https://doi.org/10.29042/2020-10-2-38-42

Helix (2020) 10 (2): 38-42

Review on Solar PV Application Oriented Multilevel Inverters

[*1]Kalyani M. Gajbhiye,[2]Manisha Pandey, [3]Vijay B. Borghate,[4]Sidharth Sabyasachi,[5]Hari Babu Gobburi
[1,2,3,4,5] Visvesvaraya National Institute of Technology
Email: kalayanigajb7114@gmail.com, pandeymanisha45104@gmail.com, vijay_borghate@rediffmail.com, sidharth.mana@gmail.com, haribabugobburi@gmail.com

Received: 20th November 2019, Accepted: 31st January 2020, Published: 30th April 2020

Abstract
Multilevel inverter is one of the leading research topics over last decades and it has various applications in industries. Now days, more emphasis given on integration of renewable energy sources with convention sources to reduce the dependency on conventional sources as they face problem like environmental issues, non-availability of fuel, etc. So, various multilevel inverter topologies, control techniques, applications in renewable energy sources and problem faced in power generation and solutions being developed for effective link between renewable energy sources and grid. This paper aim to review on some of the topologies, control technique which are developed recently.

Keywords
Multilevel Inverters, Pulse Width Modulation, Power Quality, Renewable Energy Sources (RES), Solar PV.

Introduction

The multilevel inverter (MLI) is one of the most recent research topics because of its usability in each and every application. The multilevel structure is an alternative in high power and medium voltage situation. The MLI is used to achieve higher power and to use semiconductor switches with several lower voltages dc levels to carry out the conversion by synthesising a stepped waveform. [1] For obtaining multiple input dc levels batteries, capacitors, and renewable energy voltage sources can be used so as to generate high voltage at the output. Rated voltage of the power semiconductor switches depends on the dc voltage sources from which they are connected. Therefore, the voltage stress on a power switch is lower than the operating voltage. The classifications of inverter are shown in Fig. 1.

Advantages of multilevel inverters are:

- Improved Harmonic profile and low dv/dt stresses. Thus, the filter requirement can be reduced.
- Common mode voltages produced by multilevel inverter is smaller and thus, the stress can be reduced in the bearings of a motor connected to a multilevel motor drive.
- With multiple switching combinations a given voltage level can be achieved. These redundant states can be employed to program fault tolerant operations.
- Input current drawn by MLIs has low distortion.
- Renewable energy sources can be easily interfaced to a multilevel inverter which can be operated for equal load sharing amongst input sources.

Methodology

To reduce undesirable high harmonics content at the output of MLI, modulation techniques and control have attracted a research and observation in the past years. The various modulation techniques employed for the control of Multilevel Inverter are classified based on their switching frequencies such as high switching frequency PWM and fundamental or low switching frequency as shown in Fig. 2. The low switching frequency modulation methods such as Selective Harmonic Elimination (SHE), Space Vector Control technique (SVC), Nearest Level Control technique (NLC) are generally preferred for high-power applications due to advantage of reduced switching losses, while for better power quality output, high switching frequency modulation techniques such as Sinusoidal PWM (SPWM) and Space Vector Modulation (SVPWM) are more suitable for applications with high dynamic range.

Traditional PWM techniques based on multiple carriers use to control each power semiconductor switch of inverter. Therefore, they are known as multicarrier based PWM techniques. [2][3] For inverter with *m* cells, carriers are phase shifted by 180º/m in CHB topology and 360º/m for FC topology are introduced across the cells to generate staircase multilevel output voltage waveform and this technique is known as phase shifted (PS-PWM) PWM technique.

The carriers can also be in the shifted vertically. The level-shifted PWM technique (LS-PWM) and PS-PWM techniques are extensions of carrier based SPWM for NPC topology and for multi-cell inverters topologies like CHB and FC. The LS-PWM depending upon the depending upon the disposition can be phase disposition (PD-PWM), alternate phase opposition disposition (APOD-PWM) and phase opposition disposition (POD-PWM). [4] Another modulation method is multilevel selective harmonic elimination (SHE) unlike carrier based PWM

 Helix E-ISSN: 2319-5592; P-ISSN: 2277-3495

techniques, the switching angles are calculated offline and are designed to eliminate arbitrary harmonics (usually of low order).

