International Journal of Engineering Works
ISSN-p: 2521-2419
ISSN-e: 2409-2770
Vol. 6, Issue 07, PP. 228-234, July 2019
https://www.ijew.io/
https://doi.org/10.34259/ijew.19.607288234

A Survey Report on Multi Level-Inverter Topologies

Muhammad Ilyas[1], Tanvir Ahmad[2], Shifaat Ur Rehman[3]
[1,2,3]US Pakistan Center For Advanced Studies in Energy, University of Engineering and Technology, Peshawar, Pakistan
milyas0009@gmail.com[1], tanvir.ahmad@uetpeshawar.edu.pk[2], shifaatqurtuba@gmail.com[3]
Received: 12 July, Revised: 17 July, Accepted: 24 July

***Abstract*—**Electricity demand is continuously increasing due to dependency of industrial, commercial and residential users on advance technology. To address this issue is the prime need of time. Modern trend is to harvest energy from renewable sources such as wind, PV etc, which is environmental friendly and economical comparatively. However, as Renewable-Energy- Sources (RES) are sprinkled in small scale by the nature, so usually it is difficult to get a scalable amount of energy. Furthermore, the power quality is much affected due to varying nature of these RES sources. To get maximum efficiency and reliable operation from RES, different inverter topologies are presented. This paper highlights four types of Multilevel-invertertopologies commonly used for smoother, reliable and efficient operation of renewable energy sources (RES) in medium and high power applications. These are Neutral Point-Clamped (NPC) or also called Diode-Clamped Multi Level-Inverter(DCMLI), Flying-Capacitor(FCMLI), Cascaded-Inverter (CMLI) and a Hybrid/ Mixed Multi Level-Inverter topology(HMLI/MMLI). Each topology when used with renewable energy sources has its own features with corresponding advantages and disadvantages. This review is based on controlling methodologies, Total-Harmonic-Distortion (THD), construction complexity and components need for the respective topology. Multi-level-inverter (MLI) has the advantage of extinguishing the need of passive filtering at the grid side, and hence efficiency of the grid and cost minimization can be achieved.

***Keywords*—** Multi Level Inverter(MLI), Clamped-Inverter, Total-Hormonic Distortion(THD).

I. Introduction

Electrical energy in this modern era of technology acts like backbone in the economic development of state as well as to enhance the living standards of the mankind. With recent advancement in technology during last several decades, human dependency on electrical energy hiked up. Machinery becomes a part of our life. Electrical equipments are widely used in industrial sector, house holds and commercial building to accomplish different task. Furthermore, the rise in population and industries occurs at alarming rate, in such a case it is a huge challenge to meet the energy demand for country development and boosting-up economy [1] . Majority of the energy nowadays is produced from Non-Renewable-energy sources (NRES) including Gas, Petroleum, Coal etc. but after several hundred years it will enervates [1]. Also it has enormous environmental impacts on the environmental, as it yields responsible for the destruction of ozone layer, hence causing Green-House-effects and rise in temperature [1].

Over the last few decades, research interest is diverted to get energy fromRenewable-Energy-sources(RES) instead of conventional ways of harnessing energy from fuels, coals etc. due the environmental concerns and depleting fossil fuels to meet the increasing demand of the load [2]. By integrating RenewableeEnergy Sources(RES) with the traditional grids can help us in overcoming energy shortage issue. The power from renewable energy sources can not be used directly by load or fed into grid, so a power electronics converters are used for interfacing.

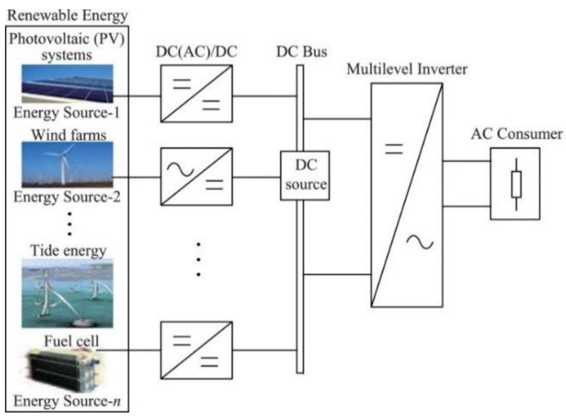

Figure 1: Illustration of Renewable-Energy-Integrated-System (REIS) [3].

