IJAREEIE
e-ISSN: 2278-8875
p-ISSN: 2320-3765

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

Volume 10, Issue 5, May 2021

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 7.122

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 5, May 2021||

DOI:10.15662/IJAREEIE.2021.1005030

Application of Multilevel Inverter in Photovoltaics

Alok Singh Parihar[1], Amita Mahor[2]

Oriental College of Technology, Bhopal, India[1,2]

ABSTRACT: This paper provides an overview of the three basic types of multilevel inverters: diode-clamped, flying-capacitor, and cascaded H-bridge multilevel inverters, as well as their variations in photovoltaic power systems. The electricity provided by a photovoltaic power system is in the DC format. As a result, it must be regulated and transformed into a usable form. An inverter is a device that converts electrical energy into electrical energy. Multilevel inverters have become a popular topic in the field of electric power systems because they can generate a staircase AC output voltage waveform without the use of a large passive filter. This paper presents the state of the art in multilevel inverter technology for photovoltaic power systems, which will be very useful to researchers in tracing the disadvantages in this field of research and, as a result, providing knowledge to address current issues in the near future.

KEYWORDS: photovoltaic power system, multilevel inverter, flying-capacitor, diode-clamped, cascaded H-bridge.

I. INTRODUCTION

The demand for clean energy is growing, resulting in a wide distribution of energy generated by renewable energy sources such as solar, wind, hydro, and other renewable energy sources [1]. The sun is the most significant renewable energy source available on the planet. PV panels transform sunlight into electricity in photovoltaic (PV) power systems. Solar panels produce DC power, which must be managed and transformed into usable forms [2-4]. Researchers have suggested various forms of power inverters. Pulse-width modulated (PWM) multilevel inverters are becoming increasingly common due to their wide range of applications [5]. Their stairwell output voltage has a low total harmonic content.

The three basic types of multilevel inverters are diode-clamped, flying-capacitor, and cascaded H-bridge multilevel inverters [9]. The following sections go over the process, benefits, and drawbacks of diode-clamped, flying-capacitor, and cascaded H-bridge multilevel inverters.

Nowadays, integrating solar energy into the power grid is a difficult task. There have already been several topologies and control methods proposed. The power electronics system that converts DC power to AC power at the desired voltage and frequency is known as an inverter. Inverter demand has risen in recent years for renewable energy applications. Different types of drives are available in the energy sector, and they require low, medium, and megawatt-level capacity. In a renewable energy system, such a requirement is difficult to meet with a traditional inverter topology. A multilevel inverter has been introduced to satisfy the industrial demand. THD reduction and reactive power compensation are also achieved using a multilevel inverter.

Multilevel inverters begin with a three-level inverter. The use of a traditional two-level pulse width modulation (PWM) inverter results in less skewed voltage and current, but switching losses are higher due to the high switching frequency. Due to the lower voltage swing of each switching cycle and the low rate of change of voltage dv/dt of switches, multilevel inverters are becoming more common in practical life as a high power, medium voltage application.

II. DIODE-CLAMPED MULTILEVEL INVERTER AND MODIFICATIONS

This section consists of two subsections as follows: a brief description of diode-clamped multilevel inverter and modified diode-clamped multilevel inverter.

Diode-clamped multilevel inverter

In 1981, the diode-clamped multilevel inverter was introduced by Nabae. First proposed diode-clamped inverter essentially consists of three levels [10]. In the 1990s, researchers published many articles on the

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (IJAREEIE)

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 5, May 2021||

DOI:10.15662/IJAREEIE.2021.1005030

experimental results of four, five, and six-level diode- clamped converter for several uses such as, variable speed motor drive, PV power system and high voltage system interconnections [11-12]. Fig. 1 shows the circuit diagram of a 5-level diode clamped multilevel inverter. It consists of eight power MOSFETs, twelve clamping-diodes, one DC voltage source and four capacitors.

