RESEARCH ARTICLE OPEN ACCESS

PV To Grid Connected Cascaded T-type Multilevel Inverter with Improved Harmonic Performance

Aakankshajain, Prof. Deepak pandey
M. Tech Scholar, Assistant Professor
Department of Electrical and Electronics Engineering
Technocrats institute of technology, Bhopal

ABSTRACT
In recent trend of using green energy, grid connected photovoltaic (PV) system are getting popular. This paper presents, the modeling of multilevel inverter based grid connected PV system is carried out using MATLAB/ Simulink. The multilevel inverter topology is developed by the cascade connection of three-level T-type inverter as it combines the positive aspects of the two-level-converter such as low conduction losses, small part count and a simple operation principle with advantages of three-level-converter such as low switching losses, and good output voltage quality. T-type inverter is used due to its buck mode operation, also. The maximum power is extracted from PV array with MPPT algorithm perturbs & observes. In this work new multicarrier based pulse width modulation technique are proposed for cascaded T-type multilevel inverter. The simulation results demonstrate the effectiveness of proposed control method for CT^2MLI based grid connected PV system.
Keywords: -Solar Power, PV Array, Inverter, Seven Level, Cascaded Multilevel

---

Date of Submission: 13-09-2021 Date of Acceptance: 28-09-2021

I. INTRODUCTION

The multilevel inverter achieves higher power rating by using a series of semiconductor switches with several low voltage DC sources to perform the power conversion by synthesizing a staircase voltage waveform. Batteries, rectifier with capacitors, and renewable energy systems are used as the multiple DC voltage sources. The switching of the power switches in the multilevel inverter add these multiple DC sources in order to achieve higher voltage at the output and voltage rating of the power semiconductor switches depends on rating of DC bus voltage to which they are connected. A multilevel inverter has several advantages over a conventional two-level inverter that uses high switching frequency pulse width modulation (PWM) technique.

Quality of output voltage: Multilevel inverters generate the output voltage with very low distortion and additionally reduce the dv/dt stresses in power semiconductor switches. Therefore electromagnetic compatibility (EMC) problems are significantly minimized.

Quality of input current: Multilevel inverters draw input current with very low distortion.

Quality of common mode voltage: Multilevel inverters produce smaller common mode (CM) voltages; therefore, the stress in the bearings of a motor can be lowered.

Effect of switching frequency: Multilevel inverters can operate either at low (fundamental) switching frequency or high switching frequency PWM technique. It should be noted that lower switching frequency usually means lower switching loss.

A voltage level of three is considered to be the smallest number in multilevel inverter topologies. Due to the bi-directional switches, the multilevel voltage source converter (VSC) can work in both rectifier and inverter modes. This is why most of the time it is referred to as a converter instead of an inverter. A multilevel converter can switch either its input or output nodes (or both) between multiple (more than two) levels of voltage or current. As the number of levels increases to reach infinity, the output total harmonic distortion (THD) approaches to zero. The number of the achievable voltage levels, however, is limited by voltage-imbalance problems, voltage clamping requirements, circuit layout and packaging constraints, complexity of the controller, and, of course, capital and maintenance costs. The more number of semiconductor switches in the multilevel inverters has a negative impact on the reliability and on the overall efficiency. On the other hand, using inverters with low number of semiconductor switches need's large and expensive LC filters to limit insulation stress of motor windings or can be applied for motors that can withstand this stress. Three different major multilevel inverter structures have been used in industrial applications such as cascaded H-bridge inverter with isolated DC sources, diode clamped inverter, and flying capacitor inverter. The different multilevel inverter structures are discussed in this chapter; and each type of multilevel inverter, may be suitable for specific application due to its structure and benefits.

The three topologies of the MLI namely, the CMLI, the NPC inverter, and the flying capacitor inverter, have aroused the widest interest to date. The CMLI has an advantage over the NPC inverter and flying capacitor inverter topologies owing to its modular circuit layout and packaging, since each level has the same structure, and there are no extra clamping diodes or voltage balancing capacitors. The number of voltage levels in CMLI can be easily increased without any complication, by including additional full-bridge modules in series. The drawback of the CMLI is the need for a separate DC source for each module, while the other two inverters (NPCI and FCI) require only one DC source.

