AN INCLUSIVE REVIEW ON VARIOUS MULTILEVEL CONVERTER TOPOLOGIES FOR A GRID CONNECTED PHOTO-VOLTAIC SYSTEM

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Abstract - *The popularity of multi-level inverters (MLIs) for high power and high voltage applications is increasing day-by-day. These MLIs are being integrated with the grid for renewable energy extraction like solar photovoltaic (PV) system. This paper presents the various MLIs, their modulation and control techniques for the grid connected applications. A detailed classification of different grid connected Multi-level inverters (GCMLIs) based on the number and arrangement of DC voltage sources is presented. Each topology has their corresponding advantages and disadvantages when embedded in a Renewable Energy Power system. The Review is formed within the aspects of Construction complexness, Total Harmonic Distortion, Controlling methodologies and Components requirement.*

Key Words: Cascaded Inverters, Flying Capacitor, Grid connected Multi-level inverters (GCMLIs), Hybrid Inverter, Multi-level inverter (MLI), Solar Photovoltaic (PV).

1. INTRODUCTION

The continuous growth of the electrical power system, resulting in an increase of electric power demand across the globe forces us to switch to other sources of energy. Renewable Energy sources are most popular among other sources because of their less carbon emission which plays a major role in reducing Global warming. As the efficiency of Renewable energy sources is relatively less than that of conventional fossil fuels, so improvements are made on either side for the purpose of power quality improvement as well increase the usage of Renewable Energy sources. In the supply side Maximum Power Point tracking is implicit whereas within the converter side the reduction of Total Harmonic distortion as well the increase of the output levels of Multilevel Inverter is done to increase the performance of Renewable Energy Sources.

2. MULTILEVEL INVERTER TOPOLOGIES

Because of reduced disturbances and operational losses at lower switching frequency makes the Multilevel Inverter more appropriate for Renewable Energy sources. Multilevel Inverters gives smoother output waveforms once the levels are increased at the same time the Total Harmonic distortion in additionally reduced [2], [14]. The numbers of levels are inversely proportional to Total Harmonic Distortion such that THD becomes zero at infinity levels. Increasing the levels increases the component necessity and control complexity, so the selection of appropriate topology is necessary to overcome the above disadvantages [4]. The usually used multilevel inverter topologies are Diode Clamped multilevel inverter (DCMLI), Flying Capacitor Multilevel Inverter (FCMLI), and Cascaded Multilevel Inverter (CMLI).

2.1 Diode Clamped Multilevel Inverter

The Neutral point Clamped MLI (NPCMLI), also known as a Diode Clamped MLI (DCMLI) [17] was first introduced by Baker and Bannister in the year 1980. Diode Clamped or Neutral Point Clamped MLI has diode that clamps the supply DC voltage to attain steps within the output wave form [6]. In DCMLI to attained N levels 2(N-1) switches, (N-1)*(N-2) Diodes for Clamping and (N-1) capacitors for DC link are required. The structure of a 3 phase DCMLI in fig 1. The source Vdc is split into different voltage levels by using capacitor C1-C2 connecting them in series. The semiconductor switches Sa_1 and $S'a_1$ should allow the entire DC voltage from capacitors when switched on using PWM pulse respectively, but the diode D1-D2 should block different voltage levels such that D1 should block 3 levels decreasing down so that D4 should block 1 level so the step waveform is achieved in the output.

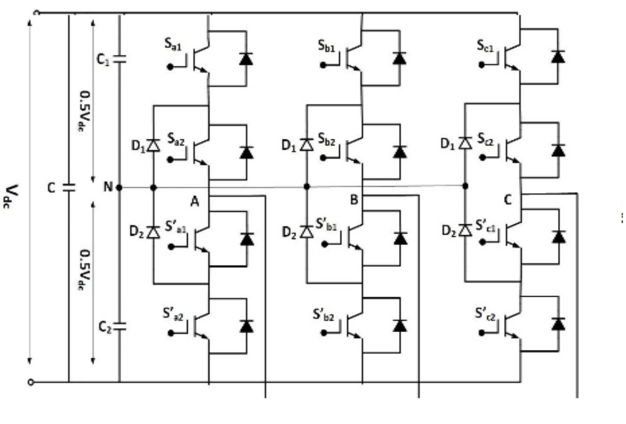

Fig -1: Three Phase diode clamped inverter

Advantages

(i)The numbers of sources required are less as the capacitors can share a single source.
(ii)At higher output levels, less number of filters are needed because the THD is reduced once the levels are increased.
(iii)Throughout the fundamental frequency switching the efficiency is high.
(iv) Pre-charging of the capacitors in group is feasible.