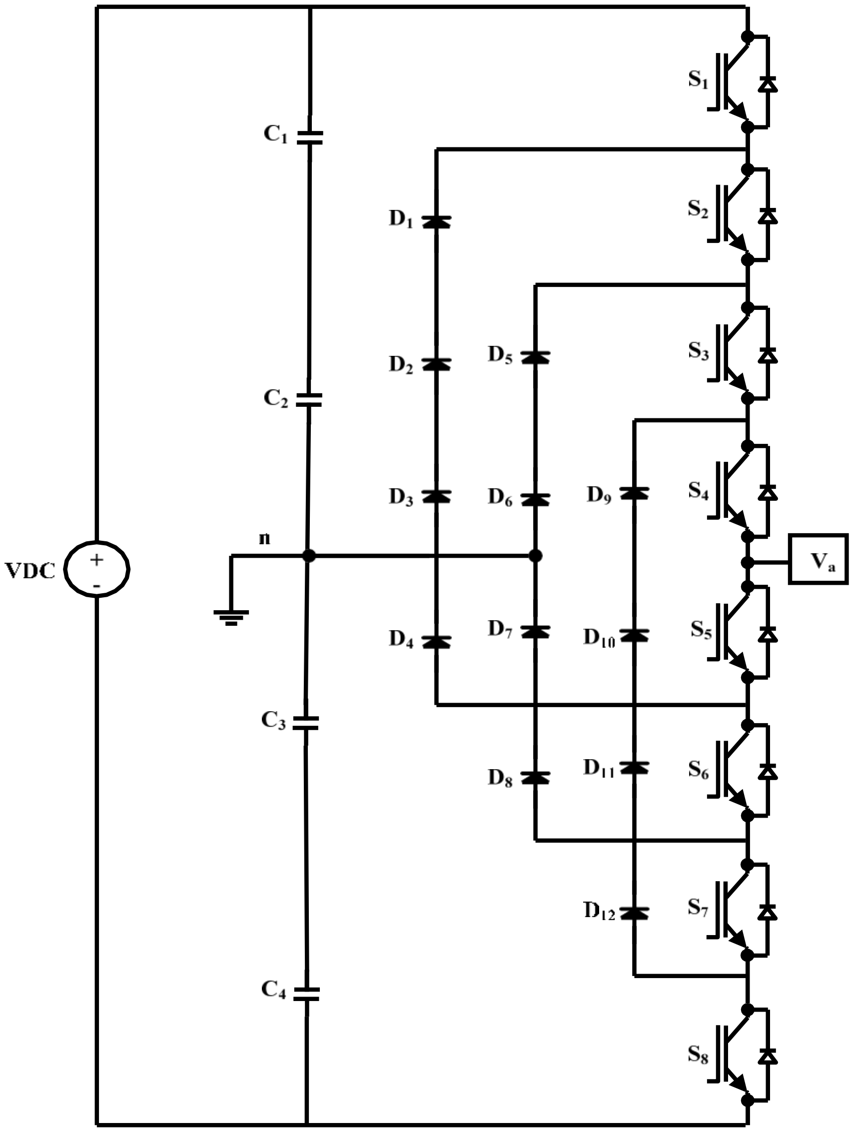


Figure-1. 5-level diode-clamped multilevel inverter.

The DC bus consists of four capacitors C1, C2, C3 and C4 as can be seen in Figure-1. For DC bus, each capacitor has VDC/4 voltage and the stress on each power MOSFET will be limited to the voltage level of one capacitor through clamping diode. The operation of 5- level diode-clamped multilevel inverter depends on switching states of inverter. Table-1 shows the switching states of 5-level diode-clamped inverter [10, 13].

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|
||Volume 10, Issue 5, May 2021||
DOI:10.15662/IJAREEIE.2021.1005030

Table-1. Switching states of 5-level diode-clamped multilevel inverter.

Van	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8
VDC/2	1	1	1	1	0	0	0	0
VDC/4	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	0
-VDC/4	0	0	0	1	1	1	1	0
-VDC/2	0	0	0	0	1	1	1	1

(Zero indicate the switch is off and 1 indicate the switch is on)

From Table-1, there are five switching combinations for producing the five voltage levels across ‘a’ and neutral point (‘n’).

a) When S1, S2, S3 and S4 are turned on the voltage level “Van” is VDC/2.
b) When S2, S3, S4 and S5 are turned on the voltage level “Van” is VDC/4
c) When S3, S4, S5 and S6 are turned on the voltage level “Van” is 0.
d) When S4, S5, S6 and S7 are turned on the voltage level “Van” is –VDC/4.
e) When S5, S6, S7 and S8 are turned on the voltage level “Van” is –VDC/2.

The number of power MOSFETs or active switches, S of diode-clamped multilevel inverter is given by the following equation [14]:

Number of power MOSFET (S) = $2*(m-1)$. (1)

The number of capacitors, C of diode clamped multilevel inverter is given by Eq. (2):

Number of Capacitors (C) = $m-1$. (2)

The number of clamping diodes, CD of diode clamped multilevel inverter is as follows:

Number of Clamping Diodes (CD) = $(m-1)*(m-2)$. (3)

Hence, m is number of inverter levels. The advantages and disadvantages of diode-clamped multilevel inverter are given in Table 2 [15-17].

Table-2. Advantages and disadvantages of diode-clamped multilevel inverter.

Advantages	Disadvantages
▪ Efficiency is high for fundamental frequency switching. ▪ The capacitors can be pre-charged as a group. ▪ All of the phases share a common DC bus, which minimizes the capacitance requirements of the converter.	▪ Real power flow is difficult for a single inverter because the intermediate DC levels will tend to overcharge or discharge without precise monitoring and control. ▪ The excessive clamping diode requires if the number of level increased therefore the use of this inverter is limited to 3-levels.

Modified diode-clamped multilevel inverter

Hybrid-diode-clamped three-level transformer- less inverter is another inverter topology for photovoltaic system [18]. It has several benefits such that the PV system has fewer harmonics and the filtering equipment will be reduced at the same time. Moreover, it reduced the losses, costs of the PV system and resolved the leakage current problem. With N inverter modules, the main disadvantage of clamped capacitor topology is imbalance of capacitor voltage in the DC side. In this topology, the capacitor CX is used to solve this problem as can be seen from Figure-2.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|
||Volume 10, Issue 5, May 2021||
DOI:10.15662/IJAREEIE.2021.1005030

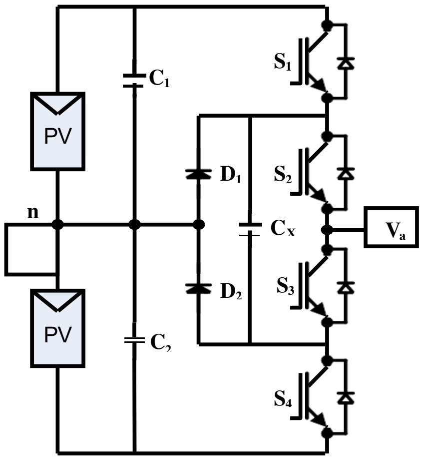


Figure-2. The hybrid clamped three-level inverter.

III. FLYING-CAPACITOR MULTILEVEL INVERTER AND MODIFICATIONS

In this section, the operation, advantages, disadvantages and modifications of flying-capacitor multilevel inverter are discussed.

Flying-capacitor multilevel inverter

In 1992, the flying-capacitor multilevel inverter was proposed by Meynard and Foch. The flying-capacitor gave large attention for high power application such as PV power system,large motor drives and static power conditioners [19]. Figure-3 shows the circuit topology of 5-level single phase flying-capacitor multilevel inverter. The five-level flying-capacitor has eight MOSFETs, four DC-link capacitors, six balancing capacitors and one DC voltage source.