Inverters act as link between the renewable energy sources and grid so selection of inverter being of the crucial part. New topologies of multilevel inverter developed which overcome limitation of existing topologies of inverters. The most popular inverters topologies already discussed like cascaded H-bridge inverter [2], Diode clamped or Neutral point clamped (NPC) inverter topology, Flying capacitor inverter (FC) or capacitor clamped inverter topology have some limitations. NPC topology in industrial application is limited to 3-level only because of the series connected capacitors require voltage balancing control. CHB has disadvantage of requirement of isolated dc sources for each cell and FC structure become impractical for increase in levels as it require large device count and difficult to control. Further, hybridized cascaded H-bridge (HCHB) multilevel inverter the only difference is in each cell of H-bridge, clamping or auxiliary switch are added for enhancement in harmonic profile of waveforms which are attained in the output. In comparison to the traditional CHB inverter, the number of components used in this topology is highly reduced for the similar output voltage level. The main limitation of HCHB topology is that it is not suitable for applications where high voltages are required. Modular multilevel converter (MMC) is one of topology used for high power application has disadvantage like capacitor voltage balancing, circulating current.

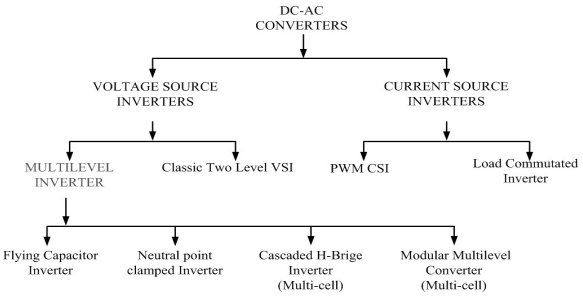

Fig. 1: Classification of Inverter.

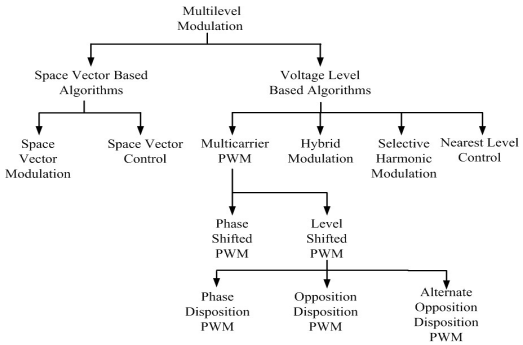

Fig. 2: Classification of Modulation Techniques.

Discussion

Recently Proposed different Multilevel Inverter Topologies

A lot of research papers are published based on various factors of multilevel inverter starting from its topological prospective to its control techniques. Various application oriented topologies are also developed which have attracted the researchers for further improvements. Some of the research papers are considered here and discussed in details.

Hybrid Modular Multilevel Converter (MMC)

A hybrid MMC has been proposed which has several advantages over conventional MMC such as more voltage levels, no circulating current, less capacitor count and better efficiency. [5] In Hybrid MMC the sub-modules are connected in series to form forms a dc-link voltage. Low Frequency Converter (LFC) converts unipolar and multilevel natured dc-link voltage into ac voltage as shown in Fig. 3(a). Here, LFC is a H-bridge converter which operates at fundamental frequency. A global MPPT is proposed which requires voltage and current signals of only one sub-module. It works satisfactorily under uniform shading however its performance deteriorates under partial shading condition. A least MPPT algorithm is proposed for inter phase power unbalance during partial shading condition.

Asymmetric Cascaded H-bridge Multilevel Inverter (ACMI) with Staircase Modulation

For asymmetric cascaded H-bridge multilevel inverter (ACMI) detail understanding of staircase modulation strategy and its application is proposed as shown in Fig. 3(b). [6] The main advantage of using staircase modulation for ACMI is it attains higher number of levels in output voltage with one of ACMI module operate at low frequency. This paper gives close loop control staircase strategy for both isolated and grid connected modes, how power processed in each module by considering three modules of ACMI and solution to improve power distribution in modules of ACMI.