As some of the Renewableeenergy sources (PV) like Fuel cell, Solar PV generate DC at it output while some produce AC, in such a case it is prerequisite to convert AC in-to DC for the purpose of storage in batteries. Whenever fault occur or power demand increases from the traditional-Grid, the stored energy is then converted back into AC from stored-DC with the help of Multi-level-Inverter(MLI) to bear the increased demand from load side. Figure 1 below shows an integrated solar PV, Wind,Tide, and so on.., connected to a DC-Bus by AC-DC/DC-DC converters which is then stored in capacitors or batteries [3, 4]. DC-Bus is then connected to a traditionallGRID with the help of Multi-Level-inverter(MLI) converting DC current either stored in batteries or directly from RES sources into AC [5].

Different types of Multi-Level-Inverter(MLI) topologies are recommended in last two decades for improving power quality, Total Harmonic Distortion [6], efficiency and is widely used nowadays for different application of renewable energy integration system (REIS) [5]. It is a well known fact, that Renewable-energy-sources (RES) efficiency is relatively less, if compared with other types of traditional fossil fuels, so it is needed to address this drawback and boost the system efficiency and power quality by harvesting the maximum possible energy from Renewable-Energy-Sources(RES). To maximize generation usually MPPT algorithm is applied at the source side while power quality can be increased and Total-Harmonic-Distortion(THD) can be condensed by increasing the Number of voltage-levels, and thus efficiency of Renewable-Energy-Sources(RES) enhances.

II. LITERATURE SURVEY

Over the past two decades, Multi-level-inverter have been developed with having a medium and higher power ratings and is used for integration and interfacing of Renewable Energy Sources(RES) like wind, Solar Photo-Voltaic(PV) etc, to the grid [7]. Majority of the Renewable Energy-Sources(RES) produce DC, which can be converted into desired AC power level by the help of Multi-Level-Inverter(MLI). Multi-Level- Inverter(MLI) are best for medium and higher power application [8] and are more worthy for Renewable-Energy- Sources(RES), due to its reduced disturbances and operation at lower switching frequency [9]. It provide smoother output waveforms due to increased number of level and hence a considerable reduction in Total harmonic distortion(THD) [10, 11]. There is an inverse relation between Total harmonic distortion and number-of-levelsNL, if the number-of-levels are increased such that it reaches to infinity, the total harmonic distortion will be zero [12].

However it is not that much easy task to rise the No oflevels (NL), because increasing the No-of-levels(NL) requires additional components and similarly increases the control complexity and hence cost [9]. Therefore it is required to select the best suitable topology from the available topologies in order to overwhelm the mentioned complications. Multiple multi-level-inverter topologies are highlighted in the relevant works for this cause [13].

The principal Multi Level-Inverter topologies are:

A. Diode Clamped Multi Level-Inverter(DCMLI) [14–16].
B. Flying-Capacitor Multi Level-Inverter(FCMLI) [17, 18].
C. Cascaded Multi Level-Inverter(CMLI) [19, 20].
D. Hybrid Multi level-Inverter(HMLI) [20].

Each of the topology mentioned above has its own advantages and disadvantages which are highlighted in detail below. Research and efforts of the engineers are for topology that gives better control of both voltage and frequency, increase the number of AC level with minimized control complexity and there drive circuits, reduced Total harmonic distortion and use small number of components i.e. switches and capacitors e.t.c. This paper presents a comparison between several principal topologies, emphasizing their pros and cons, number of components used. The detail study is as under.

(A) Diode-Clamped Multi Level Inverter(DCMLI):

Diode-clamped Multi-Level-Inverter was presented for the first time by Nabae in 1981, which was consist of 3-levels [21]. Experimental outcomes for 4, 5 and 6-level inverter articles are published in 1990's, by many researchers [22, 23]. Diode- Clamped or also called Neutral-Point-Clamped Multi-level- Inverters(MLI) has diode for clamping the DC voltage of the source and hence a step waveform is formed at the output [24]. For achieving -levels in a Diode clamped MLI to achieve -levels the following components are required [24]:

- Diodes for clamping:
- Number of switches:
- Capacitors for DC Link:)

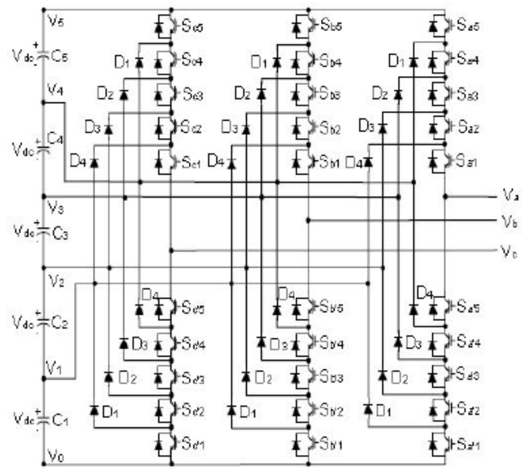

Figure 2: 6-level, 3-Phase Diode clamped MLI [25].