The operation of five-level flying-capacitor multilevel inverter depends on switching states of inverter. There are many ways to produce the same level of voltage by changing the switching states. It causes redundancy in the switching states of the topology. The sum of a certain output voltage is generated by the DC bus voltage ±VDC/2 and one or more of the clamping capacitor voltages are added together. Since every capacitor is rated for the voltage VDC/4, DC-capacitor and clamping capacitor are identical for the output voltage. For this example, VDC/4 is generated by the DC-bus positive top value VDC/2 and the reverse voltage of clamping capacitor C1. The switching states of 5-level flying- capacitor inverter are presented in Table-3.

Table-3. Switching states of 5-level flying-capacitor multilevel inverter.

Van	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8
VDC/2	1	1	1	1	0	0	0	0
VDC/4	1	1	1	0	1	0	0	0
0	1	1	0	0	1	1	0	0
-VDC/4	1	0	0	0	1	1	1	0
-VDC/2	0	0	0	0	1	1	1	1

(Zero indicate the switch is off and 1 indicate the switch is on)

From Table 3, there are five switching combinations for producing the 5-level voltages across 'a' and 'n'.

a) When S1, S2, S3 and S4 are turned on the voltage level "Van" is VDC/2.
b) When S1, S2, S4 and S5 are turned on the voltage level "Van" is VDC/4.
c) When S1, S2, S5 and S6 are turned on the voltage level "Van" is 0.
d) When S1, S5, S6 and S7 are turned on the voltage level "Van" is –VDC/4.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 5, May 2021||

DOI:10.15662/IJAREEIE.2021.1005030

e) When S_5, S_6, S_7 and S_8 are turned on the voltage level "V_{an}" is –VDC/2.

The number of MOSFETs or active switches, S of diode clamped multilevel inverter is given by:

Number of MOSFET (S) = $2*(m-1)$. (4)

The number of DC-link capacitors, C of diode clamped multilevel inverter is given by:

Number of DC-link Capacitors (C) = $m-1$. (5)

The number of balancing capacitors, BC of flying capacitor multilevel inverter is given by:

Number of Balancing Capacitors (BC) = $\frac{(m-1)*(m-2)}{2}$.(6)

Hence, m is number of levels. The advantages and disadvantages of flying-capacitor multilevel inverter are given in Table 4 [20-22].

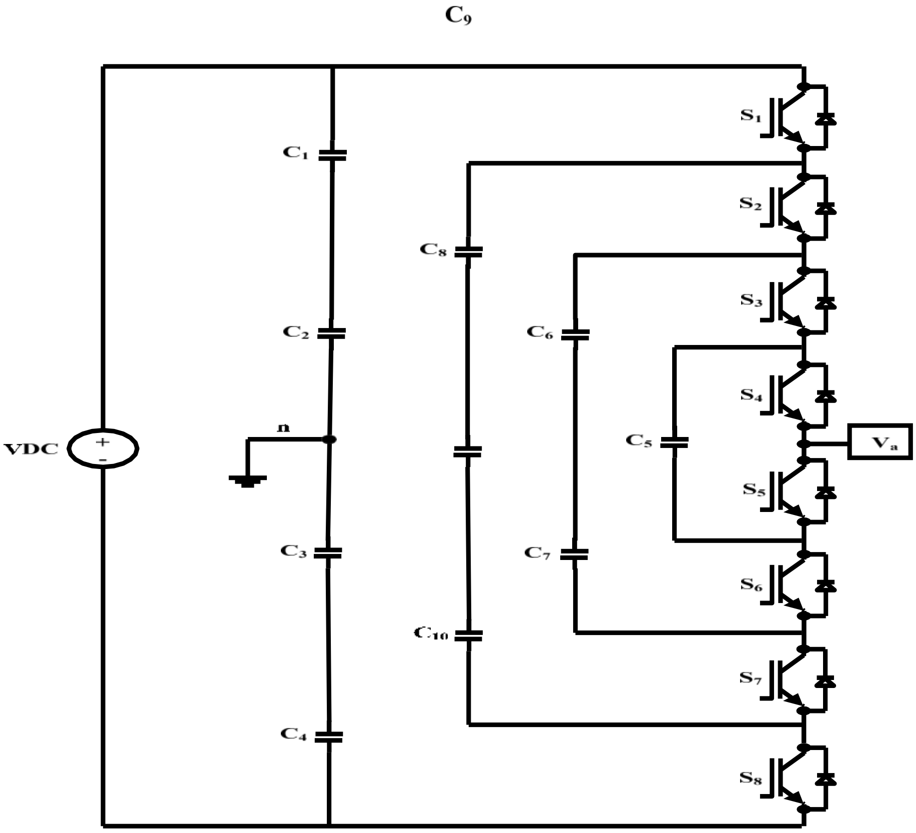


Figure-3. 5-level flying-capacitor multilevel inverter.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 5, May 2021||

DOI:10.15662/IJAREEIE.2021.1005030

Table-4. Advantages and disadvantages of flying-capacitor multilevel inverter.

Advantages	Disadvantages
▪ Real and reactive power flow can be controlled compared to diode-clamped multilevel inverter. ▪ For m number of levels, the harmonics content is low compared to diode-clamped multilevel inverter. ▪ The capability of storage power is high due to large number of capacitors. ▪ The large number of capacitors enables the inverter to ride through short duration outages and deep voltage sags. ▪ For balancing, the voltage levels of the capacitors several phase redundancies are available.	▪ Control is complicated to track the voltage levels for all of the capacitors. ▪ Pre-charging of all the capacitors to the same voltage level and startup are complex. ▪ Efficiency and switching utilization is poor for real power transmission. ▪ Packaging is more difficult for a high number of levels due to the requirement of large number of components as compared to cascaded H-bridge inverter. ▪ The flying-capacitor inverter is often expensive and bulky compared to the cascaded H-bridge inverter.

Modified flying-capacitor multilevel inverter

To cope the drawbacks of classical flying- capacitor multilevel inverter, the researchers proposed several modified flying-capacitor multilevel inverters based on bridge modular switched-capacitor [23-26]. These topologies require lower number of components as compared to classical flying-capacitor topology. In addition, these topologies have features of voltage balancing property, purge the more dc source, boost-up the output voltage levels, and provide better the output frequency range.