Disadvantages

(i) Tough to observe and control of overcharging of DC levels within the inverter so affecting the real power flow [7].
(ii) Higher number (i.e., (N-1)*(N-2)) of clamping diodes are required to attain higher number of levels.

2.2 Flying Capacitor Multilevel Inverter

The Flying Capacitor MLI (FCMLI), also known as Clamping Capacitor MLI (CCMLI), was first introduced by Menard and Foch in the year 1992 [18]. FCMLI resembles similar structure of DCMLI in which the capacitors replaces the diodes [3]. Here the determination of voltage levels is done by the charging and discharging of the flying capacitors connected to the neutral point [11], [12]. Switching ON semiconductor switches S1 and S2 charges the flying capacitor C_F link when the switches are turned OFF the capacitor starts discharging. The variable discharging time of every clamping capacitor creates a Multilevel within the output voltage. For obtaining N levels ((N-1)*(N-2))/2 clamping capacitors are needed. Similar to diode clamped (N-1) capacitors of same rating are needed.

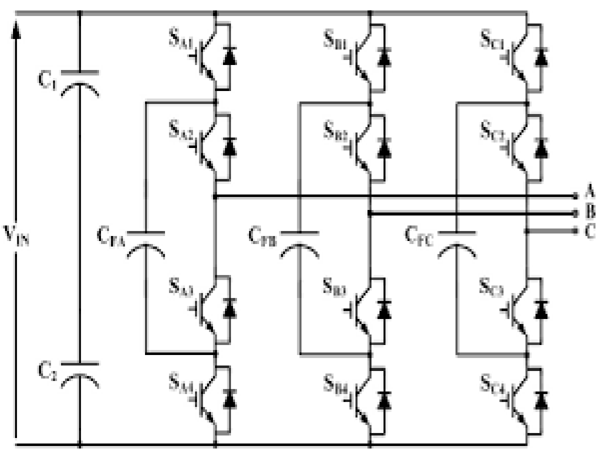

Fig -2: Capacitor Clamped Multilevel Inverter

Advantages

(i) It is possible to Control real and reactive power flow.
(ii) Does not require any clamping diodes.
(iii)No transformer is needed to achieve the required number of voltage levels [5].
(iv)Balancing capacitor shares single DC supply.

Disadvantages

(i) Pursuing of voltage levels in capacitors is lots of complicated as compared to diodes.
(ii) Determination of pre-charging time of all capacitors is difficult.

2.3 Cascaded Multilevel Inverter

A Cascaded Multilevel Inverter or H-Bridge Multilevel Inverter topology is the simplest topology of Multilevel Inverter. For N levels (N-1)/2 sources are required. Each supply is connected by an H-bridge containing four semiconductor switches [9]. The H-Bridges are connected in series or cascaded manner together such that the output is taken from the top leg of the first bridge and bottom leg of the last bridge. The switching cycle of each bridge is such a way that 1st Bridge is ON so Vdc from the source 1 produces a level again when 2nd bridge is ON the bridges 1 and 2 are cascaded therefore total of the two sources offers another level within the output is obtained. Finally when N bridges is ON the sum of the all the sources gives the maximum output voltage with N-level

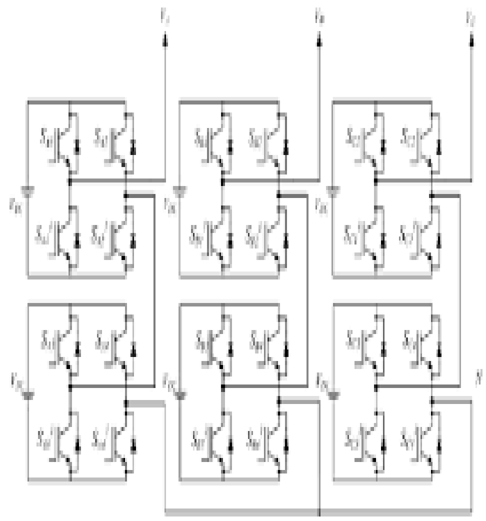

Fig -3: Cascaded Multilevel Inverter

Advantages

(i) Does not require any clamping diodes as well as clamping capacitors therefore the number of components needed for N levels is extremely less as compared to the other topologies [10].
(ii) Simple DC bus regulation.
(iii) Easy to construct and easier to regulate the switching cycle of the semiconductor devices.