Figure 2, shows a sketch of -phase, -level Diode-clamped MultiiLevel-Inverter(MLI).Capacitor -to- are connected in series with each other, which are connected across the voltage source Vdc. The source voltage Vdc divides in capacitor -to- .The semi-conductor switches and , (where) are controlled by employing Pulse-Width-Modulation(PWM) approach. The function of switches is to allow the capacitor voltage to appear at the output. The Diode is used to block different level of voltages. Diode is used to block Four-Levels, and the process continues in such away that finally is used to block One-Level, respectively. By following this sequence, a step waveform is generated at the output of MLI.

Advantages

- Requires Less number of sources [24].
- Single source is shared by Cascaded Capacitors [25].
- THD decreases as the number of level increases, enhancing power quality [10].
- Gives Better Efficiency for switching at fundamental frequency [26].
- Capacitors can be Pre-Charged in the form of Group [25].
- Suitable for adjustable speed drive applications[27].

Disadvantages

- Over-charging and Dis-charging of inverter DC-Levels is hard to control and monitor [27].
- Real Power flow is affected [28].
- If Number-of-Levels are , Then Number of Clamping-Diodes are needed. Thus increasing complexity [27, 29, 30]

(B) Flying-Capacitor Multi-Level Inverter(MLI)

Flying-Capacitor Multi level-Inverter(FCMLI) or also called Capacitor-Clamped Multi Level-Inverter, is analogous in appearance to Diode-Clamped Multi-Level-inverter, but instead of diodes it uses balancing capacitor to keep voltages at the required value [1]. Figure 3, shows a schematics of Flying-Capacitor Multi Level-Inverter, in which charging and Dis-charging of the capacitors connected to neutral point determines the level of voltage [31, 32].When semi-conductor switches and is Switched-ON, Flying Capacitors in link start charging. When the same switches is switched-off, semiconductor switches and charges the flying capacitor link, while in switched-off condition of these switches, the same capacitors start dis-charging [31]. Multi-levels of voltage at the output of MLI is produced due to different time-constants of each Clamping-Capacitor. The number of Clamping-Capacitors required to obtain -levels is $((N_L - 1)$ [32]. Similarly the number of capacitors required is ( ) , as like for that of Diode Clamped MLI.

Advantages

- Active and reactive power flow is controllable [31].
- No need of T/F, to get the desired number-of voltage levels [31, 32].
- No need of Clamping-Diode [31].
- Single DC-Source is shared by balancing capacitors[18, 33].
- The inverter can withstand to voltage sags and to outages for short because of enormous number of capacitors [30].

Disadvantages

- Monitoring the voltage-levels is a tedious job in capacitors compared to diodes [34].
- Switching efficiency is lower in real power transmission scenarios[34].
- Difficult to determine the pre-charging time for all capacitors [18].
- Large number of capacitor increases weight and cost and thus complexity in packaging [29].
- Complex control strategy and high frequency, leading to high switching losses in real power transfer [35].

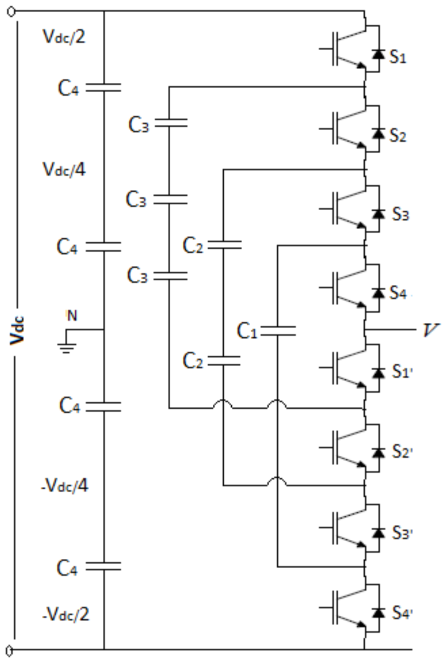

Figure 3: 5-level, 1-Phase Flying-Capacitor MLI [9].

(C) Cascaded Multi-Level-Inverter(CMLI)

Cascaded or H-Bridge Multi-Level-Inverter was invented by Jih-Sheng, in 1996 [36]. It is the simplest of all Multi-levelinverter topologies. Structurally Cascaded-MLI topology is different from Diode-Clamped MLI and Flying-Capacitor MLI topology. No-of-levels in the output waveform can be easily regulated by either joining or elimination of H-bridge. The number of sources required for -levels in cascaded MLI topology is . H-Bridge consist of 4 Semi-conductor switches and a separate supply source is connected to each Bridge [10]. In cascaded MLI topology, all the H-Bridges are attached to one another in cascade. Output is taken between the upper hand of initial bridge and lower hand of last-bridge as demonstrated in Figure 4.

