.1109/ICASSP.2013.6638770.

[15] S. Bhattacharya, D. M. Divan and B. B. Banerjee, "Control and reduction of terminal voltage total harmonic distortion (THD) in a hybrid series active and parallel passive filter system," Proceedings of IEEE Power Electronics Specialist Conference - PESC '93, 1993, pp. 779-786, doi: 10.1109/PESC.1993.472012.

[16] Camilo C. Gomes, Allan F. Cupertino, Heverton A. Pereira, Damping techniques for grid-connected voltage source converters based on LCL filter: An overview, Renewable and Sustainable Energy Reviews, Volume 81, Part 1, 2018, Pages 116-135, ISSN 1364 0321, https://doi.org/10.1016/j.rser.2017.07.050.

[17] X. Wang, X. Ruan, S. Liu and C. K. Tse, "Full Feedforward of Grid Voltage for Grid-Connected Inverter With LCL Filter to Suppress Current Distortion Due to Grid Voltage Harmonics," in IEEE Transactions on Power Electronics, vol. 25, no. 12, pp. 3119-3127, Dec. 2010, doi: 10.1109/TPEL.2010.2077312.