Review on Modular Cascaded Multi-level Inverter Topologies

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Abstract — Multi-Level Inverter (MLI) are the widely adopted power conversion devices in modern power system. They have excellent performance characteristics in medium and high voltage level as well as they have wide range of applications. The conventional topologies of MLI are neutral point, fixed capacitance and cascaded topologies. Among the three types, cascaded has the modular type structure. The conventional topologies have high component requirement as the levels increases. Hence the researchers developed the modified reduced count topologies. This paper presents the literature survey on such topologies in order to achieve high voltage level with better efficiency and low component requirements as compared to conventional MLI topologies.

Keywords: Multilevel inverter (MLI), MLI with Reduced Switch Count (MLI-RSC), Modular Multilevel Converter, Voltage Source Converter (VSC), Cascaded H-Bridge, Pulse Width Modulation (PWM).

I. INTRODUCTION

DC-AC power conversion has now become a key technology in the areas of generation, transmission, distribution and utilization of electric energy. To serve this purpose of modern setup, DC-AC converters (`inverters') are playing an important role in various key areas such as HVDC power transmission, static VAR compensators, electric drives, Flexible AC Transmission Systems (FACTS), renewable energy integration (such as solar PV, DFIG and variable speed wind turbine system, fuel cells) and electric vehicle/hybrid electric vehicles. Based on the nature of output waveform, inverters are classified as: two level or square wave inverters, quasisquare wave inverters, two-level PWM inverters and multilevel inverters (MLIs). The major problem associated with two level square wave and PWM inverters is that for medium and high power level system, they require devices of high power rating which is many times not available and hence to serve the purpose many devices need to be connected in series/parallel strings to obtain the required voltage/current capacity. Another problem with these inverters is the poor power quality output and filtering requirements before the load. The multilevel inverter (MLI) structure is introduced as an alternative for such power levels. Basic concept of MLI is that it uses several DC sources along with several low rated power semiconductor switches for synthesizing a stepped voltage waveform for achieving higher power levels.

Various energy sources such as batteries, capacitors, fuel cells, solar PV panels can be used for the purpose of multiple input DC sources. Power switches are then controlled using suitable algorithms so as to add all these multiple DC sources to achieve high output voltage, while at the same time the voltage blocking of each controlled switch depends on the sum of DC sources connected to it at any instant. This reduces the voltage stress on each controlled switch as compared to operating voltage. The classification of MLI is shown in figure 1.

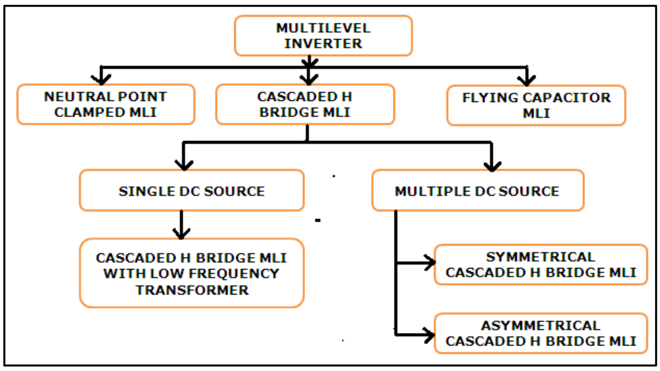

Fig. 1: Classification of MLI

A. *Reduced Count MLI Topologies*

MLI with Reduced Switch Count (MLI-RSC) is with higher voltage levels is gaining high attention particularly for application oriented topologies [14]. For designing MLI-RSC with higher voltage levels, modular topology is best suited which is cascaded H bridge MLI with isolated DC voltage sources. With higher voltage level, some applications require higher output levels. The basic idea is the more the number of level, the high is the inversion level with good efficiency and negligible stress on each component. Hence, seeing to the need for high level in MLI like 13, 15, 17, etc. topological advancement is required in MLI. In conventional topologies, for higher number of output level higher components are required, also the driver circuit for generating gate pulses becomes complicated which may results in reduced efficiency. Hence a reduced modified MLI topologies are developed which has the following advantages;

1) High total voltage blocking capability.
2) Reduced switch count.
3) Can be applicable to symmetrical and asymmetrical configuration of sources.
4) Capable of level generator and polarity generator.
5) Even power distribution across each semiconductor switch.
6) Negligible switching losses at fundamental frequency switching.
7) Have modular structure.

All the above features of modified reduced count topology of MLI has made it popular in modern power system applications.

II. LITERATURE SURVEY

The problems associated with the classical topologies have been discussed above, hence academsians and researchers have gone for new multilevel topologies. But still none of the topologies can be claimed to be absolutely advantageous. Most of them are application oriented and are intended to serve some particular application. Some topologies are best suited for some application while others are not at all suitable for that application. Some of these contributions are discussed in this subsection. Ebrahimi et al. [21] presented a Multilevel

Module (MLM) based multilevel inverter for high power quality applications which utilizes combination of both unidirectional and bidirectional switches of different ratings and requires considerable number of DC sources along with reduction in power losses for same number of levels. Buticchi et al. [22] have presented a single phase transformerless grid connected multilevel inverter topology for photovoltaic system which is based on two cascaded two-full bridges with different DC link voltages and one bridge supplied with flying capacitor. Converter is switched suitably so as to improve efficiency, reduce common mode voltage, harmonics and ground leakage current. Manjrekar and Lipo [23] have presented application of hybrid MLI for a 500 hp induction motor drive and has also investigated capacitor voltage balancing, design optimization and harmonic analysis of output waveform. Glinka and Marquardt [24] and Glinka [27] presented a new single DC source based multilevel topology, through his patent in Germany, known as `Modular Multilevel Converter (MMC)', and presented its main application in HVDC back to back transmission system and traction system. A new configuration of MLI for high voltage applications has been presented by Ebrahimi et al. [28]. This structure has not only reduced the number of switches but also the full bridge converters used in the topology are operating at low voltage and thus eliminating the requirement of high voltage switches for H-bridge and thus extending the application of proposed converter for high voltage applications.