If there are N-number of bridges, the output AC voltage produces will be of levels [37]. The output waveform is generated by individual bridge as, when First-Bridge is in the ON-State, Voltage-level at output is form due to Vdc of respective source connected to that bridge. If Second-Bridge is put into service at same time with first-bridge already in service, Now voltage level in the output waveform will be the sum of two sources connected to first and second bridge, respectively and so on. Finally, in case of N-bridges in the turn ON-state, the voltage-level in output waveform will be the sum of all the sources connected to each bridge, Thus maximum voltage at the output can be achieved. Increasing the number of H-bridges will increase the voltage-levels at the output, thus reducing Total Harmonic-Distortion(THD).

Advantages

- No need of Clamping-Diodes or Capacitors, So total number of components required is less if compared with other topologies [14].
- Possibility to implement soft switching [3].
- DC-Bus regulation is easy [20].
- Semi-conductor switching cycle control is simple with ease in construction [28].
- Packaging is simple and hence can be manufactured in low cost [28].

Disadvantages

- To get higher voltage-levels the number of DC sources required increases [38, 39].
- No common DC Bus [38].
- MLI control technique is implied for controlled operation of H-Bridges, thus output waveform is generated [34].
- Carrier and reference wave form should be synchronized for proper communication between H-Bridges[3].

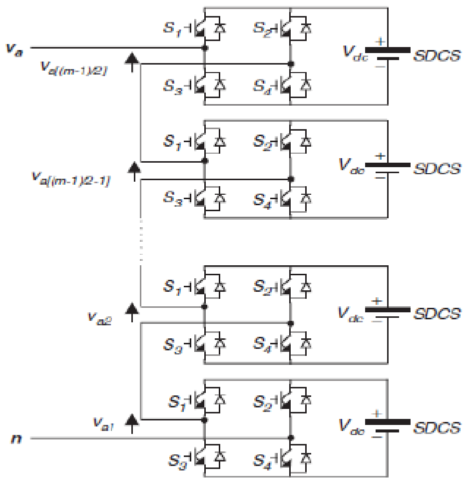

Figure 4: Cascade H-Bridge MLI with N-Bridges

(D) Cascaded Hybrid-Multi-Level-Inverter

Hybrid Multi Level-Inverter is the combination of two or more topologies discussed above in a single structure [20]. The aim of Hybrid Multi-Level inverter topology is to overcome the limitation of basic topologies by combining their benefits into single one and to minimize the number of DC sources connected individually in more power & high voltage applications. A simple Cascaded-Hybrid Inverter is shown in Fig. 5, in which 9-level cascaded inverter is integrated with a 3-level diode-clamped inverter.

In conventional Cascaded H-bridge Multi Level-Inverter(MLI), Single-phase MLI require four DC-sources, while Three-Phase MLI requires 12 DC-sources [40]. However, in this hybrid topology the number of DC sources needed is less comparatively. Also it can be noticed from Figure 5, that the semi-conductor switches required is less compared to other topologies thereby minimizing total number of components, which results in reduction in size,weight and cost [41].

Advantages

- Simple in construction with high reliability [9, 42].
- Less number of separated DC sources is required [9].
- Improved power quality and efficiency [39, 43].
- Lower Electromagnetic interference [42]
- Reduced Power losses and low cost [41, 43].

Disadvantages

- It's use is limited to specific application [34].
- Hybrid structure make its control complex[7, 36].

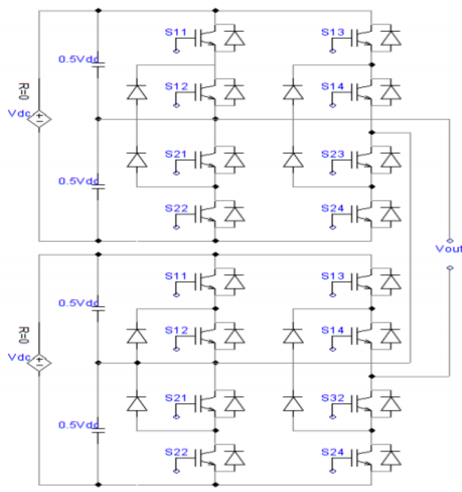

Figure 5: Cascaded Hybrid Multi-Level Inverter(MLI). [38]

III. Topology Comparison

This section gives a brief comparison between Capacitor-Clamped, Diode-Clamped and Cascaded H-Bridge Multi-Level-Inverter topologies. Comparison of components needed for different Multi-LevellInverter topologies are conveyed in Table I.