Single Phase Seven Level T-Type

A single phase seven level T-type MLI for grid connected PV inverter in parallel has been proposed as shown in Fig. 3(c). [7] Failure of any source will not stop the overall generation as MLIs are connected in parallel in distributed power generations systems. A controller has also been proposed so as to maintain the DC link voltage as well as the AC voltage level at inverter side and to inject sinusoidal current into the grid. The controller effectiveness has been noticed for sudden change in irradiation and the grid voltage. Comparative study is done for seven level T-type PV inverter and conventional seven level PV inverters on the basis of manufacturing cost and total standing voltage.

  Helix E-ISSN: 2319-5592; P-ISSN: 2277-3495

Asymmetric Cascaded Multilevel Inverter

A 9 level asymmetric cascaded multilevel inverter for grid connected PV system with carrier based level shifted control technique (LSPWM) is proposed as shown in Fig. 3(d) which generates an even power distribution among the cells and leads to less voltage distortion and less current harmonic distortion. [8] Even under the variation of solar irradiance and fluctuating grid voltage, the proposed controller maintains the dc link voltage (1:3) and maintains the unity power factor by injecting sinusoidal current into the grid. And the stability analysis done show that the proposed grid connected system remains stable even under the step of variation of irradiance.

In this paper [9], solar energy conversion system (SECS) based grid-connected cascaded H-bridge multilevel inverter (CHBMLI) suffer from problem of unequal dc link voltages due to various reasons like Partial shading conditions, different rating of the PV panels, different environmental conditions, dust and soiling, cracks in cells, bubble formation, corrosion or bond degradation. Proposed control scheme, balance the dc link voltages along with improvement in power quality of grid voltage and injected current as per standards.

Quasi-Impedance Source Inverters (qZSIs)

Decrease in performance of nine level quasi-impedance source inverters (qZSIs) with fault and its effect on THD and output voltages are discussed. To overcome the effects of fault and increase post fault period performance a novel control algorithm is proposed as shown in Fig. 3(e). [11]

Modified Single Phase Cascaded H-Bridge

A modified single phase 5 level CHB is proposed with 6 switches. [12] The CHB has been chosen for its advantages. With changing levels and the switching frequencies relation of THD is noted. A 7 level with frequency of 6 kHz has been noted to give best performing system but with an LC filter the 5 level and 7 level converter produces same THD level. Thus, 5 level CHB has been chosen because of less complexity. Also, different PWM techniques is investigated and level shifted in-phase disposition PWM technique has been chosen as it has provided the best performance for the proposed system.

Five-Level E-Type Inverter

Three phase five-level E-type inverter (5L E-Type Inverter) is proposed as shown in Fig. 3(f) with a new concurrent control scheme for grid connected applications. [13] Further selection of resonant balancing circuit, dc-bus capacitors, inverter devices and output filter with performance in terms of switching and conduction losses, efficiency, power quality, cost and weight are discussed with experimental validation.

In this paper [8], asymmetrical cascaded H-Bridge (ACHB) is made suitable for high power and high voltage applications. Without connecting the converter to high voltage energy source the proposed switching pattern for the single sourced ACHB inverter having a high frequency link converter can be implemented. Switching patterns applied will optimizes the firing angle such that power flows to auxiliary bridge from main H-bridge is as minimum (less than 5%) as possible and minimum THD is obtained at output of the inverter. The main H-bridge is switched with fundamental frequency which leads to minimum leakage current. The proposed technology has reduced high frequency transformer size and cost.

Modified Pack U-Cell

Modified structure of one phase of pack U-cell (MPUC) MLI is proposed which will generate more output voltage level than available dc link voltage with reduced device count and mainly target photovoltaic grid connected applications.[14] Topology of MPUC, switching algorithm designed in respect with reduced switching losses and boosting operation of MPUC are discussed with experimental validation.