Lezana et al. [29] presented a reduced cell cascaded multilevel converter with reduced single phase rectifier at input and H-bridge at output with the purpose of motoring and problem free regenerative mode (for downhill conveyors) while effectively controlling the waveform of input current and of the output voltage. To optimize the performance of voltage source converters in terms of magnitude of semiconductor losses and converter footprint, Adam et al. [30] have proposed a hybrid cascaded converter for HVDC system with DC short circuit proof feature, which is essential for a high integrity multi-terminal HVDC grid with details of modulation strategy and capacitor voltage balancing. To increase the power rating of a Voltage Source Converter (VSC), Laka et al. [31] have presented a new VSC topology with high power handling capacity over a standard three-phase VSC. The proposed converter has interconnected three three-phase converters with 3L-NPC using two Zero Sequence Blocking Transformers (ZSBT) to avoid undesirable overcurrent. The main advantage of this topology is that its power rating has increased three times as compared to a standard three phase converter by using low VA rating magnetic components. To utilize the transformerless operation advantage of MLI, Du et al. [32] have shown the implementation of cascaded multilevel boost inverter for the application of electric vehicles and hybrid electric vehicles without using the bulky inductors and utilizing Selective Harmonic Elimination (SHE) as modulation strategy for the control of the inverter output. For achieving low input current distortion and high power factor with low switching frequency of 1kHz and without using bulky LC filters, Ooi et al. [33] have presented two new 5-level multiple pole AC/DC/AC converter topologies with front end unidirectional and bidirectional rectifiers with small total component count. Both types of topologies are controlled using LS-PWM control scheme.

Thus, even after so much study on the various aspects of the multilevel inverters, researchers are continuing their efforts to develop new MLI topologies to best suit some particular application. In spite of many advantages of MLIs, their application in terms of number of output levels is still a limiting factor for the MLIs due to many factors such as number of power semiconductor switches, number of DC sources, number of gate driver circuits, protection circuits, heat sinks and complex control strategy. These all factors add to complexity, cost and bulkiness of the inverter. In recent years, many authors have proposed many new topologies for synthesizing multilevel output for achieving the purpose of either reducing the number of controlled power semiconductor device count or individual DC source requirements or reducing the number of the gate drive circuits [21], [30]. Bahravar et al. [49] proposed a new multilevel inverter topology referred as ‘Reduced Variety of DC Voltage Sources based cascaded multilevel Inverter (RVDC-CMLI)’. The proposed cascaded MLI comprised of series connection of proposed basic cell. Each basic cell or module is made up of two dc symmetrical voltage sources, two unidirectional – blocking – bidirectional - conducting power switches, and an H-bridge. Each cell has its own separate ‘level generator’ and ‘polarity generator’. The proposed topology is highly modular in nature and number of DC levels in output can be extended by cascading more modules. The new topologies presented till year 2013, have already been comprehensively reviewed in [34]. After that many newer efficient topologies have come into existence which are further reducing the number of switch count, gate driver circuits and independent DC sources. A brief survey of the numerous topologies with modified structure is presented in table-1 below. This paper aims to present a review of such topologies with exclusive purpose of reducing the power switch count and DC sources requirement.

Reference Paper	Number Type of MLI	Advantages	Problems
30	Reduced switch MLI	Less number of switches to achieve more output voltage levels	Increase in input DC voltage sources
31	Symmetric	Best suited for low voltage level	Failure in finding out the PWM technique
32	Symmetric	Best suited for low voltage level	
33	Asymmetric	Capable of attaining higher voltage level	Failure in designing the filter for harmonic reduction
34	Asymmetric cascaded	Capable of attaining	More number of switches

	MLI	higher voltage level	are used
35	Hybrid	Reduced switch with high voltage level	Control technique is complex
36	Symmetric and Asymmetric	High level with RSC	More blocking voltages due to bidirectional switches More switching losses Not applied for High voltage applications Cost Increases due to Bidirectional switches
37	Symmetric	Is applicable to both single as well as double source topology	More peak inverse voltage

Table 1: MLI-RSC comparison

III. CONCLUSION

MLI has inherent advantages, therefor it finds application in industrial as well as research stream widely. As the applications are increasing for MLI its level are also enhanced. In higher level of MLI topology, they have restrictions for component requirements and high losses across the components. As well as the conventional topologies becomes less efficient while moving towards higher levels. Hence a special class of MLI are developed which is very modular in nature. This new class of MLI has low component requirement and high efficiency when applied to higher output levels.

This paper presents the application-oriented literature survey for such reduced count modified MLI topology. Several papers are discussed in brief with their topological architecture and applications. Advantages and disadvantages of all the presented topologies in literature are also discussed in this paper.

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