Figures 6 to 8 shows a general comparison of the components required for each topology, in which Cascade H-Bridge MLI requires the minimal number of elements comparatively.

TABLE I. COMPONENT REQUIRED FOR EACH TOPOLOGY

Basic Topology	Diode-Clamped MLI	Capacitor-Clamped MLI	Cascaded H-bridge MLI
Semi-conductor Switches	*2*(-1)*	*2*(-1)*	*2*(-1)*
Clampingdiodes/ phase	*(-1)*(-2)*	*None*	*None*
DC-Bus-Capacitor	*(-1)*	*(NL-1)*	*0.5*(-1)*
Balancing-Capacitors	*None*	*0.5*(-1) *(-2)*	*None*
Voltage-Unbalancing	*Moderate*	*Maximum*	*Minimum*
Applications	*Motor-drives application's*	*Motor-drives application's*	*Batteries,Wind, PV systems*

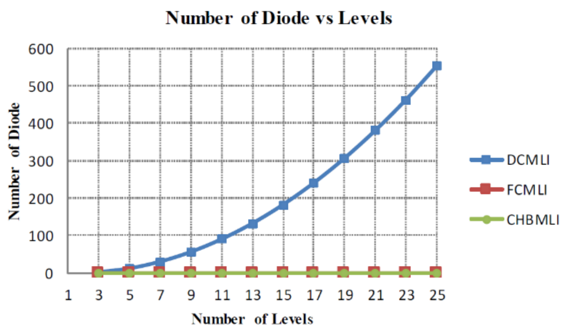

Figure 6: Clamping-Diodes required for MLI.

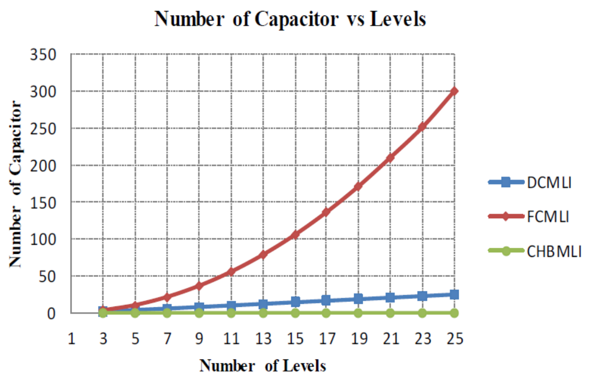

Figure 7: Balancing Capacitors required for MLI.

Figure 6, show that for Diode-clamped Multi-LevellInverter only clamping-diodes are required. Figure-7 is a graph between Number of level and capacitor required. It can be seen from the graph that diode-clamped and capacitor-clamped MLI requires balancing capacitor. Figure 8, shows the total number of components required for each topology. It can be observed, that cascaded H-bridge MLI topology entail minimum number of components and is therefore preferred in various application. like PV,high AC Power supplies etc.

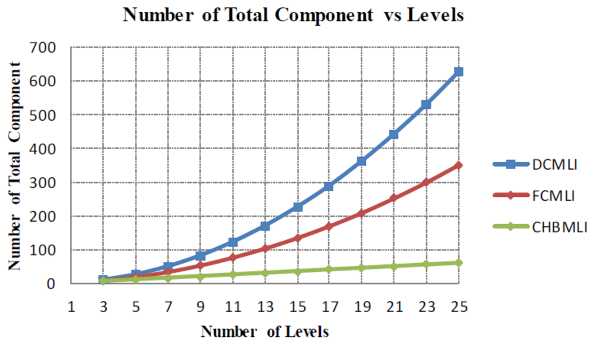

Figure 8: Total Components Required for each topology.

However, the number of sources needed in cascade H-Bridge MLI topology is high. Diode-Clamped and Capacitor-Clamped MLI inverter topologies share a common DC-bus, resulting in reduced number of supply sources [2, 39]. Taking into account the level of complexity, Diode-clamped MLI and Cascaded MLI can be easily controlled than Flying-Capacitor MLI, but construction wise it is a bit complex topology, as it is difficult to select clamping diodes [24]. On the other hand, in case of Flying-Capacitor it is difficult to determine capacitor Pre-charging and Dis-charging time. Detail analysis of all the topologies based on the components requirement and application, Cascaded H-Bridge MLI topology proves to be the best selection among other choices and is widely use in different applications.