Nine Level Flying Capacitor Inverter Topology

A 9 level FC-based multilevel inverter topology which is an upgrade of 5 level ANPC (active neutral point clamped) is proposed. [15] The proposed converter consists of 5L ANPC with 2 switches working at the line frequency. The output voltage having double peak value than that in conventional 9L ANPC inverter keeping dc-link voltage magnitude identical. A logic gate based balancing method is developed to regulate the FC inverter topology voltage. A comparative evaluation of different MLI had been done and the proposed inverter requires the minimum number of switching semiconductor devices and had the highest level/switch (semiconductor devices) ratio among all topologies.

Modified ANPC

In this paper [16], 9 Level Modified ANPC (MANPC) is derived by 5 level NPC with addition to 2 Level converter leg. The 5 level ANPC requires minimum number of structural disarrangement while extending it into 9-level. In comparison to conventional ANPC the MANPC requires half the number and half voltage rating of dc link voltage sources for generating output voltage with same peak to peak value and number of levels. This is obtained by additional two semiconductor switches working at line frequency. The voltage balancing method is used to regulate the dc link voltage across FC topology, and natural balancing algorithm of the dc link capacitors voltage is presented in this paper with voltage ripple tolerance under acceptable limits. A grid-connected case is considered for the proposed inverter performance examination.

Advantages of multilevel inverters are well known and most famous topology is cascaded H-bridge inverter uses less number of components for generating same voltage levels as compared to other types of multilevel inverters topologies. Thus CHB used in this paper with phase-shifted pulse width modulation technique (PS-PWM). This

  Helix E-ISSN: 2319-5592; P-ISSN: 2277-3495

paper propose conservative power theory (CPT) control strategy for regulation of dc link voltage of each cell of H-bridge and compensation of distorted current due to various disturbing load conditions. [17] The proposed control strategy does not involve any source transformation.

Five Level Packed U-cell

Single phase grid connected 5-level packed U-cell (PUC5) inverter with output filter as LCL is proposed in this paper. [18] Selection of passive elements and converter rating are given based on grid tied operation. Linear quadratic regulator (LQD) with operation as an integral action for injecting sinusoidal nature of currents for lower THD and unity power factor in grid. So, modelling of PUC5 is done in DQ frame. A sensor less capacitor voltage balancing is applied with a switching technique for generating five level output voltage.

