International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 7 Issue 4, July-August 2023 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Photovoltaic Connected Cascaded H-bridge Multilevel Inverters with Improved Harmonic Performance

Anamika[1], Pramod Kumar Rathore[2]

[1]M Tech Scholar, RKDF College of Engineering, Bhopal, Madhya Pradesh, India
[2]Assistant Professor, RKDF College of Engineering, Bhopal, Madhya Pradesh, India

ABSTRACT
Multilevel inverters act as a promising solution for medium voltage, high power applications due to their modularity and reduced voltage stress across the switches. Cascaded H Bridge Multilevel Inverters (CHB-MLI) are being considered as the best choice for grid connected Photovoltaic (PV) systems since they require several sources on the DC side. By means of MLI's, high quality output with less harmonic distortion is obtained compared to a two-level inverter. In this work, a comparative analysis of CH-MLI's is presented. Control scheme based on Sinusoidal Pulse Width Modulation (SPWM) is adopted due to its ease of implementation. More number of levels results in reduced THD and nearly sinusoidal output. Simulation is performed using MATLAB/Simulink.

***KEYWORDS**: Cascaded H Bridge Multilevel Inverter (CHB- MLI), Photovoltaic (PV), THD, SPWM*

How to cite this paper: Anamika | Pramod Kumar Rathore "Photovoltaic Connected Cascaded H-bridge Multilevel Inverters with Improved Harmonic Performance" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-7 | Issue-4, August 2023, pp.999-1006, URL: www.ijtsrd.com/papers/ijtsrd59848.pdf

IJTSRD59848

1. INTRODCUTION

In the pursuit of sustainable energy solutions, photovoltaic (PV) systems have emerged as a prominent source of renewable power [1]. However, integrating these systems with the conventional power grid requires effective conversion from DC to AC, posing technical challenges, particularly concerning harmonic performance. Addressing this issue, Cascaded H-bridge multilevel inverters have gained attention as a transformative technology [2]. These innovative inverters offer a modular architecture with multiple H-bridge modules interconnected in a cascaded fashion. This setup allows them to efficiently convert DC power generated by PV arrays into grid-compatible AC power while significantly improving harmonic performance [3]. By generating high-quality, low-distortion sinusoidal waveforms, they minimize electrical noise and distortion, ensuring the seamless integration of PV-generated electricity into the grid. This paper delves into the design, operation, and performance evaluation of Photovoltaic Connected Cascaded H-bridge multilevel inverters, emphasizing their remarkable ability to enhance harmonic performance [4]. We explore the potential of these inverters to revolutionize renewable energy integration, reduce grid disturbances, and contribute to a greener and more sustainable energy landscape. Through detailed analysis and experimental validation, we aim to highlight their practicality and advantages in real-world PV applications, ultimately paving the way for cleaner and more efficient energy generation and utilization [5].

1.1. Components of Solar PV Grid Connected Inverter System: Main components of a solar PV based grid interactive inverter system are shown in figure 1.

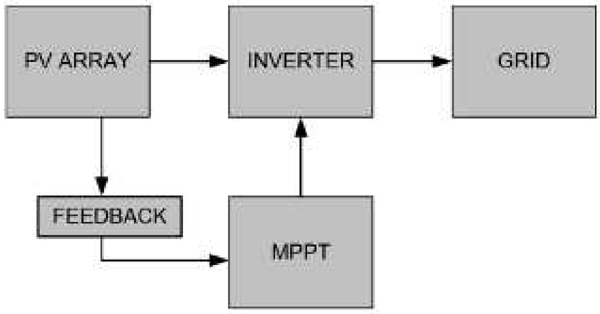

Figure 1: Components of a grid interactive inverter system

1.2. Types of Multilevel Inverters

Multilevel inverters are specialized power electronic devices used for high-voltage, high-power applications. They provide multiple voltage levels in the output waveform, reducing harmonic distortion and improving the quality of the generated AC power [6]. Here are some common types of multilevel inverters:

- Diode-Clamped Multilevel Inverter (Neutral-Point Clamped Inverter): This type of multilevel inverter uses diodes and capacitors to create multiple voltage levels [7]. It has a fixed DC bus voltage and can generate several different output voltage levels, making it suitable for medium-voltage applications.
- Flying Capacitor Multilevel Inverter (Capacitor-Clamped Inverter): Flying capacitor inverters use multiple capacitors to achieve voltage steps [8]. The capacitors are switched to various voltage levels to create the desired output waveform. They are commonly used in medium-voltage drives and renewable energy systems.
- Cascaded H-Bridge Multilevel Inverter: Cascaded H-bridge inverters consist of multiple H-bridge modules connected in series [9]. Each H-bridge module can independently control its DC source, allowing for precise voltage level generation. These inverters are highly modular and scalable, making them suitable for a wide range of applications, including high-voltage transmission and renewable energy systems.
- Hybrid Multilevel Inverter: Hybrid multilevel inverters combine different multilevel techniques, such as diode-clamped and cascaded H-bridge configurations, to optimize performance and reduce component count. They aim to strike a balance between efficiency and complexity [10].
- H-bridge Multilevel Inverter: This is a simpler form of multilevel inverter that uses H-bridge modules to create multiple voltage levels. While not as complex as some other multilevel inverters, it is still effective in reducing harmonic distortion and improving power quality. It is often used in low to medium-voltage applications [11].
- T-type Multilevel Inverter: T-type inverters utilize a combination of switches and capacitors to achieve multilevel output voltage levels. They are known for their ability to reduce common-mode voltage and electromagnetic interference in motor drives and other high-power applications [12].
- Neutral Point Clamped (NPC) Multilevel Inverter: NPC inverters are a variation of the diode-clamped inverter that provides better voltage balance among the phases. They are commonly used in medium-voltage motor drives and industrial applications.

The choice of multilevel inverter type depends on the specific application, voltage requirements, and desired performance characteristics. Each type offers advantages and trade-offs, making it important to select the most suitable one for a particular application.

2. METHODOLOGY

2.1. Solar (PV) Systems

The solar PV system consists of a PV module, the dc/dc boost converter, the maximum power point tracking algorithm and the load. Radiation (R) is incident on the PV module. It generates a voltage (V) and current (I) which will be fed into the load [13]. The voltage power characteristic of a photovoltaic (PV) array is nonlinear and time varying because of the changes caused by the atmospheric conditions. When the solar radiation and temperature varies the output power of the PV module also changes. In order to obtain the maximum efficiency of the PV module, it must operate at the maximum point of the PV characteristic. The most extreme power point relies upon the temperature and irradiance which are non-direct in nature. The greatest power point following control framework is utilized and work viability on the non-straight varieties in the parameters, such as temperature and radiations [14]. A MPPT is used for extracting the maximum power from the solar PV module and transferring that power to the load. A dc/dc converter (boost converter) serves the purpose of transferring maximum power from the solar PV module to the load. A dc/dc converter acts as an interface between the load and the module. The dc/dc converter with maximum power point tracking algorithm and the load is shown in Figure 2. By changing the duty cycle, the load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power. Therefore, MPPT techniques are needed to maintain the PV array's operating at its MPP [15].