II. PV ARRAY

The photovoltaic cell converts the light energy into electrical energy depending on the irradiation of the sun and temperature in the atmosphere. Basically PVC is a PN junction diode [8] [4]. But in PN junction diode DCI AC source is needed to work, but here light energy is used as a source to produce DC output. PVC is a current control source not a voltage control source. The equivalent electrical circuit diagram of PVC is shown in the Figure 1.

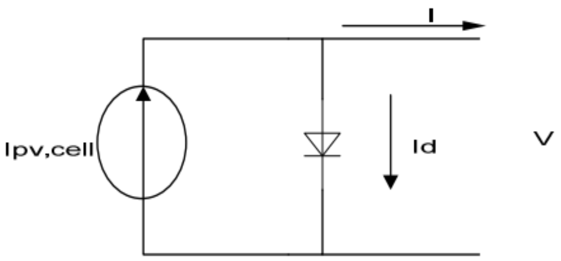


Figure 1: Show ideal photovoltaic cell equivalent circuit

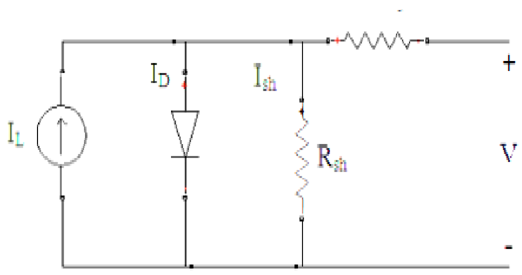


Figure 2: Equivalent Electrical Circuit of PVC

$$I_D = I_0[\exp(V + IR_S)/KT - 1] \quad (1)$$

Therefore PVC output current is given in equation 2.

$$I = I_L - I_D - I_{Sh} \quad (2)$$

$$I = I_L - I_0[\exp(q(V + IR_S))/KT - 1] - (V + IR_S)/R_{Sh} \quad (3)$$

Where I_D the diode is current, R_{sh} is the shunt resistance, I_L is the light generated current of solar array. Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation. Under the influence of the internal electric fields of the p-n junction, these carriers are swept apart and create a photocurrent which is directly proportional to solar insolation. PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature.

MPPT ALGORITHM:- Because of the lesser efficiency of photovoltaic array most of the energy, impacting over array gets wasted. The algorithm known as maximum power point tracking may be helpful to enhance the performance of solar panel. The MPPT algorithm works on principal of Thevenin, according which the power output of a circuit is maximum when impedance of circuit matches with the load of impedance. So now we have to match the impedance instead of tracking maximum power point.

There are different techniques used to track the maximum power point. Few of the most popular techniques are:

- Perturb and observe (hill climbing method)
- Incremental Conductance method
- Fractional short circuit current
- Fractional open circuit voltage
- Neural networks
- Fuzzy logic

Perturb and observe

The P&O algorithm and "hill-climbing", both names refer to the same algorithm depending on how it is implemented. The basic difference between these two is that Hill-climbing involves a deviation of the duty cycle of the power converter and in P&O anxiety on the operating voltage of the DC link between the PV array and the power converter takes place [3]. The deviation of duty cycle of the power converter is the modification of the voltage of DC link between the PV array and the power converter refer as Hill-climbing, so both names refer to the same technique. What should be the next perturbation is decided by considering the sign of the last perturbation and the sign of the last increment in the power.

The perturbation will remain in the same direction if power is incremented, and if power is decreased then next perturbation will be in the opposite direction. The process will be repeated until the point of maximum power will be reached. Then the operating point oscillates around the MPP.

Incremental conductance

The slope of the curve between power and voltage of PV module is the deciding factor in incremental conductance algorithm, if it is zero it shows point of MPP positive (negative) on the left of it and negative (positive) on the right.

- $\Delta V/\Delta P = 0$ at the MPP
- $\Delta V/\Delta P > 0$ on the left
- $\Delta V/\Delta P < 0$ on the right

The change of MPP voltage is identified by comparing the change of the power to increment of the voltage of current curve.

Fractional short circuit current

Fractional short circuit current method states that the ratio between array voltage at maximum power V_{MPP} to its open circuit voltage V_{OC} is nearly constant.