Disadvantages

(i) Large number of DC sources are needed to achieve higher levels.
(ii) All Bridges must be in working in order to achieve output.

2.4 Z-source Multilevel Inverter

The impedance source or Z-source inverter was proposed for the first time by [19] and is shown in Fig.4. Z-source inverters distinguished it selves from other conventional types of inverters by providing voltage boost capability in common inverters. Due to generating the output voltage lower than the DC input voltage the conventional inverters are invariably a buck converter [20]. In addition, if the upper and lower power switch conducts all together; the DC source will short-circuit. Therefore, a dead band is provided purposefully between the switching on and off of the complimentary power switches of the identical leg, consequently some distortions in the output current are caused by this dead band. These drawbacks are overcome in the Z-source inverter [20]. Comprehensive discussion on the Z-source inverter is given in [21,22,23].

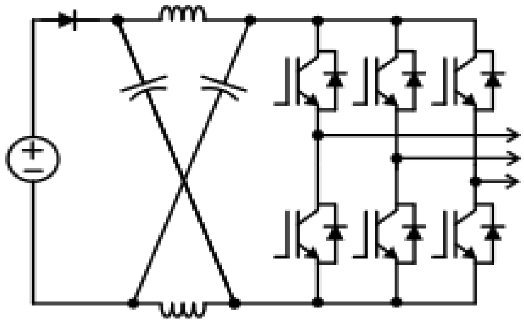

Fig -4: Name of the figure

Advantages

(i) There is no requirement of a boost circuit. This reduces the cost of the system for specific applications.
(ii) Another important advantage is the Z source inverter is single stage in contrast to a normal inverter used with a boost converter. This improves the system efficiency for the Z source inverter. But for the normal inverter inclusion of an additional power processing stage affects the efficiency slightly.
(iii) Z source inverter also provides inherent short circuit protection due to the input inductor.

Disadvantages

(i) Z-source inverter has lower average switching device power in low boost ratio range (1 ÷ 2). In cases when a low voltage is used and a boost ratio much higher than 2 is required, the dc–dc boosted PWM inverter will acts as the best configuration.
(ii) The identified RHP zero in Z-source impedance network can't be eliminated by adjusting the Z-source parameters.

2.5 Quasi Impedance Source or QZSI Multilevel Inverter

Fig.5 presents the QZSI topology which was proposed in [16] as a derivative of the original Z-source inverter; so it contains all the benefits of the ZSI. The impedance source or Z-source inverter has the weakness of discontinuous input (DC) current throughout boost mode, high voltages across the capacitors, and higher stress on power switches [20, 22].These limitations are overcome by QZSI [22,23]. Drawing continuous current from DC supply, decreasing the voltage across the capacitor C2, lower elements count and therefore high reliability as well as putting lower voltage stress on the power switches are considered as the major advantages of a QZSI [20].

Advantages

(i) This type of topology has reduced the component ratings and improved reliability.
(ii) It draws a continuous constant dc current from the source.

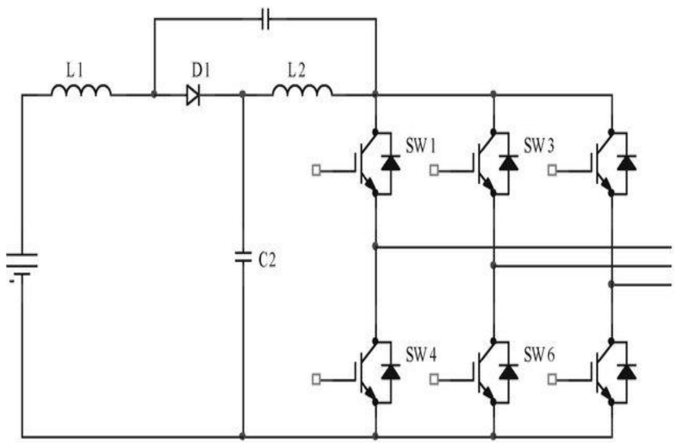

Fig -5: QZSI topology

(iii) The inverter operates in the shoot-through mode during the shoot through period. It results in a wide voltage gain [20].