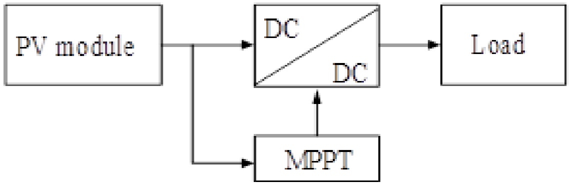

Figure 2: Block Diagram of PV System with MPPT

2.2. Maximum Power Point Tracking

Most extreme Power Point Tracking (MPPT) is helpful apparatus in PV application. Sun oriented radiation and temperature are the primary factor for which the electric power provided by a photovoltaic framework. The voltage at which PV module can create greatest power is called 'most extreme power point (pinnacle control voltage). The primary rule of MPPT is in charge of separating the greatest conceivable power from the photovoltaic and feed it to the heap by means of dc-to-dc converter which steps up/ down the voltage to required size [16]. The operating point of a PV generator is located at the intersection of its current-voltage curve with the load-line. This operating point may be far from the maximum power point (MPP) of the generator wasting a significant part of the available solar power. To achieve optimum matching between the PV generator and the load, an MPP tracker, normally comprised of a simple dc-dc converter, is used. The duty ratio of the converter is controlled by an MPPT algorithm to maximize the power delivered to the load. A number of different MPPT algorithms have been proposed [17], including the P&O algorithm. This simple algorithm does not require previous knowledge of the PV generator characteristics or the measurement of solar intensity and cell temperature and is easy to implement. The algorithm perturbs the operating point by increasing or decreasing a control parameter by a small amount and measures the PV array output power before and after the perturbation. If the power increases, the algorithm continues to perturb the system in the same direction; otherwise the system is perturbed in the opposite direction (Figure 3).

There are two common approaches for implementing the P&O algorithm; reference voltage perturbation and direct duty ratio perturbation. For reference voltage perturbation, the PV array output voltage reference is used as the control parameter in conjunction with a controller (usually a PI controller) to adjust the duty ratio of the MPPT power converter [18]. The PI controller gains are tuned while operating the system at a constant voltage equal to the standard test condition (STC) value of the MPP voltage. These gains are kept constant while the reference voltage is controlled by the MPPT algorithm. For direct duty ratio perturbation, the duty ratio of the MPPT converter is used directly as the control parameter.