IV. CASCADED H-BRIDGE MULTILEVEL INVERTER AND MODIFICATIONS

In this section, the operation, advantages, disadvantages and several modifications of cascaded H- bridge multilevel inverters (i.e., Quasi-Z source, switched- capacitor, and switched-battery boost multilevel inverter) are discussed.

Cascaded H-bridge multilevel inverter

A cascaded H-bridge multilevel inverter is different from diode clamped multilevel inverter and flying capacitor multilevel inverter in structure. The number of output voltage levels can be easily adjusted by adding or removing the H-bridge. H-bridge was introduced in 1975 [7]. It was the first multilevel inverter. In 1996, the cascaded H-bridge multilevel inverter was proposed by Jih-Sheng [27].

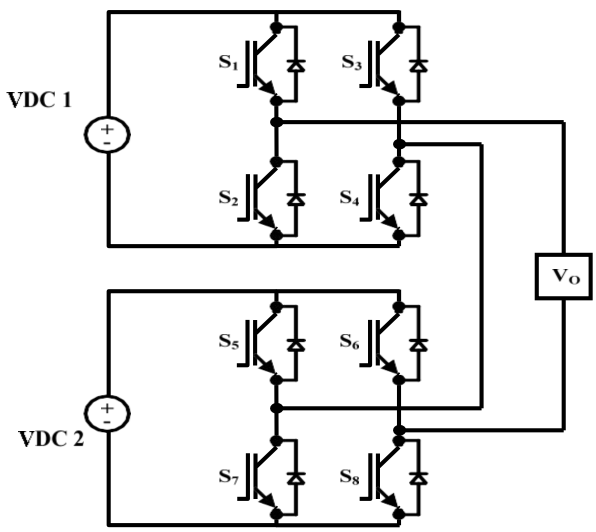


Figure-4. 5-level cascaded H-bridge multilevel inverter.

Cascaded H-bridge multilevel inverter is among the most popular inverter topology in stand-alone PV systems. Figure-4 shows 5-level cascaded H-bridge multilevel inverter. H-bridge inverters are connected in series

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 5, May 2021||

DOI:10.15662/IJAREEIE.2021.1005030

with their output voltages are summed up. Hence, it has voltage boosting capability and highly reliable with lowest voltage unbalance problem. With N number of H- bridge inverters, the output staircase AC voltage produced consists of 2N+1 levels [28]. This inverter topology requires separate DC source for each H-bridge inverter as can be seen from Figure-4.The operation of 5-level cascaded H-bridge multilevel inverter is dependent on switching states of inverter. Table-5 shows the switching states of 5-level cascaded H-bridge multilevel inverter.

Table-5. Switching states of 5-level cascaded H-bridge multilevel inverter.

Vo	S 1	S 2	S 3	S 4	S 5	S 6	S 7	S 8
2VDC	1	0	0	1	1	0	0	1
VDC	1	0	0	1	0	0	1	1
0	1	1	0	0	1	1	0	0
-VDC	0	1	1	0	1	1	0	0
-2VDC	0	1	1	0	0	1	1	0

(Zero indicate the switch is off and 1 indicate the switch is on)

From Table-5, there are five switching combinations to produce five voltage levels are discussed as follows:

a) When S1, S4, S5 and S8 are turned on the voltage level "V_O" is 2VDC.

b) When S1, S4, S7 and S8 are turned on the voltage level "V_O" is VDC.

c) When S1, S2, S5 and S6 are turned on the voltage level "V_O" is 0 or when S3, S4, S7 and S8 are turned on the voltage level "V_O" is 0.

d) When S2, S3, S5 and S6 are turn on the voltage level "V_O" is -VDC.

e) When S2, S3, S6 and S7 are turn on the voltage level "V_O" is -2VDC.

The number of levels, m of cascaded H-bridge multilevel inverter is calculated by following equation:

$$\text{Number of level } (m) = 2N+1. \quad (7)$$

Hence, m is the number of inverters and N is the number of H-bridge inverter. The total number of power MOSFETs can be calculated through Eq. (8). The main advantages and disadvantages of cascaded H-bridge multilevel are discussed in Table 6 [29-31].

$$\text{Number of MOSFET} = 2*(m-1). \quad (8)$$

Table-6. Advantages and disadvantages of cascaded H-bridge multilevel inverter.

Advantages	Disadvantages
▪ Less number of components is required to get equal voltage level as compared to diode-clamped and flying-capacitor multilevel inverters. ▪ Extra capacitor and diode are not necessary. ▪ The series of H-bridges makes packaging easier with modularized layout. ▪ Due to structural flexibility of cascaded H-bridge, the manufacturing process is cheap and fast.	▪ Separate DC source are required for each H-bridge. ▪ The synchronization of reference and the carrier waveforms is required to communicate between the H-bridges.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|
||Volume 10, Issue 5, May 2021||
DOI:10.15662/IJAREEIE.2021.1005030

V. COMPARISON OFBASIC TYPES OF MULTILEVEL INVERTERS

In this section, the comparison between diode- clamped, flying-capacitor, and cascaded H-bridge multilevel inverter is presented. The comparison indicate that the cascaded H-bridge multilevel inverter has gained higher popularity due to several features such as: it does not require an excessively large number of clamping-diode and flying-capacitor. The output voltage levels easily can be controlled by adding or removing the H-bridge. By increasing the number of levels, it produces a multistep staircase voltage waveform which is nearly sinusoidal. The cascaded H-bridge multilevel inverter structure consists of a cascaded connection of H-bridge units and each bridge is fed with separate DC source, therefore it does not require voltage balance circuit. The required number of components for diode-clamped, flying- capacitor and cascaded H-bridge multilevel inverter are shown in Figure-5(a) to 5(c).