$V_{MPP} \approx k_1 V_{OC}$

The constant K_1 is having value between 0.71 to 0.78. Now the value of V_{MPP} can be calculate by periodically measuring V_{OC}. This method is simple and cheap to implement but its efficiency is relatively low due to the utilization of inaccurate values of the constant k1 in the computation of V_{MMP}.

Total Harmonic Distortion

The total harmonic distortion (THD or THDi) is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. Distortion factor, a closely related term, is sometimes used as a synonym.

In audio systems, lower distortion means the components in a loudspeaker, amplifier or microphone or other equipment produce a more accurate reproduction of an audio recording.

In radio communications, devices with lower THD tend to produce less unintentional interference with other electronic devices. Since harmonic distortion tends to widen the frequency spectrum of the output emissions from a device by adding signals at multiples of the input frequency, devices with high THD are less suitable in applications such as spectrum sharing and spectrum sensing.

In power systems, lower THD implies lower peak currents, less heating, lower electromagnetic emissions, and less core loss in motors.

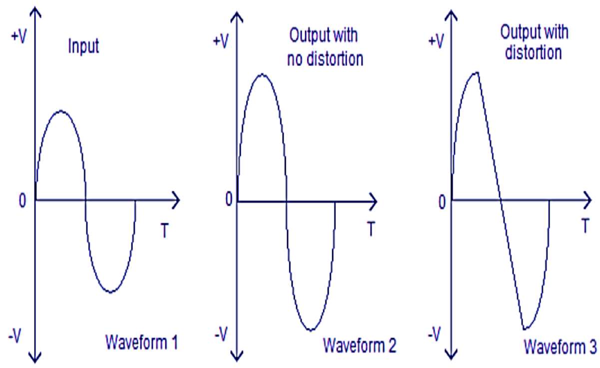


Figure 3: Output Waveform of Distortion

III. PROPOSED METHODOLOGY

Renewable energy sources use to generate green energy for reduce environment pollution problem. In this work build a PV system that is transmit a power to the grid. A grid connected photovoltaic system is becoming increasingly important for the solution in renewable energy. Various types of inverter have been proposed for PV grid connected application such as multilevel inverters, current source inverter, voltage source inverter and etc. In this block diagram shows PV to grid connected system. This work processed in two stage where, stage one is the DC-DC boost converter with MPPT (Maximum power point) tracking and second stage is the seven-level inverter. For this stage proposed a new five-level inverter topology which is reduce the switched count and other parameters. After this stage leveled output passes through designed LCL filter which gives AC output and connected to grid

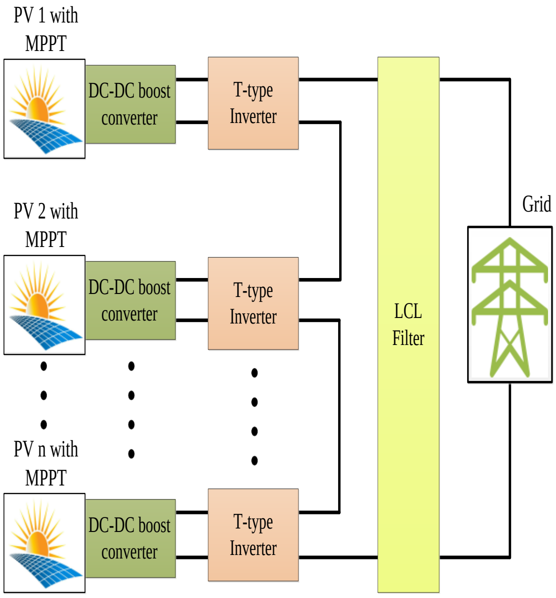


Figure 4: Representation of cascaded PV to grid connected system

Designing of T-Type Inverter

In this work proposed a T-type inverter which is suitable to connect PV and transmit a power to the grid. Proposed inverter generates a three-level at the output of the inverter as $V_{dc}/2$, 0, $-V_{dc}/2$. Proposed topology is represented in figure 4.2. This topology has 2 unidirectional switch and 1 bidirectional switch and it have 2 capacitors as a dc-bus capacitor which is connected after the first stage which is DC-DC boost converter. Levelled voltage as a three-level voltage occurs at the output of the inverter. By connected three modules in the cascaded form we can create 7-level as a levelled output of the inverter. This cascaded T-type system provides a levelled voltage as $1.5V_{dc}$, $1V_{dc}$, $0.5V_{dc}$, 0, $-0.5V_{dc}$, $-1V_{dc}$, $-1.5V_{dc}$.