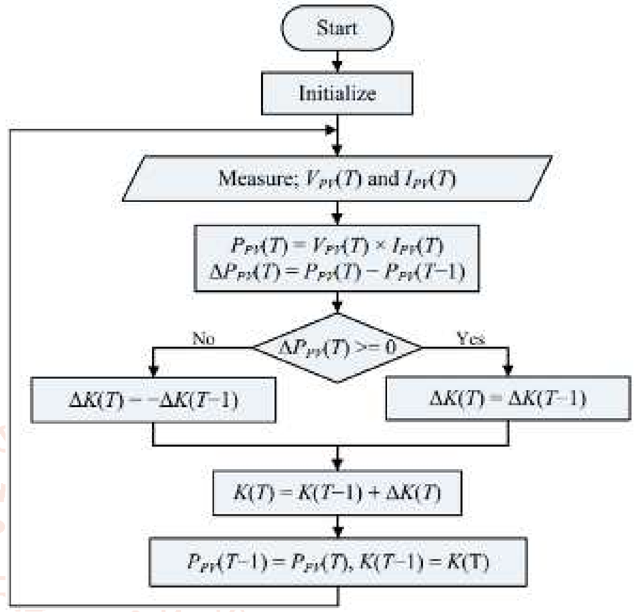

Figure 3: Flowchart of P&O MPPT algorithm

2.3. Cascaded H-Bridge Multilevel Inverter (CH-MLI)

The choice of inverter topology is a critical decision in the design of grid-connected PV systems, impacting their efficiency, power quality, and grid compatibility. The Cascaded H-Bridge Multilevel Inverter (CH-MLI) has gained prominence as an ideal choice due to its inherent characteristics. CH-MLI offers the advantage of producing high-quality, low-harmonic output waveforms, which are essential for grid-connected applications. Its cascading structure, comprising multiple H-bridge modules, enables precise control and modulation of the output voltage [19]. The modularity of CH-MLI allows for scalability, making it suitable for various voltage and power rating requirements in grid-connected systems. CH-MLI can generate multiple voltage levels, reducing the Total Harmonic Distortion (THD) in the output, and this is crucial for maintaining power quality. Its ability to provide step-like voltage levels minimizes switching losses, contributing to higher overall efficiency. CH-MLI exhibits lower electromagnetic interference, reducing the risk of disrupting other sensitive electronic equipment connected to the grid. The topology's suitability for grid applications lies in its capability to seamlessly synchronize with the grid's frequency and voltage levels [20]. CH-MLI facilitates effective control strategies for mitigating issues such as grid voltage fluctuations and disturbances. It can easily accommodate changes in the grid's operational requirements and variations in the PV system's output. The modularity simplifies maintenance and repair, as a malfunctioning H-bridge module can be replaced without affecting the entire system. CH-MLI's robust design reduces the likelihood of system failures and downtime, ensuring a reliable grid-connected PV system. Its high-voltage handling capability makes it suitable for medium to high-power grid applications, including commercial and industrial settings [21]. The advanced control algorithms that can be implemented with CH-MLI contribute to efficient power conversion and grid integration. It excels in applications requiring a high level of power quality, making it a preferred choice for sensitive loads. CH-MLI's flexibility and adaptability allow for the integration of various renewable energy sources, not limited to PV systems alone [22]. The topology's performance characteristics align with industry standards and grid codes, ensuring compliance with regulatory requirements. Overall, the selection of CH-MLI underscores its proven track record in grid-connected applications, where high efficiency, power quality, and reliability are paramount. Its adoption promises enhanced grid stability and a smoother transition toward a more sustainable and renewable energy-driven future [23].

2.4. Phase Shifted (PS-PWM)

Phase-shifted PWM (PSPWM) is a natural extension of traditional PWM techniques, specially conceived for FC and CHB converters. Since each FC cell is a two- level converter, and each CHB cell is a three-level inverter, the traditional bipolar and unipolar PWM techniques can be used, respectively. Due to the modularity of these topologies, each cell can be modulated independently using the same reference signal [24]. A phase shift is introduced between the carrier signals of contiguous cells, producing a phase-shifted switching pattern between them. In this way, when connected together, a stepped multilevel waveform is originated. It has been demonstrated that the lowest distortion can be achieved when the phase shifts between carriers are 180 or 360°/k for a CHB Inverter. (where k is the number of power cells). This difference is related to the fact that the FC and CHB cells generate two and three levels, respectively [25].

Since all the cells are controlled with the same reference and same carrier frequency, the switch device usage and the average power handled by each cell is evenly distributed. For the case of the CHB, this means that multipulse diode rectifiers can be used to reduce input current harmonics. It is noticed in the FC, the advantage of the even power distribution is that once the flying capacitors are properly charged (initialized to their corresponding values), no un--balance will be produced due to the self-balancing property of this topology [26], hence there is no need to control the dc-link voltages. Another interesting feature is the fact that the total output voltage has a switching pattern with k times the frequency of the switching pattern of each cell. This multiplicative effect is produced by the phase-shifts of the carriers.

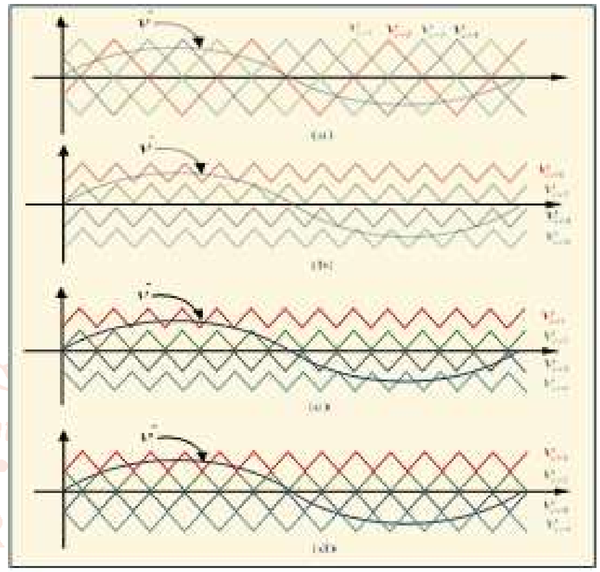

Figure 4: Phase shifted and Level shifted PWM carrier arrangements (a) Phase shifted PWM (b) PD, (c) POD, (d) APOD

Hence, better total harmonic distortion (THD) is obtained at the output, using k times lower frequency carriers.