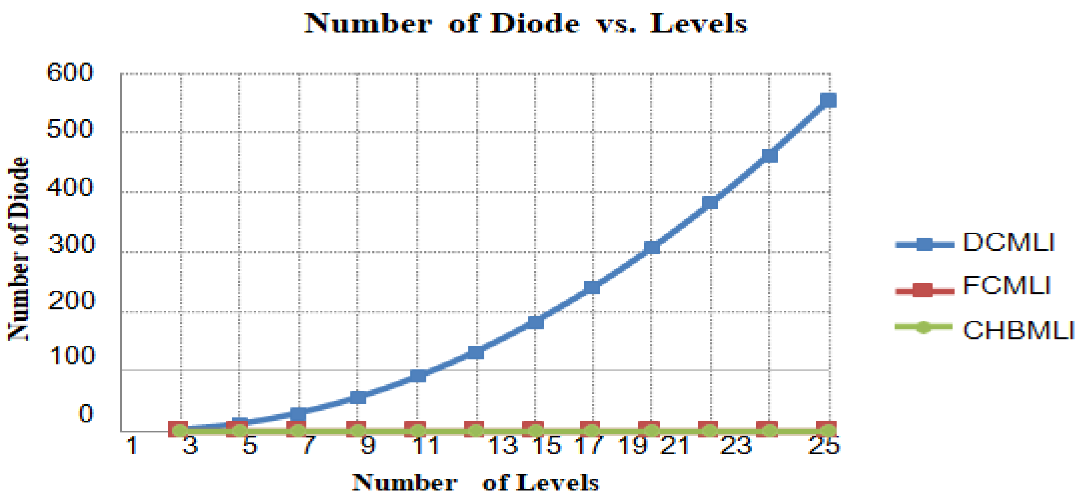


Figure-5(a). Required number of diode for different types of multilevel inverter.

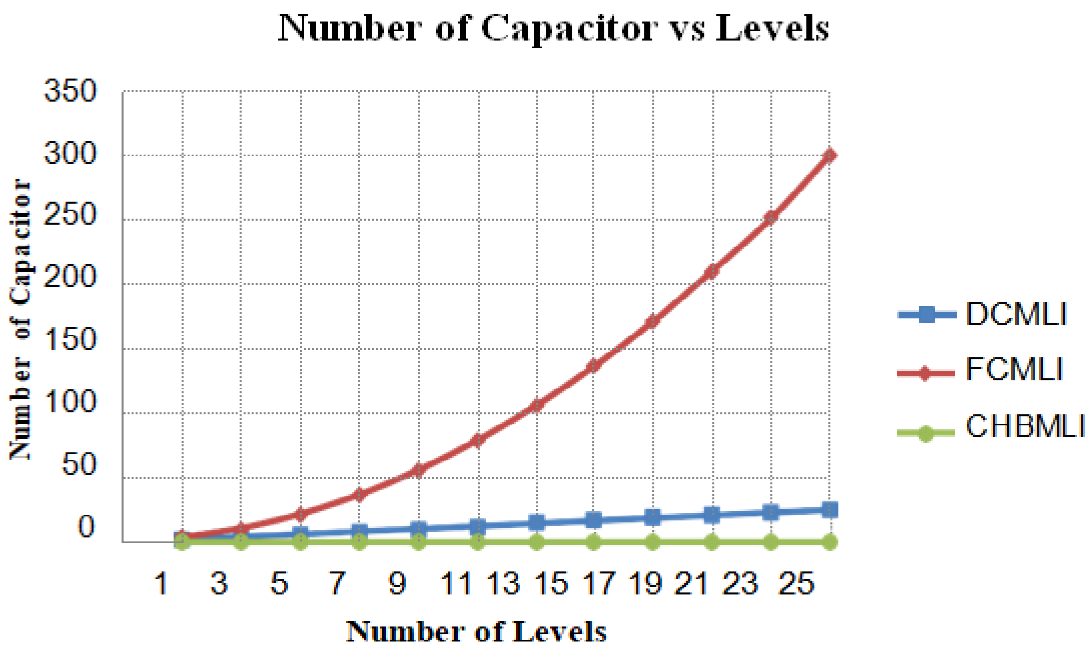


Figure-5(b). Required number of capacitor for different types of multilevel inverter.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|
||Volume 10, Issue 5, May 2021||
DOI:10.15662/IJAREEIE.2021.1005030

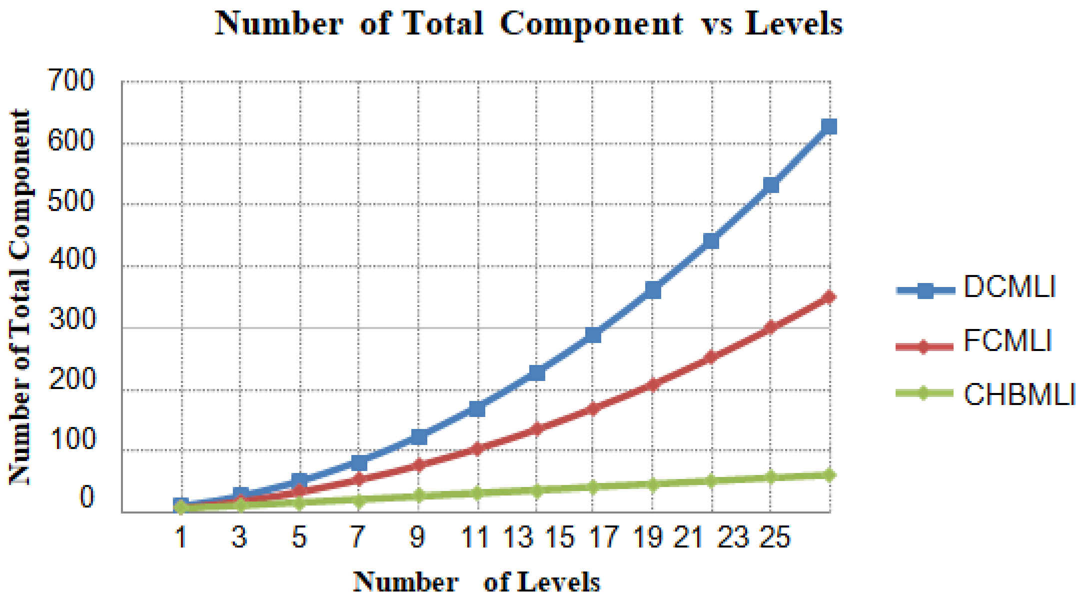


Figure-5(c). Required number of total components for different types of multilevel inverter