2.6 T-Type Multilevel Inverter

The T-type MLI was introduced in Jana et al. (2016) to achieve the higher voltage levels with the reduced device count. The T-type MLI mentioned in Fig. 6 comprises one H-bridge (H1, H2, H3 and H4) and two bidirectional switches (S1, S2). To further increase the number of voltage levels, the number of bidirectional switches along with capacitors at the DC link need to be increased.

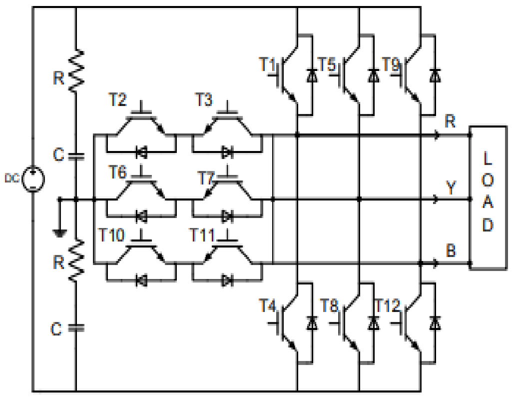

Fig -6: 3-Phase 3-Level T-type Inverter model using NPC topology

2.7 Mixed or Hybrid Multilevel Inverter

Hybrid Multilevel Inverter is the new Multilevel Inverter obtaining by combining any two or all the above topologies [1]. The hybrid inverters are designed to overcome the disadvantages of each topology in their respective applications. A simple Hybrid Cascaded Inverter is shown in Fig. 7, conventional two-level leg in the H-bridge module of the CMI with diode clamped or capacitor clamped multilevel leg in order to reduce the number of separate DC sources. Each module of this topology gives the output of three-level voltage and each phase contains a cascaded NPC-based H-bridge module [15, 19]. The number of switching devices in the conversion system will be reduced by taking the hybrid topologies.

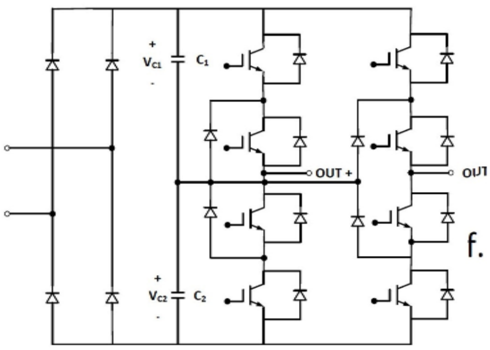

Fig -7: 3-Phase 3-Level T-type Inverter model using NPC topology

Advantages

(i) Simple in construction with high reliability.
(ii) Improved power quality and efficiency [8].
(iii) Power losses are less.

Disadvantages

(i) Limited to specific applications.
(ii) Complexity in control.

3. Comparison of the MLI Topologies

A comparison of the different components required is shown in Table 1, from the table it is clearly seen that the number of components required is relatively low within the Cascaded H-bridge Inverter. But the sources needed is high, however the other topologies shares single DC bus makes the number sources needed very low[15]. Considering the control, the controlling of Diode clamped and Cascaded Inverter is easier than Flying Capacitor Inverter. But the construction wise, selection of clamping diode makes it a complex topology [13]. Similarly determining pre-charging and discharging time of the capacitor in Flying Capacitor Inverter is difficult. On comparing all topologies the Cascaded H Bridge Inverter topology is found to be the best among all other inverter topologies for any application.

Table -1: Components for each topology

Inverter Configuration	**Diode Clamped**	**Flying Capacitors**	**Cascaded inverter**
Main switching devices	2(N-1)	2(N-1)	2(N-1)
Main diodes	2(N-1)	2(N-1)	2(N-1)
Clamping diodes	(N-1)*(N-2)	0	0
DC bus capacitors	(N-1)	(N-1)	0
Balancing Capacitors	0	(N-1)*(N-2)/2	0

3. CONCLUSION

In the application of Renewable energy sources the Cascaded H-bridge Inverters are the more suitable one. In photovoltaic power systems or Hybrid power systems having multiple sources, by employing a cascaded H-bridge Inverter all the sources are connected to single Inverter since this topology needs different DC sources for achieving multilevel output. As the components required are less so losses are reduced and cost is also gets reduced thereby the efficiency is increased. Increasing the levels reduces Total Harmonic distortion therefore at higher levels the THD is reduced and also the power quality is improved.

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