2.5. Level Shifted PWM (LS-PWM)

Level-shifted PWM (LSPWM) is the natural extension of bipolar PWM for multilevel inverters. Bipolar PWM uses one carrier signal that is compared to the reference to decide between two different voltage levels, typically the positive and negative busbars of a VSI [27]. By generalizing this idea, for a multilevel inverter, m−1 carriers are needed. They are arranged in vertical shifts instead of the phase-shift used in PS-PWM. Each carrier is set between two voltage levels; [28] hence the name B level shifted. Since each carrier is associated to two levels, the same principle of bipolar PWM can be applied, taking into account that the control signal has to be directed to the appropriate semiconductors in order to generate the corresponding levels. The carriers span the whole amplitude range that can be generated by the converter. They can be arranged in vertical shifts, with all the signals in phase with each other, called phase disposition (PD-PWM); with all the positive carriers in phase with each other and in opposite phase of the negative carriers, known as phase opposition disposition (POD-PWM); and alternate phase opposition disposition (APOD-PWM), which is obtained by alternating the phase between adjacent carriers [29]. An example of these arrangements for a five- level inverter (thus four carriers) is given in Figure 4, respectively.

In brief, rather than level shifted PWM, phase shifted PWM technique has finite merits like, no rotation in switching, less switching losses and easy to implement. Indeed, in present article all productive topologies are implemented with sinusoidal PWM approach [30]. Next sections provide the details of conventional CMI topology and performance verifications and challenging aspects to resolve.

3. SIMULATION RESULTS & ANALYSIS

3.1. Results

To evaluate the performance of the proposed Simulink Model – Dual Diode PV Model with Cascaded H-Bridge Multilevel PV Inverter_ Phase-shifted SPWM (PS-SPWM) switching scheme is then applied to control the switching devices of each H-bridge. and the control system, MATLAB/Simulink software has been utilized. Table 1 shows the characteristics of the simulated system.

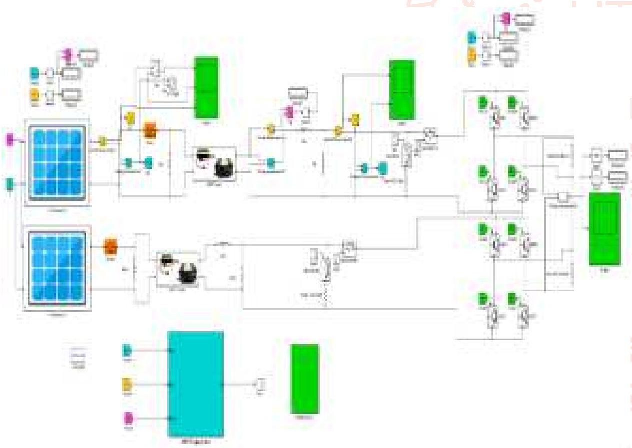

Figure 5: MPPT Algorithms & Cascaded H-bridge Multi Level Inverter

TABLE 1: PV PARAMETERS

PV Paramters

Pmax (W)	200	n	1.3417
Isc (A)	8.21	Rs (ohm)	0.2172
Voc (V)	32.9	Rsh (ohm)	951.9317 (951.93)
ki (%/°)	3.18e-3/8.21 (0.00038733)	Ns	3
kv (%/°)	-0.123/32.9 (-0.0037386)	Np	3
Ncs	54		

Figure 6 shows Experimental power extracted from PV panels with MPPT_ The harvested solar power waveform of each phase with MPPT Booster Algorithms

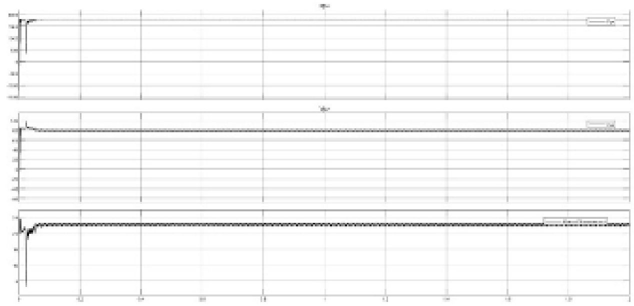

Figure 6: PV Voltage, PV Current & PV Power Vs Time in (S)

Figures. 7, 8, and 9 show the experimental output of voltage and current measurement for a dual diode, a dual generator, and a cascaded H-Bridge Multilevel inverter.