Figure-5(a) shows that the clamping diode is required only for diode-clamped multilevel inverter and Figure-5(b) shows that the balancing capacitor is required for diode-clamped and flying-capacitor multilevel inverter. The lower number of components is required for cascaded H-bridge multilevel inverter which can be seen from Figure-5(c). Due to lower number of component cascaded H-bridge multilevel inverter has recently become most popular topology in high AC power supplies and PV system. In addition, the probability of system failure is decreases and control of the switches is not complicated.

VI. CONCLUSIONS

The paper presents a thorough review of simple multilevel inverter topologies and their variations. Furthermore, the fundamental forms of Different aspects of multilevel inverters are contrasted. The advantages and drawbacks of each technique have been addressed for traditional multilevel inverter structures. The key benefit of a multilevel inverter is that it solves the issues of THD and dv/dt tension on the switch. Based on the preceding discussion, it can be concluded that, in comparison to other forms of multilevel inverters, cascaded multilevel inverters require the least number of components. As a result, it generates a higher stepped performance with fewer switches.

REFERENCES

[1] S. Daher, J. Schmid, F.L.M. Antunes. 2008. Multilevel inverter topologies for stand-alone PV systems. IEEE T. Power. Electron. 55: 2703-2712.
[2] S.B. Kjaer, J.K. Pedersen, S. Member, F. Blaabjerg. 2005. A review of single-phase grid-connected inverters for photovoltaic modules. IEEE T. Ind. Appl. 41: 1292-1306.
[3] I. Colak, E. Kabalci, R. Bayindir. 2011. Review of multilevel voltage source inverter topologies and control schemes. Elsevier J. Energy Convers. Manage. 52: 1114-1128.
[4] Y. Zhou, H. Li. 2014. Analysis and suppression of leakage current in cascaded-multilevel-inverter-based PV systems. IEEE T. Power. Electron. 29: 5265-5277.
[5] J. Lai, S. Member, F.Z. Peng. 1996. Multilevel converters-a new breed of power converters, IEEE T. Ind. Appl. 32: 509-517.
[6] C. Cecati, F. Ciancetta, P. Siano. 2010. A multilevel inverter for photovoltaic systems with fuzzy logic control. IEEE T. Ind. Electron. 57: 4115-4125.
[7] R. H. Bannister. 1975. Electric Power Converter, Prentice Hall.
[8] K.K. Gupta, A. Ranjan, P. Bhatnagar, L.K. Sahu, S. Jain. 2016. Multilevel inverter topologies with reduced device count: a review. IEEE T. Power Electron. 31: 135-151.
[9] M.H. Rashid. 2003. Power Electronics Circuits Devices and Applications. 3rd ed. Pearson/Prentice Hall.
[10] A. Nabae, I. Takahashi, H. Akagi. 1981. A new neutral-point-clamped PWM inverter, IEEE T. Ind. Appl. IA-17: 518-523.

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|

||Volume 10, Issue 5, May 2021||

DOI:10.15662/IJAREEIE.2021.1005030

[11] K.H. Jung, L.H. Dong, S.S. Ki. 2001. A new PWM strategy for common-mode voltage reduction in neutral-point-clamped inverter-fed AC motor drives.IEEE T. Ind. Appl. 37: 1840-1845.

[12] C. Xia, G. Zhang, Y. Yan, X. Gu, T. Shi, X. He. 2016. Discontinuous space vector PWM strategy of neutral-point-clamped three-level inverters for output current ripple reduction. IEEE T. Power. Electron. 36: 1-10.

[13] R. Mahalakshmi, K.C.S. Thampatty. 2015. Grid connected multilevel inverter for renewable energy applications. Procedia Tech. 21: 636-642.

[14] Q. Li, P. Wolfs. 2008. A review of the single phase photovoltaic module integrated converter topologies with three different DC link configurations. IEEE T. Power. Electron. 23: 1320-1333.

[15] E. Ozdemir, S. Ozdemir, L.M. Tolbert. 2009. Fundamental-frequency-modulated six-level diode- clamped multilevel inverter for three-phase stand- alone photovoltaic system. IEEE T. Ind. Electron. 56(2009) 4407-4415.

[16] G.P. Adam, S.J. Finney, B.W. Williams. 2012. Quasi- two-level and three-level operation of a diode- clamped multilevel inverter using space vector modulation. IET Power Electron. 5: 542-551.

[17] J. Rodriguez, S. Bernet, P.K. Steimer, I.E. Lizama. 2010. A survey on neutral-point-clamped inverters. IEEE T. Ind. Electron. 57: 2219-2230.

[18] S.B. Monge, J. Rocabert, P. Rodríguez, S. Alepuz, J. Bordonau. 2008. Multilevel hybird-clamped converter for photovoltaic generators with independent voltage control of each solar array. IEEE T. Ind. Electron. 55: 2713-2723.

[19] T.A. Meynard, H. Foch. 1992. Multilevel conversion: high voltage choppers and voltage-source inverters. In Power Electron. Spec. Conf., 1992, 23rd IEEE. 39: 1397-403.

[20] J. Amini, M. Moallem. 2016. A fault-diagnosis and fault-tolerant control scheme for flying capacitor multilevel inverters, IEEE T. Ind. Electron. Early access.