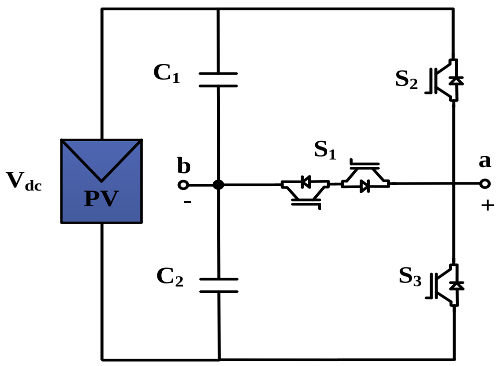


Figure 5: Proposed T-type inverter topologies

DC-DC Boost Converter

DC-DC boost converter used for constant output voltage for grid connected photovoltaic application system. The boost converter is designed to step up a fluctuating solar panel voltage to a higher constant DC voltage. It uses voltage feedback to keep the output voltage constant. To do so, a microcontroller is used as the heart of the control system which it tracks and provides pulse-width-modulation signal to control power electronic device in boost converter. The boost converter will be able to direct couple with grid-tied inverter for grid connected photovoltaic system.

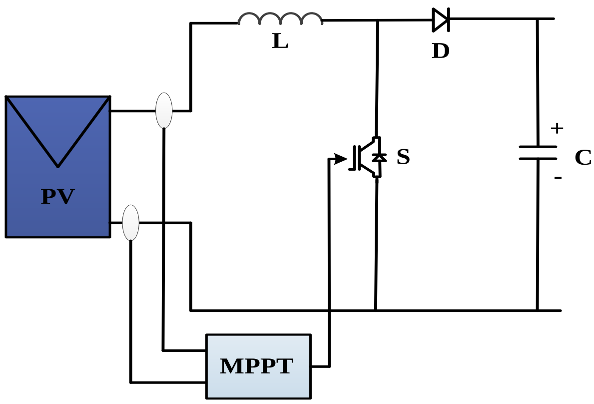
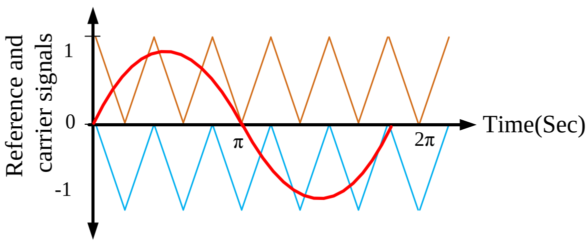


Figure 6: DC-DC boost converter with MPPT tracking

PWM Signal

The PWM method should be used to produce necessary switching pulses in order to provide a low and fixed switching frequency suitable for high power and industrial applications. Some switching techniques, such as hysteresis, have a variable switching frequency, which causes irritating audible noises. To modulate the measured reference signal, carriers are transferred vertically.



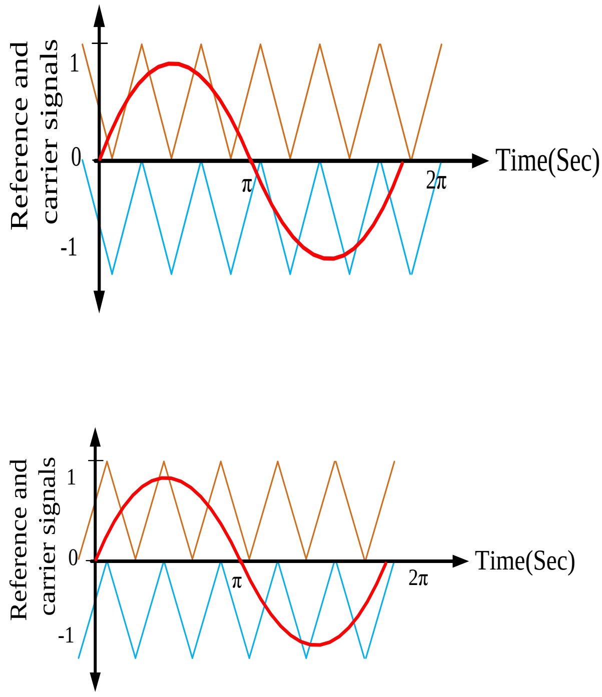


Figure 7: Level shifted PWM reference and carrier signals (a) For module-1 with zero phase shift in carrier signal (b) For module-2 with 120° phase shift in carrier signal (c) For module-3 with 240° phase shift in carrier signal

Grid Synchronization

The number of PV installations has an exponential growth, mainly due to the governments and utility companies that support programs that focus on grid-connected PV systems.