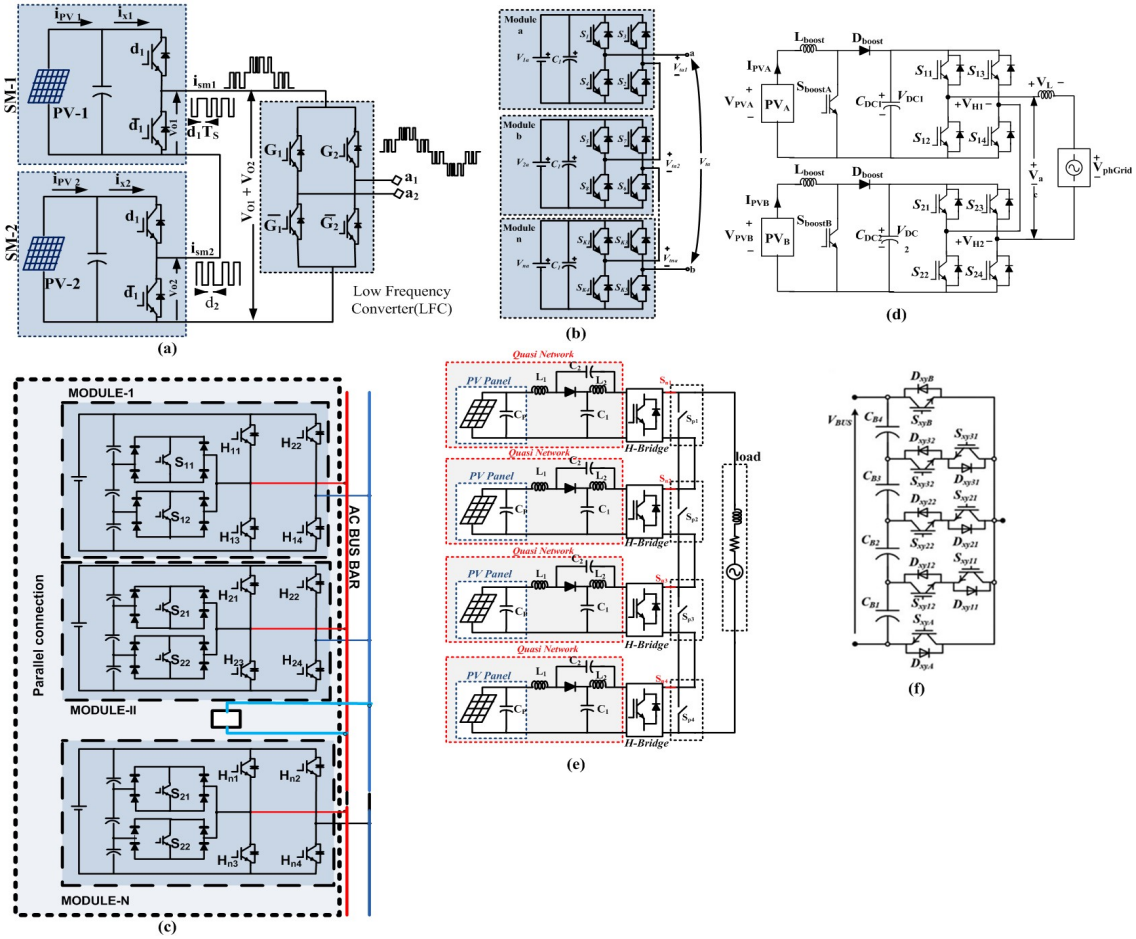

Fig. 3: (a) One Phase of Hybrid MMC, (b) Single Phase Cascaded Multilevel Inverter, (c) N-Parallel-Connected MLI Modules, (d) Gird Connected CHB-MLI, (e) Nine-Level qZSI Connected to Load (RL Load/Utility Grid) provided with Bypass Switches, (f) Single-leg 5L E-Type Inverter Configuration.

Conclusion

The paper discusses some recent topologies which are developed for solar PV applications for both standalone and grid synchronization. Topologies are developed based on different factors like reduced device count, symmetrical as well as asymmetrical source configurations, more voltage levels etc. Different control techniques applicable to multilevel inverter are also discussed based on different switching frequencies. Multilevel inverter improves the power quality as well as the cost of the overall system. Cascaded structure of the multilevel inverter helps to extend the power handling capability and the load can be extended easily by modifying the existing structure. Multilevel inverter also takes care of the fault handling capability which helps during the grid synchronization for continuity of power.