CONCLUSION

In this paper a comprehensive discussion on basic multilevel inverter topologies are carried out and compared in different aspects. As each of the topology has its own strength and weaknesses, so the choice of each inverter can made depend upon it application. The most important benefit of Multilevel inverter is providing a solution to THD problem. For Renewable-energy-sources (RES) Cascaded H-Bridge MLI topology seems to be the best option.In Hybrid Renewable-Energy-system (HRES) there are multiple sources like Wind, PV etc. The use of Cascaded H-Bridge MLI topology gives flexibility to connects all the sources to a single inverter, as this topology need to be fed from different sources to get Multi-Level waveform at the output. Cascaded Multi-Level-Inverter(MLI) can be designed using less number of components compared to other MLI topologies. So less number of semi-conductor switches are used, due to which losses as well as total cost is reduced with increased efficiency. The complexity of the circuit also decreases with the decrease of semiconductor switches. Furthermore, the most important benefit is reduction in Total-Harmonic-Distortion as the number of level increases, thus improving power quality.

REFERENCES

[1] G. P. Adam et al. "New flying capacitor multilevel converter". In: 2011 IEEE International Symposium on Industrial Electronics. 2011, pp. 335–339. DOI: 10 . 1109/ISIE.2011.5984181.

[2] S. S. Priyan and K. Ramani. "Implementation of closed loop system for flying capacitor multilevel inverter with stand-alone Photovoltaic input".

In: 2013 International Conference on Power, Energy and Control (ICPEC). 2013, pp. 281–286. DOI: 10 . 1109 / ICPEC . 2013 .6527666.

[3] L. Wang, Q. H. Wu, and W. Tang. “Novel Cascaded Switched-Diode Multilevel Inverter for Renewable Energy Integration”. In: IEEE Transactions on Energy Conversion 32.4 (2017), pp. 1574–1582. ISSN: 0885- 8969. DOI: 10.1109/TEC.2017.2710352.

[4] P. Sotoodeh and R. D. Miller. “Design and Implementation of an 11-Level Inverter With FACTS Capability for Distributed Energy Systems”. In: IEEE Journal of Emerging and Selected Topics in Power Electronics 2.1 (2014), pp. 87–96. ISSN: 2168-6777. DOI: 10 . 1109 / JESTPE.2013.2293311.

[5] S Senthil and K Ravi. “A new compilation of renewable energy sources using multilevel inverter with space vector modulation techniques”. In: Green Computing Communication and Electrical Engineering (ICGCCEE), 2014 International Conference on. IEEE. 2014, pp. 1–6.

[6] Amrita Tuteja, Amita Mahor, and Aarti Sirsat. “A review on mitigation of harmonics in cascaded H-bridge multilevel inverter using optimization techniques”. In: International Journal of Emerging Technology and Advanced Engineering 3.2 (2013), pp. 30–34.

[7] J Rodiguez. “Multilevel inverter: a survey of topologies, controls, and application”. In: IEEE Transaction on Industrial Electronics 49.4 (2002), pp. 724–738.

[8] Ashish Bendre and Giri Venkataramanan. “Neutral current ripple minimization in a three-level rectifier”. In: IEEE transactions on industry applications 42.2 (2006), pp. 582–590.

[9] Derakhshanfar Mohammadreza. “Analysis of different topologies of multilevel inverters”. In: (2010).

[10] Dogga Raveendhra, Pracheta Prakash, and Parvesh Saini. “Simulation based analysis of FPGA controlled Cascaded H-Bridge Multilevel inverter fed solar PV system”. In: Energy Efficient Technologies for Sustainability (ICEETS), 2013 International Conference on. IEEE. 2013, pp. 568–572.

[11] Yugo Kashihara and Jum-ichi Itoh. “Power losses of multilevel converters in terms of the number of the output voltage levels”. In: Power Electronics Conference (IPEC-Hiroshima 2014-ECCE-ASIA), 2014 International. IEEE. 2014, pp. 1943–1949.

[12] H Jabir et al. “Development of a transformer-based multilevel inverter topology for stand-alone photovoltaic system”. In: Power Electronics and Applications (EPE),topology for stand-alone photovoltaicvsystem”. In: Power Electronics and Applications (EPE), 2013 15th European Conference on. IEEE. 2013, pp. 1–10.

[13] S Boobalan and R Dhanasekaran. “Hybrid topology of asymmetric cascaded multilevel inverter with renewable energy sources”. In: Advanced Communication Control and Computing Technologies (ICACCCT), 2014 International Conference on. IEEE. 2014, pp. 1046 1051.

[14] Md Rabiul Islam et al. “A 43-level 33 kV 3-phase modular multilevel cascaded converter for direct grid integration of renewable generation systems”. In: Innovative Smart Grid Technologies-Asia (ISGT Asia), 2014 IEEE. IEEE. 2014, pp. 594–599.