[21] J. Amini, A.H. Viki and A. Radan. 2015. An active capacitor voltage control for symmetrical / non-symmetrical H-bridge flying capacitor multilevel inverter, In 6th Power Electron., Drive Syst. & Tech. Conf. pp. 125-130.

[22] E.I. Silva, B.P. McGrath, D.E. Quevedo, G.C. Goodwin. 2007. Predictive control of a flying capacitor converter, In American. Control Conf. pp. 3763-3768.

[23] D.H. Park, N.J. Ku, R. Y. Kim. 2015. A novel switching loss minimization method for single-phase flying-capacitor multilevel inverter. In IEEE 2nd Int. Fut. Energy Electron. Conf. pp. 1-6.

[24] N. Maheshkumar, V. Maheskumar, M. Divya. 2013. The new topology in flying capacitor multilevel inverter. In Int. Conf. Comput. Comm. Info. pp. 1-6.

[25] S.S. Priyan, K. Ramani. 2013. Implementation of closed loop system for flying capacitor multilevel inverter with stand-alone photovoltaic input. In Int. Conf. Power, Energy & Control. pp. 281-286.

[26] M. Trabelsi, L.B. Brahim. 2011. Development of a grid connected photovoltaic power conditioning system based on flying capacitors inverter. In 8th Int. Multi-Conf. Syst. Sig. & Dev. pp. 1-6.

[27] L.J. Sheng and P.F. Zheng. 1996. Multilevel converters-a new breed of power converters. IEEE T. Ind. Electron. 32: 509-517.

[28] M. Sadikin, T. Senjyu, A. Yona. 2013. High- frequency link DC for power quality improvement of stand-alone PV system in cascaded multilevel inverter. In IEEE 10th Int. Conf. Power Electron. & Drive Syst. 597-601.

[29] E. Babaei, S.H. Hosseini, G.B. Gharehpetian, M.T. Haque and M. Sabahi. 2007. Reduction of DC voltage sources and switches in asymmetrical multilevel converters using a novel topology, Elsevier J. Electric Power Syst. Res. 77: 1073-1085.

[30] L.A. Tolbert, P.F. Zheng, T. Cunnyngham and J.N. Chiasson. 2002. Charge balance control schemes for cascade multilevel converter in hybrid electric vehicles. IEEE T. Ind. Electron. 49: 1058-1064.

[31] E. Villanueva, P. Correa, J. Rodriguez, M. Pacas. 2009. Control of a single-phase cascaded H-bridge multilevel inverter for grid-connected photovoltaic systems. IEEE T. Ind. Electron. 56: 4399-4406.

[32] Y. Liu, B.G. Ferreira, A.T. Almeida, H.A. Rub. 2011. Modeling and SVPWM control of quasi-z-source inverter, In 11th Int. Conf. Electric. Power Quality. & Utilization. pp. 1-7.

[33] S. Dongsen, G. Baoming, F.Z. Peng, A.R. Haitham, B. Daqiang, L. Yushan. 2012. A new grid-connected PV system based on cascaded H-bridge quasi-z source inverter. In IEEE Int. Symp. Ind. Electron. pp. 951- 956.

[34] Y. Liu, H.A. RuB, F.Z. Peng. 2013. A modular multilevel space vector modulation for photovoltaic quasi-z-source cascade multilevel inverter, In 28th Ann. IEEE Appl. Power Electron. Conf. & Expo. pp. 714-718.

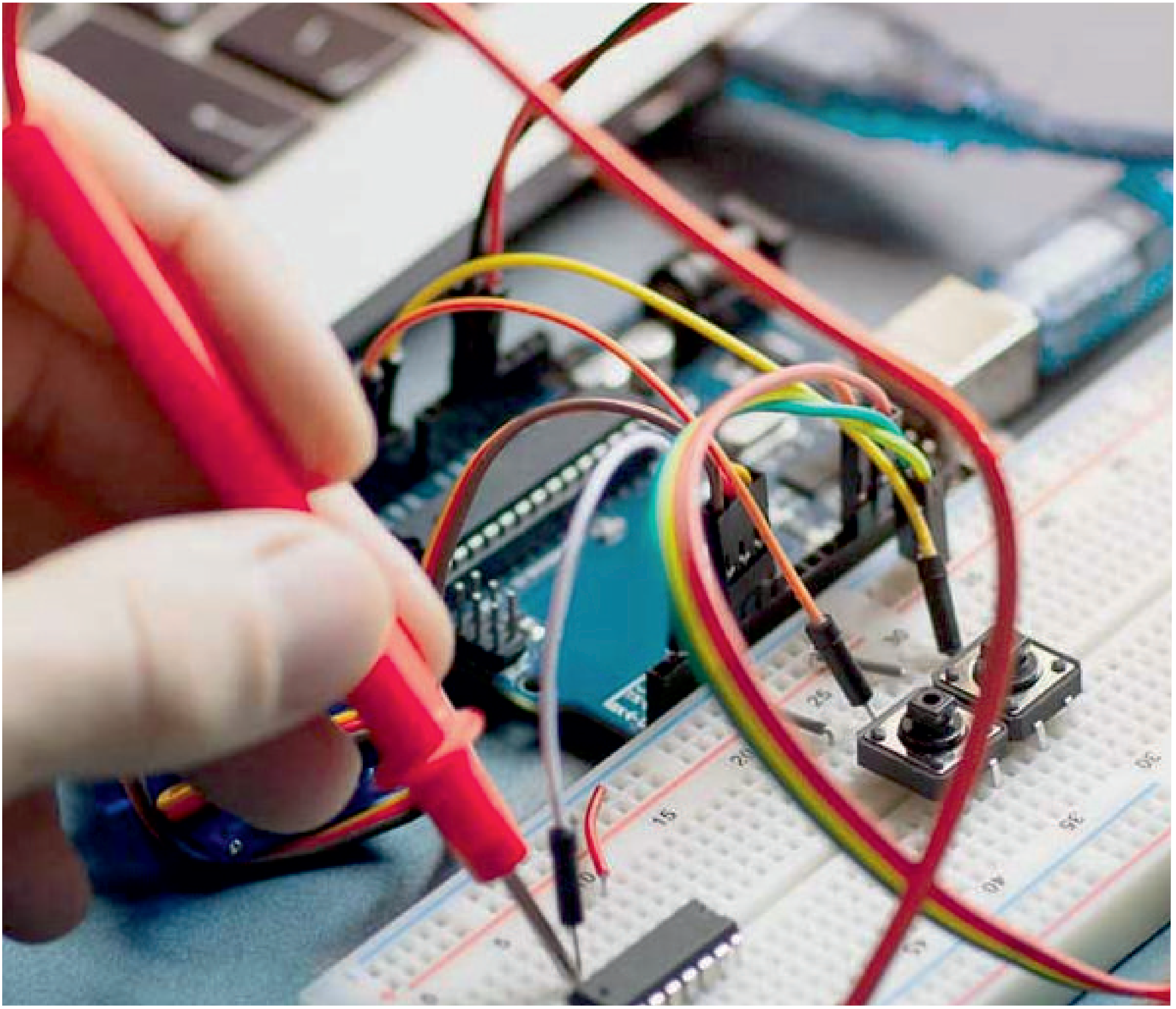
[35] M. Mosa, H.A. Rub, J. Rodríguez. 2013. High performance predictive control applied to three-phase grid connected quasi-z-source inverter, In 39th Ann. Conf. IEEE Ind. Electron. Soc. pp. 5812-5817.