 Helix E-ISSN: 2319-5592; P-ISSN: 2277-3495

References

1. Franquelo L. G., J. Rodriguez, J. I. Leon, S. Kouro, R. Portillo and M. A. M. Prats. June 2008. The age of multilevel converters arrives. IEEE Industrial Electronics Magazine, vol. 2, no. 2, pp. 28-39.
2. Rodriguez J., Jih-Sheng Lai and Fang Zheng Peng. Multilevel inverters: a survey of topologies, controls, and applications. Aug. 2002. IEEE Transactions on Industrial Electronics, vol. 49, no. 4, pp. 724-738.
3. Gupta K. K., A. Ranjan, P. Bhatnagar, L. K. Sahu and S. Jain. . Jan. 2016. Multilevel Inverter Topologies With Reduced Device Count: A Review. IEEE Transactions on Power Electronics, vol. 31, no. 1, pp. 135-151.
4. Carrara G., S. Gardella, M. Marchesoni, R. Salutari and G. Sciutto. 1990. A new multilevel PWM method: a theoretical analysis. IEEE Conference on Power Electronics Specialists, pp. 363-371.
5. Basu, T.S and S. Maiti. Sept.-Oct. 2019. A Hybrid Modular Multilevel Converter for Solar Power Integration. IEEE Transactions on Industry Applications, vol. 55, no. 5, pp. 5166-5177.
6. Busarello,T. D. C., A. L. de Sousa Marcondes Reuter, A. Péres and M. G. Simões. Sept.-Oct. 2019. Understanding the Staircase Modulation Strategy and Its Application in Both Isolated and Grid-Connected Asymmetric Cascaded H-Bridge Multilevel Inverters. IEEE Transactions on Industry Applications, vol. 55, no. 5, pp. 5371-5382.
7. Sinha. A, K. C. Jana, and M. K. Das. 2019. Control strategy of PV-fed, grid-interfaced, seven-level T-type MLI for distributed power generation. IET Power Electronics, vol. 12, no. 12, pp. 3208-3219.
8. Sinha, A, M. K. Das and K. C. Jan. 2019. Control of asymmetrical cascaded multilevel inverter for a grid-connected photovoltaic system. IET Renewable Power Generation, vol. 13, no. 9, pp. 1456-1465.
9. Sharma, B. and J. Nakka. 2019. Single-phase cascaded multilevel inverter topology addressed with the problem of unequal photovoltaic power distribution in isolated dc links. IET Power Electronics, vol. 12, no. 2, pp. 284-294.
10. Rahman, S., M. Meraj, A. Iqbal and L. Ben-Brahim. 2019. Novel voltage balancing algorithm for single-phase cascaded multilevel inverter for post-module failure operation in solar photovoltaic applications. IET Renewable Power Generation, vol. 13, no. 3, pp. 427-437.
11. Shuvo, S., E. Hossain, T. Islam, A. Akib, S. Padmanaban and M. Z. R. Khan. 2019. Design and Hardware Implementation Considerations of Modified Multilevel Cascaded H-Bridge Inverter for Photovoltaic System. IEEE Access, vol. 7, pp. 16504-16524.
12. Benedetto, M. di., A. Lidozzi, L. Solero, F. Crescimbini and P. J. Grbović. Sept-Oct. 2018. Five-Level E-Type Inverter for Grid-Connected Applications. IEEE Transactions on Industry Applications, vol. 54, no. 5, pp. 5536-5548.
13. Ahmed, A., M. Sundar Manoharan and J. Park. March 2019. An Efficient Single-Sourced Asymmetrical Cascaded Multilevel Inverter With Reduced Leakage Current Suitable for Single-Stage PV Systems. IEEE Transactions on Energy Conversion, vol. 34, no. 1, pp. 211-220.
14. Vahedi, H., M. Sharifzadeh and K. Al-Haddad. Sept. 2018. Modified Seven-Level Pack U-Cell Inverter for Photovoltaic Applications. IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 6, no. 3, pp. 1508-1516.
15. Sandeep, N. and U. R. Yaragatti. 2018. Design and implementation of active neutral-point-clamped nine-level reduced device count inverter: an application to grid integrated renewable energy sources. IET Power Electronics, vol. 11, no. 1, pp. 82-91.
16. Sandeep, N. and U. R. Yaragatti. June 2018. Operation and Control of a Nine-Level Modified ANPC Inverter Topology With Reduced Part Count for Grid-Connected Applications. IEEE Transactions on Industrial Electronics, vol. 65, no. 6, pp. 4810-4818.
17. Mortezaei, A., M. G. Simões, T. D. C. Busarello, F. P. Marafão and A. Al-Durra. May-June 2018. Grid-Connected Symmetrical Cascaded Multilevel Converter for Power Quality Improvement. IEEE Transactions on Industry Applications, vol. 54, no. 3, pp. 2792-2805.
18. Arab, N., H. Vahedi and K. Al-Haddad. Jan 2020. LQR Control of Single- Phase Grid-Tied PUC5 Inverter with LCL Filter. IEEE Transactions on Industrial Electronics, vol. 67, no. 1, pp. 297-300.

  Helix E-ISSN: 2319-5592; P-ISSN: 2277-3495