In a general structure distributed system, the input power is transformed into electricity by means of a power conversion unit whose configuration is closely related to the input power nature. The electricity produced can be delivered to the local loads or to the utility network, depending where the generation system is connected.

One important part of the distributed system is its control. The control tasks can be divided into two major parts:

(1) Input-side controller: Its main property is that it can extract the maximum power from the input source. Naturally, protection of the input-side converter is also important to be considered.

(2) Grid – side controller: It performs the following:

(a) It controls the active power generated

(b) It controls the reactive power transfer between the PV and the grid

(c) Control of the dc-link voltage is done by the grid-side controller

(d) It ensures high quality of the injected power

The items listed above for the grid-side controller are the basic features this controller should have. In addition to the above, auxiliary services like voltage harmonic compensation, active filtering or local voltage and frequency regulation might be requested by the grid operator.

The necessity of voltage feed forward and cross-coupling term is the major drawback of the control structure implemented in synchronous reference frame. In addition to that the phase angle of the grid voltage is a must in this implementation. In the case of control structure implemented in a stationary reference frame, if PR controllers are used for current regulation, the complexity of the control becomes lower compared to the structure implemented in dq frame. In addition to that, the phase angle information is not a necessity, and filtered grid voltages can be used as templates for the reference current waveform.

IV. SIMULATION RESULT

This work simulates at a 2 KW power rating and use a PV module as 1 parallel and 6 series connected string at specific module. Also, specified 290 maximum dc output voltage. Graph plot of current and power with respect to voltage shown in figure 8.

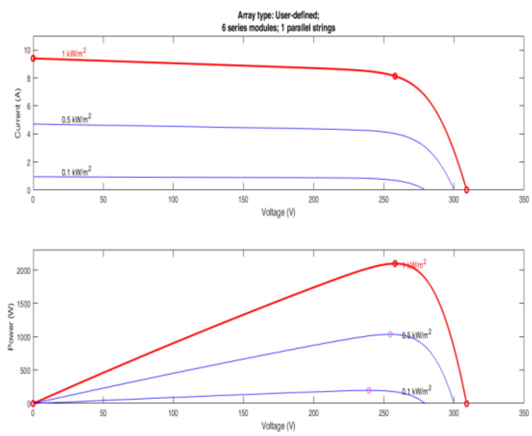


Figure 8: PV power and current with respect to voltage

This three-level inverter generates a levelled AC voltage as a form of $+V_{dc}/2$, 0, $-V_{dc}/2$. For increasing power of the system introduce a cascading method but it increases the output voltage peak of the system. By using T-type inverter we can reduces the peak of the voltage because it's worked in a buck-mode here peak of the output voltage is $V_{dc}/2$. Three-level output voltage of the T-type converter shown in figure 5.4. PWM switching pulsed which is applied to operates a three-level inverter shown in figure 5.5. By the cascading of these three-module generates a seven-level at the output of the system which is shown in figure 5.6.

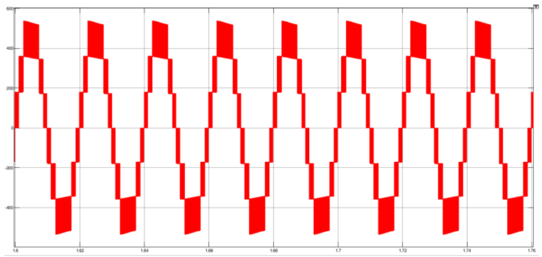


Figure 9: Cascaded seven-level output voltage waveform

This work also reduces the harmonics of the grid current and grid voltage by the use of LCL filter at the grid side. For verification of reduced harmonics FFT analysis is done by using MATLAB platform. FFT analysis of grid voltage and grid current shown in figure 10 and figure 11 respectively. In an analysis of grid voltage harmonics only present fundaments component at the 50Hz frequency so 100% power presents in this component.