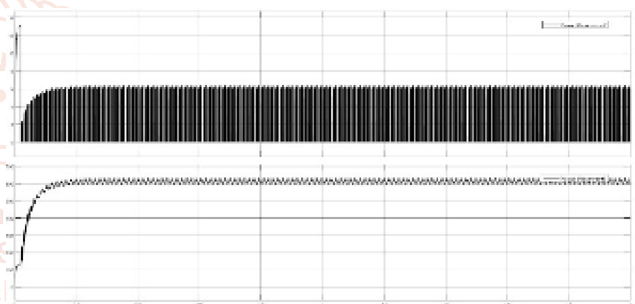

Figure 7: Voltage & Current Vs Time in (S)

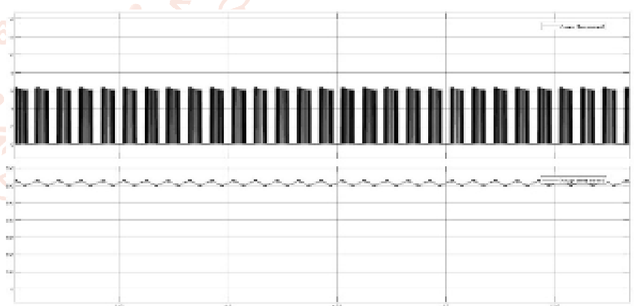

Figure 8: Voltage & Current Vs Time in (S)

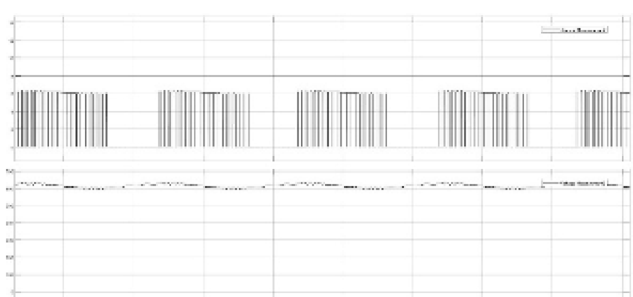

Figure 9: Voltage & Current Vs Time in (S)

Figures. 10 & 11 Shows Experimental inverter output voltages with modulation compensation _Cascaded H Bridge Multilevel Inverter Output Voltage Wave form.

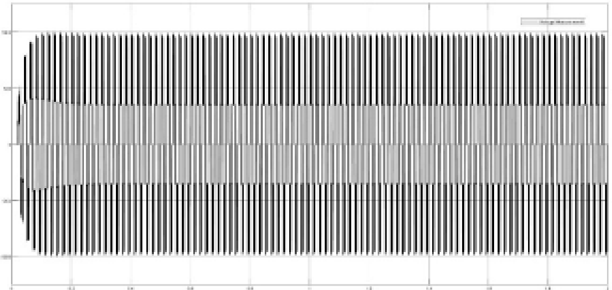

Figure 10: PV Voltage, PV Current & PV Power Vs Time in (S)

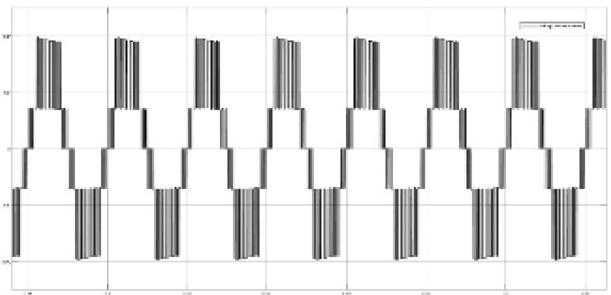

Figure 11: PV Voltage, PV Current & PV Power Vs Time in (S)