[36] Y. Liu, H.A. Rub, F.Z. Peng. 2014. An effective control method for quasi-z-source cascade multilevel inverter-based grid-tie single-phase photovoltaic power system. IEEE T. Ind. Info. 10: 399-407.

[37] Y. Liu, H.A. Rub, F.Z. Peng. 2014. An effective control method for three-phase quasi-z-source cascaded

| e-ISSN: 2278 – 8875, p-ISSN: 2320 – 3765| www.ijareeie.com | Impact Factor: 7.122|
||Volume 10, Issue 5, May 2021||
DOI:10.15662/IJAREEIE.2021.1005030

multilevel inverter based grid-tie photovoltaic power system. IEEE T. Ind. Electron. 61: 6794-6802.
[38] D. Sun, B. Ge, X. Yan, D. Bi, H. Zhang, Y. Liu, H.A. Rub, L.B. Brahim, F.Z. Peng. 2014. Modeling, impedance design, and efficiency analysis of quasi-z source module in cascaded multilevel photovoltaic power system.IEEE T. Ind. Electron. 61: 6108-6117.
[39] E. Zamiri, N. Vosoughi, S.H. Hosseini, R. Barzegarkhoo, M. Sabahi. 2016. A new cascaded switched-capacitor multilevel inverter based on improved series-parallel conversion with less number of components. IEEE T. Ind. Electron. 63: 3582-3594.
[40] C. Marouchos, M. Darwish, M.S. Moghadam, M. Georgiou. 2015. A new switched capacitor inverter for stand-alone photovoltaic applications. In 50th Int. Uni. Power Eng. Conf. 1-4.
[41] C.C. Marouchos, M. Darwish, L. Diomidou. 2013. A new concept for a multilevel switched capacitor sinusoidal grid connected inverter. In 48th Int. Uni. Power Eng. pp. 1-6.
[42] J. Liu, K.W.E. Cheng, Y. Ye. 2014. A cascaded multilevel inverter based on switched-capacitor for high-frequency AC power distribution system.IEEE
T. Power Electron. 29: 4219-4230.
[43] M.F. Kangarlu, E. Babaei. 2013. A generalized cascaded multilevel inverter using series connection of sub-multilevel inverters. IEEE T. Power Electron. 28: 625-636.
[44] K.V. Korotkih, N.N. Lopatkin. 2013. Design of a teaching-research laboratory breadboard for studying of the multilevel voltage inverter with switched capacitors. In: 14th Int. Conf. Young Spec. Micro/Nanotech. Electron. Dev.305-309.
[45] J. Ebrahimi, E. Babaei, G.B. Gharehpetian. 2012. A new multilevel converter topology with reduced number of power electronic components. IEEE T. Ind. Electron. 59: 655-667.
[46] E. Babaei, F. Sedaghati. 2011. Series-parallel switched-capacitor based multilevel inverter, In Int. Conf. Electric. Mach. & Syst. pp. 1-5.
[47] Y. Hinago, H. Koizumi. 2010. A single-phase multilevel inverter using switched series/parallel DC voltage sources, IEEE T. Ind. Electron. 57: 2643- 2650.
[48] E. Babaei, S. Alilu and S. Laali. 2014. A new general topology for cascaded multilevel inverters with reduced number of components based on developed H-bridge. IEEE T. Ind. Electron. 61: 3932-3939.
[49] E. Babaei, S.S. Gowgani. 2014. Hybrid multilevel inverter using switched capacitor units. IEEE T. Ind. Electron. 61: 4614-4621.
[50] K.K. Gupta, S. Jain. 2014. A novel multilevel inverter based on switched DC sources. IEEE T. Ind. Electron. 61: 3269-3278.
[51] M.A. Yusof, Y.C. Tan, M. Othman, S.S. Lee, M.A. Roslan, S.L. Ong, J.H. Leong. 2015. Comparison of switching angle arrangement techniques in single- phase boost multilevel inverter for low THD operation, Appl. Mater. Mech. 793: 167-171.
[52] S.S. Lee, B. Chu, N.R.N. Idris, H.H. Goh, Y.E. Heng. 2016. Switched-battery boost-multilevel inverter with GA optimized SHEPWM for standalone application. IEEE T. Ind. Electron. 63: 2133-2142.



INNO SPACE

SJIF Scientific Journal Impact Factor

Impact Factor:
7.122

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

निस्केयर
NISCAIR

International Journal of Advanced Research

in Electrical, Electronics and Instrumentation Engineering