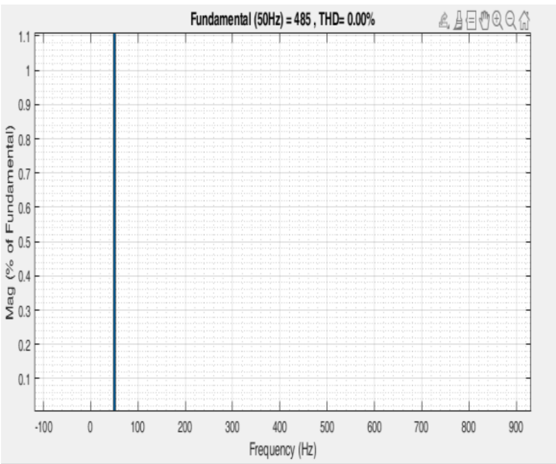


Figure 10: FFT analysis of grid voltage

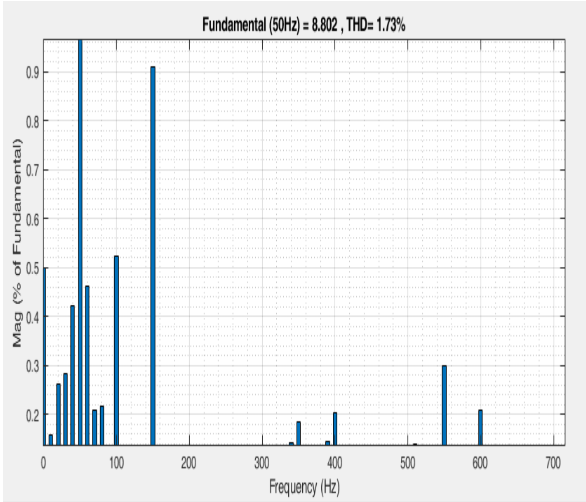


Figure 11: FFT analysis of grid current

V. CONCLUSION

For connection of renewable energy source to the grid required a power electronics converter. PV system generates a power in a form of DC so here required an inverter which is convert this dc power to the levelled AC power. It is a second stage of the proposed system in this stage convert DC voltage into the levelled AC voltage and cascaded T-type inverter used in this stage. By using of single T-type inverter generates a three-level at the output although cascaded of three modules through T-type inverter generates seven-level at the point of levelled AC output.

This proposed system simulates and design on 2.5kW power and inverter working on 10KHz switching frequency. At this high frequency and specific power justified that this system is highly efficient and reduces a power loss in between the power converter.

Similarly in the grid current analysis maximum power component present in the same 50Hz frequency also second maximum component present at the 150Hz frequency but its only 0.9% so 99.1% component present at the grid frequency so its justified that its reduces the harmonics.

REFERENCES

[1]. M. Abarzadeh and K. Al-Haddad, “An improved active-neutral-point-clamped converter with new modulation method for ground power unit application,” IEEE Trans. Ind. Electron., vol. 66, no. 1, pp. 203–214, Jan. 2019.

[2]. Y. P. Siwakoti, “A new six-switch five-level boost-active neutral point clamped (5L-Boost-ANPC) inverter,” in Proc. IEEE Appl. Power Electron. Conf. Expo., 2018, pp. 2424–2430.

[3]. A. K. Yadav,M. Boby, S. K. Pramanick, K.

Gopakumar, L. Umanand, and L. G. Franquelo, “Generation of high-resolution 12-sided voltage space vector structure using low-voltage stacked and cascaded basic inverter cells,” IEEE Trans. Power Electron., vol. 33, no. 9, pp. 7349–7358, Sep. 2018.

[4]. W. Li, J. Hu, S. Hu, H. Yang, H. Yang, and X. He, “Capacitor voltage balance control of five-level modular composited converter with hybrid space vector modulation,” IEEE Trans. Power Electron., vol. 33, no. 7, pp. 5629–5640, Jul. 2018.

[5]. D. Cui and Q. Ge, “A novel hybrid voltage balance method for five-level diode-clamped converters,” IEEE Trans. Ind. Electron., vol. 65, no. 8, pp. 6020–6031, Aug. 2018.