4. CONCLUSION

Dual Diode Photovoltaic Model Cascaded H-Bridge Multilevel PV Inverter with MPPT Booster Algorithms for Grid-Connected Applications presented in this work show that cascading H-bridge multilevel inverters are the most suitable inverter topologies for grid-connected applications. CH-MLI are performed, and a phase-shifted SPWM (PS-SPWM) switching scheme is then applied to control the switching devices of each H-bridge. The control scheme allows for high PV module utilisation and improves the overall efficiency of the PV system. The distorted grid current caused by PV mismatches is solved by modulation compensation without increasing the difficulty of the control system or causing extra power loss. Even though the capacity for balancing grid current is limited, the compensation scheme helps reduce the percentage of unbalanced grid current. And it also helps to avoid overmodulation. Hence, the findings indicate that the CHMLI produces the lowest THD contents and utilises fewer components. Moreover, the PS-SPWM produces less THD than SPWM.

REFERENCES

[1] Rushikesh Mali; Nitin Adam; Akshay Satpaise; A. P. Vaidya "Performance Comparison of Two Level Inverter with Classical Multilevel Inverter Topologies" 2019 IEEE International Conference on Electrical, Computer and Communication Technologies (ICECCT).

[2] Shengwen Fan; Yongji Yu; Yongchang Zhang; Haitao Yang "Multi-mode Synchronized PWM Schemes for three-level NPC Inverter" 2019 22nd International Conference on Electrical Machines and Systems (ICEMS).

[3] V. Anil Kumar; M. Arounassalame "Comparison of CHB Multi level inverters using Level shifted Modulation techniques with closed loop PI control" 2018 4th International Conference on Electrical Energy Systems (ICEES).

[4] Ryosuke Kikuchi; Ryunosuke Araumi; Tomoki Yokoyama" Deadbeat control for Multi-level Inverter using 1MHz Multisampling Method for Utility Interactive System" Ryosuke Kikuchi; Ryunosuke Araumi; Tomoki Yokoyama 2018 International Power Electronics Conference (IPEC-Niigata 2018 - ECCE Asia).

[5] Gurcharan Singh; Vijay Kumar Garg "THD analysis of cascaded H-bridge multi-level inverter" 2017 4th International Conference on Signal Processing, Computing and Control (ISPCC).

[6] Sayeeda Farzana; Y. Sumith; K. Ravisankar "Performance enhancement of three phase induction motor by using multi-level inverter" 2017 International Conference on Innovative Mechanisms for Industry Applications (ICIMIA).

[7] Martin Cheerangal Joy; Jayanand B "Three-phase infinite level inverter fed induction motor drive" 2016 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES).

[8] Ben Bing; Zhang Chunjiang; Guo Zhongnan; Zhao Xiaojun "Three phase three level inverter digital control based on over sample and multi-time calculation" 2016 IEEE 8th International Power Electronics and Motion Control Conference (IPEMC-ECCE Asia).

[9] A. Madhukar Rao; N. Kiran Kumar; K. Sivakumar "A multi-level inverter configuration for 4n pole induction motor drive by using conventional two-level inverters" 2015 IEEE International Conference on Industrial Technology (ICIT).

[10] Abhishek Kumar Ranjan; D. Vijaya Bhaskar; Nibedita Parida "Analysis and simulation of cascaded H-bridge multi-level inverter using level-shift PWM technique" 2015 International Conference on Circuits, Power and Computing Technologies [ICCPCT-2015].

[11] Rakesh Kumar Dhal; Tapas Roy “A comparative study between different multi-level inverter topologies for different types of bus clamping PWM techniques using Six Region Selection Algorithm” Michael Faraday IET International Summit 2015.

[12] Martin Votava; Tomas Glasberger “Comparative study of pulse width modulation techniques for three-level voltage source based on cascaded connection of two-level inverters” 2015 16th International Scientific Conference on Electric Power Engineering (EPE).

[13] V Ravi Kumar; A. Sreedevi “Design and development of Z-source multi-level inverter for solar energy” 2015 International Conference on Applied and Theoretical Computing and Communication Technology (iCATccT).