[15] Edris Pouresmaeil, Daniel Montesinos-Miracle, and Oriol Gomis-Bellmunt. “Control scheme of three-level NPC inverter for integration of renewable energy resources into AC grid”. In: IEEE systems journal 6.2 (2012), pp. 242–253.

[16] Miguel Chaves et al. “New approach in back-to-back mlevel diode-clamped multilevel converter modelling and direct current bus voltages balancing”. In: IET Power Electronics 3.4 (2010), pp. 578–589.

[17] Xianglian Xu et al. “FPGA based multiplex PWM generator for diode-clamped cascaded inverter in the direct-driven wind power system”. In: Power Electronics and Motion Control Conference (IPEMC), 2012 7th International. Vol. 2. IEEE. 2012, pp. 1268–1272.

[18] Sanghun Choi and Maryam Saeedifard. “Capacitor voltage balancing of flying capacitor multilevel converters by space vector PWM”. In: IEEE Transactions on Power Delivery 27.3 (2012), pp. 1154–1161.

[19] Ahmad Alyan et al. “New topology three phase multilevel inverter for grid-connected photovoltaic system”. In: Industrial Electronics (ISIE), 2014 IEEE 23rd International Symposium on. IEEE. 2014, pp. 592–599.

[20] Xiaonan Lu et al. “High performance hybrid cascaded inverter for renewable energy system”. In: Applied Power Electronics Conference and Exposition (APEC), 2011 Twenty-Sixth Annual IEEE. IEEE. 2011, pp. 970– 975.

[21] Akira Nabae, Isao Takahashi, and Hirofumi Akagi. “A new neutral-point-clamped PWM inverter”. In: IEEE Transactions on industry applications 5 (1981), pp. 518–523.

[22] Hee-Jung Kim, Hyeoun-Dong Lee, and Seung-Ki Sul. “A new PWM strategy for common-mode voltage reduction in neutral-point-clamped inverter-fed AC motor drives”. In: IEEE Transactions on Industry Applications 37.6 (2001), pp. 1840–1845.

[23] Changliang Xia et al. “Discontinuous space vector PWM strategy of neutral-point-clamped three-level inverters for output current ripple reduction”. In: IEEE Transactions on Power Electronics 32.7 (2017), pp. 5109–5121.

[24] Yong Wang et al. “Diode-free T-type three-level neutralpoint- clamped inverter for low-voltage renewable energy system”. In: IEEE Transactions on Industrial Electronics 61.11 (2014), pp. 6168–6174.

[25] Muhammad H Rashid. Power electronics handbook. Butterworth-Heinemann, 2017.

[26] Engin Ozdemir, Sule Ozdemir, and Leon M Tolbert. “Fundamental-frequency-modulated six-level diodeclamped multilevel inverter for three-phase stand-alone photovoltaic system”. In: IEEE Transactions on Industrial Electronics 56.11 (2009), pp. 4407–4415.

[27] Leon M Tolbert, Fang Zheng Peng, and Thomas G Habetler. “Multilevel converters for large electric drives”. In: IEEE Transactions on Industry Applications 35.1 (1999), pp. 36–44.

[28] ID Pharne and YN Bhosale. “A review on multilevel inverter topology”. In: Power, Energy and Control (ICPEC), 2013 International Conference on. IEEE. 2013, pp. 700–703.

[29] Sergio Daher. Analysis, design and implementation of a high efficiency multilevel converter for renewable energy systems. Kassel University Press, 2006.

[30] Ibrahim Haruna Shanono. Multilevel converters: the future of renewable energy: design, simulation and implementation of a multilevel converter. LAP LAMBERT Academic Publishing, ein Imprint der/a trademark of AV Akademieverlag GmbH & Company KG, 2012.

[31] Mohamad Agha Shafiyi et al. “A grid-connected PV power supply based on flying capacitor multicell converter with modified MPPT based control for active power filtering”. In: Renewable Energy and Distributed Generation (ICREDG), 2012 Second Iranian Conference on. IEEE. 2012, pp. 141–146.

[32] Georgios Konstantinou et al. “The seven-level flying capacitor based ANPC converter for grid intergration of utility-scale PV systems”. In: Power Electronics for Distributed Generation Systems (PEDG), 2012 3rd IEEE International Symposium on. IEEE. 2012, pp. 592–597.

[33] Mostafa Khazraei et al. “Active capacitor voltage balancing in single-phase flying-capacitor multilevel power converters”. In: IEEE Transactions on Industrial Electronics 59.2 (2012), pp. 769–778.