[6]. W. Sheng and Q. Ge, “A novel seven-level ANPC converter topology and its commutating strategies,” IEEE Trans. Power Electron., vol. 33, no. 9, pp. 7496–7509, Sep. 2018.

[7]. H. Tian, Y. Li, and Y. W. Li, “A novel seven-level-hybrid clamped (HC) topology for medium-voltage motor drives,” IEEE Trans. Power Electron., vol. 33, no. 7, pp. 5543–5547, Jul. 2018.

[8]. Y. P. Siwakoti and F. Blaabjerg, “Common-ground-type transformerless inverters for single-phase solar photovoltaic systems,” IEEE Trans. Ind. Electron., vol. 65, no. 3, pp. 2100–2111, Mar. 2018.

[9]. N. D. Dao and D.-C. Lee, “Operation and control scheme of a five-level hybrid inverter for medium-voltage motor drives,” IEEE Trans. Power Electron., vol. 33, no. 12, pp. 10178–10187, Dec. 2018.

[10]. H. Wang, L. Kou, Y.-F. Liu, and P. C. Sen, “A seven-switch five-level active-neutral-point-clamped converter and its optimal modulation strategy,” IEEE Trans. Power Electron., vol. 32, no. 7, pp. 5146–5161, Jul. 2017.

[11]. J. Rodríguez, S. Bernet, B. Wu, J. O. Pontt, and S. Kouro, “Multilevel voltage-source-converter topologies for industrial medium-voltage drives,” IEEE Trans. Ind. Electron., vol. 54, no. 6, pp. 2930–2945, Dec. 2007.

[12]. F. Z. Peng, “A generalized multilevel inverter topology with self-voltage balancing,” IEEE Trans. Ind. Electron., vol. 37, no. 2, pp. 611–618, Feb. 2001.

[13]. F. Rong X. Gong and S. Huang "A novel grid-connected PV system based on MMC to get the maximum power under partial shading conditions" IEEE Trans. Power Electron. vol. 32 no. 6 pp. 4320-4333 Jun. 2017.

[14]. H. Wang, L. Kou, Y.-F. Liu, and P. C. Sen, “A seven-switch five-level active-neutral-point-clamped converter and its optimal modulation strategy,” IEEE Trans. Power Electron., vol. 32, no. 7, pp. 5146–5161, Jul. 2017.

[15]. G. Farivar B. Hredzak and V. G. Agelidis "A dc-side sensorless cascaded H-bridge multilevel converter-based photovoltaic system" IEEE Trans. Ind. Electron. vol. 63 no. 7 pp. 4233-4241 Jul. 2016.

[16]. Y. Yu G. Konstantinou B. Hredzak and V. G. Agelidis "Power balance of cascaded H-bridge multilevel converters for large-scale photovoltaic integration" IEEE Trans. Power Electron. vol. 31 no. 1 pp. 292-303 Jan. 2016.

[17]. J. I. Leon S. Kouro L. G. Franquelo J. Rodriguez and B. Wu "The essential role and the continuous evolution of modulation techniques for voltage-source inverters in the past present and future power electronics" IEEE Trans. Ind. Electron. vol. 63 no. 5 pp. 2688-2701 May 2016.

[18]. Y. Yu G. Konstantinou B. Hredzak and V. G. Agelidis "Operation of cascaded H-bridge multilevel converters for large-scale photovoltaic power plants under bridge failures" IEEE Trans. Ind. Electron. vol. 62 no. 11 pp. 7228-7236 Nov. 2015.

[19]. H. Snani M. Amarouayache A. Bouzid A. Lashab and H. Bounechba "A study of dynamic behaviour performance of DC/DC boost converter used in the photovoltaic system" Proc. IEEE 15th Int. Conf. Environ. Elect. Eng. pp. 1966-1971 2015.

[20]. Bayhan, S & Abu-Rub, H 2015, 'Model predictive control of quasi-z source three-phase four-leg inverter', in 41st Annual Conference of the IEEE Industrial Electronics Society, IECON 2015, pp. 362-367.

[21]. R. J. Wai, C. Y. Lin, C. Y. Lin, R. Y. Ouan, and Y. R. Chang, "High efficiency power conversion system for kilowatt-level stand-alone generation unit with low input voltage," IEEE Irans. Ind. Electron. vol. 55, no. 10, pp. 3702- 3714, Oct. 2008.