[14] Saketh Dogga; Sumanth Kumar A. V; Umasankar S. “A new nine level symmetrical inverter derived from seven level inverter” 2014 International Conference on Advances in Electrical Engineering (ICAEE).

[15] Manoj Hirani; Sushma Gupta; D. M. Deshpande “Comparison of performance of induction motor fed by sine pulse width modulated inverter and multi-level inverter using XILINX” 2014 IEEE International Conference on Advanced Communications, Control and Computing Technologies.

[16] Luyao Xie; Jun Qi; Guoqing Weng; Youbing Zhang “Multi-level PV inverter with photovoltaic groups independent MPPT control” 2014 17th International Conference on Electrical Machines and Systems (ICEMS).

[17] Meher Kalyan U; Sivakumar K “Switching panels for complete utilisation of battery banks in multi-level inverters for PV systems” 2014 14th International Conference on Environment and Electrical Engineering.

[18] Debanjan Roy; Tapas Roy “A new technique to implement conventional as well as advanced Pulse Width Modulation techniques for multi-level inverter” 2014 IEEE 6th India International Conference on Power Electronics (IICPE).

[19] Pedram Sotoodeh; Ruth Douglas Miller “A single-phase 5-level inverter with FACTS capability using modular multi-level converter (MMC) topology” 2013 International Electric Machines & Drives Conference

[20] Abdessattar Guermazi; Karima Halfaoui “Direct space vector PWM algorithm for multilevel inverters independent of that of two levels with neutral point balancing” 10th International Multi-Conferences on Systems, Signals & Devices 2013 (SSD13).

[21] Ilhami Colak; Ersan Kabalci; Gokhan Keven “Comparision of multi-carrier techniques in seven-level asymmetric cascade multilevel inverter” 4th International Conference on Power Engineering, Energy and Electrical Drives Year: 2013.

[22] Bhanu Naga V Angirekula; Olorunfemi Ojo “Modeling and analysis of single phase multi string five level inverter for distributed energy resources” IECON 2013 - 39th Annual Conference of the IEEE Industrial Electronics Society.

[23] Danjiang Chen; Yinzhong Ye; Rong Hua “Fault diagnosis of three-level inverter based on wavelet analysis and Bayesian classifier” 2013 25th Chinese Control and Decision Conference (CCDC).

[24] Masoud Soleimanipour; Hamed Sadeghi Goughari; Nader Sargolzaei “Analysis and Comparison of Multi-level Inverters Based on Two-Level Space Vector PWM” 2012 UKSim 14th International Conference on Computer Modelling and Simulation.

[25] Musamer Shamil; Mohamed Darwish; Christos Marouchos “Single phase Multi level inverter with desire harmonics” 2012 47th International Universities Power Engineering Conference (UPEC).

[26] P. RoshanKumar; P. P. Rajeevan; K. Mathew; K. Gopakumar; Jose I. Leon; Leopoldo G. Franquelo “Common-mode voltage eliminated three-level inverter using a three-level flying-capacitor inverter and cascaded H-Bridge” 2012 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES).

[27] G. Preethi; J. Gayathri Monika; V. Jamuna “Digital simulation of multicarrier PWM strategy for multi-level inverter” 2012 International Conference on Computing, Electronics and Electrical Technologies (ICCEET).

[28] E. Prasad; A. Sudhakar; Vijay Kumar "Simulation of five-level inverter fed PMSM based on fast SVPWM" 2012 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES).

[29] Ben Slimene Marwa; Khlaifi Mohamed Larbi; Ben Fredj Mouldi; Rehaoulia Habib "Modeling and analysis of double stator induction machine supplied by a multi-level inverter" 2012 16th IEEE Mediterranean Electrotechnical Conference.

[30] Dmitry Baimel; Raul Rabinovici; Jacek Tomasik; Adrian Zuckerberger; Dmitriy Tokar "Five-level H-bridge inverter fed by multi-pulse rectifier" 2012 IEEE 27th Convention of Electrical and Electronics Engineers in Israel.