[34] Ilhami Colak, Ersan Kabalci, and Ramazan Bayindir. “Review of multilevel voltage source inverter topologies and control schemes”. In: Energy conversion and management 52.2 (2011), pp. 1114–1128.

[35] Moncef Ben Smida and Faouzi Ben Ammar. “Modeling and DBC-PSC-PWM control of a three-phase flying capacitor stacked multilevel voltage source inverter”. In: IEEE Transactions on Industrial Electronics 57.7 (2010), pp. 2231–2239.

[36] Jih-Sheng Lai and Fang Zheng Peng. “Multilevel converters-a new breed of power converters”. In: IEEE Transactions on industry applications 32.3 (1996), pp. 509–517.

[37] Muhammad Sadikin, Tomonobu Senjyu, and Atsushi Yona. “High-frequency link DC for power quality improvement of stand-alone PV system in cascaded multilevel inverter”. In: Power Electronics and Drive Systems (PEDS), 2013 IEEE 10th International Conference on. IEEE. 2013, pp. 597–601.

[38] Surin Khomfoi and Leon M Tolbert. "Multilevel power converters". In: Power Electronics Handbook (Third Edition). Elsevier, 2011, pp. 455–486.

[39] M Charai et al. "Performance Evaluation for Different Levels Multilevel Inverters Application for Renewable Energy Resources". In: Journal of Engineering Technology (ISSN: 0747-9964) 6.1 (2017), pp. 90–96.

[40] WA Hill and CD Harbourt. "Performance of medium voltage multi-level inverters". In: Industry Applications Conference, 1999. Thirty-Fourth IAS Annual Meeting. Conference Record of the 1999 IEEE. Vol. 2. IEEE. 1999, pp. 1186–1192.

[41] Y. Suresh and Anup Kumar Panda. "Investigation on hybrid cascaded multilevel inverter with reduced dc sources". In: Renewable and Sustainable Energy Reviews 26 (2013), pp. 49 –59. ISSN: 1364-0321. DOI: https : / / doi . org / 10 . 1016 / j . rser . 2013 . 04 . 027. URL: http : / / www. sciencedirect . com / science / article / pii / S1364032113002797. [42] E. Najafi and A. H. M. Yatim. "Design and Implementation of a New Multilevel Inverter Topology". In: IEEE Transactions on Industrial Electronics 59.11 (2012), pp. 4148–4154. ISSN: 0278-0046. DOI: 10.1109/TIE. 2011.2176691.

[42] E. Najafi and A. H. M. Yatim. "Design and Implementation of a New Multilevel Inverter Topology". In: IEEE Transactions on Industrial Electronics 59.11 (2012), pp. 4148–4154. ISSN: 0278-0046. DOI: 10.1109/TIE. 2011.2176691.

[43] Sizhao Lu et al. "Modularized high frequency high power 3-level neutral point clamped PEBB cell for renewable energy system". In: Energy Conversion Congress and Exposition (ECCE), 2014 IEEE. IEEE. 2014, pp. 2594–2599.

Authors Details:

Engr. Muhammad Ilyas has received B.Sc Electrical Engineering degree from Department of Electrical Engineering, University of Engineering and Technology, Peshawar, Pakistan in 2015. He is currently pursuing MS in Electrical Energy Systems Engineering from United States Pakistan Center for Advanced Studies in Energy (USPCAS-E) at University of Engineering and Technology Peshawar. He worked on Efficiency Improvement of Small Scale and Micro Hydro Power Plants for the potential sites in KPK, Pakistan.

Dr. Tanvir Ahmad has received PhD degree with specialization in Wind Farm Coordinated Control and Optimization from School of Engineering and & Computing Science, Durham Universtiy, UK in 2017. He is currently working as a Assistant Professor at US-Pakistance Center for Advance Studies in Energy, University of Enegineering and Technology Peshawar, Pakistan. Tanvir's main research interests involve Smart Control of power system based on Artificial Intelligence (AI) and heuristic based optimization techniques, Energy Management Systems, Energy Auditing, Socio-Technical models for Energy Systems, Data Analytics for efficient utilization of Renewable Energy, Wake Flow Models and Wind Deficit Models.

Engr. Shifaat Ur Rehman has received BS degree in Electrical Engineering from University of Engineering & Technology Peshawar KP, Pakistan in 2014. Currently pursuing MS degree in Electrical Energy System Engineering from US Pakistan Center for Advanced Studies in Energy(USPCAS-E), University of Engineering & Technology Peshawar. He has availed exchange program to the partner university of USPCAS-E Arizona State University (ASU), USA in 2016, as a research scholar. He has good hands on experience in the field of renewable energies especially PV reliability.