A REVIEW ON MULTILEVEL VSC TOPOLOGY

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Abstract— **In electrical power system, Flexible AC Transmission System (FACTS) Devices provides better performance than conventional controllers. Voltage Source Inverter (VSI) based devices are more favorable FACTS controllers. In last couple of decades, many control technologies for VSC have been proposed. In this review paper, authors have categorized different control algorithm, switching schemes and converter topologies. Different multilevel converter schemes are proposed for the better performance of the Voltage Source Converter. Cascade H-bridge multilevel converter topology gives the better results than other topologies. For multilevel converter conventional PI, FUZZY controller, FUZZY-PI and FUZZY-PID controllers are used. The application of multilevel topologies in different FACTS devices has be discussed in the reviewed publications.**

Keywords— FACTS devices; STATCOM; voltage source converter; multilevel converter; Fuzzy logic controller; power system stability; Power quality.

I. INTRODUCTION

Electricity demand has been increased nowadays, hence stresses on the power system are increasing. Operation of power system is becoming more complex and less secure. This power system security problem has become a major concern in deregulated electricity market. Flexible AC Transmission System (FACTS) controllers are designed to improve the performance of weak electric grid and increases the power transmission limits. FACTS devices are used for active and reactive power compensation as well as to regulate the voltage magnitude [1]-[3]. Voltage stability mainly depends on the reactive power level of the line. The maximum loading capacity of the line depends on the reactive power level. Advantages of using FACTS devices are [4]:

i. Better control
ii. Response time is faster
iii. Reliable and flexible control
iv. Reduced the stress and losses in the system

Electrical power system never remains in stable position. Due to occurrence of unwanted disturbances, stability gets disturbed. In this paper influence of STATCOM on the stability of the power system is studied. To maintain synchronous stability, it is necessary to control the voltage by compensation of reactive power and STATCOM plays major role in reactive power compensation.

For active power flow in the line, it is necessary to maintain voltage level. Reactive power compensation is used to maintain voltage within limit. Reactive power is supplied by capacitors, as capacitor stores energy in the form of electrostatic field. When the capacitor is connected in the circuit, it builds full voltage difference for a specific time period. Thus capacitor voltage is always changing and opposes the change in voltage, therefore voltage lags behind the current.

Reasons for the reactive power compensation are [4]

i. Increase system stability.
ii. Voltage regulation.
iii. Reduction of losses associated with the system.

Reactive power compensation mitigates these problems as well as improves the transient response. Various FACTs devices are used for reactive power compensation. STATCOM is member of controller family. It is capable of generating or absorbing reactive power. It is solid state switching device that generates reactive power according to fulfill the need of reactive power at PCC.

Converter produces controlled three phase output voltage by switching operation. Use of multilevel inverter reduces the total harmonic distortion in the output voltage of inverter. Power flows from controller to line or line to controller depending upon the voltage level of DC link capacitor. This voltage is in phase with line voltage. In conventional STATCOM application two level voltage source converters are used. However, now a day's multilevel voltage source converters are used because of their modular structure and large power handling capacity. Multilevel inverter for solar and wind energy application are widely used [5]-[13]. Fig. 1 shows the connection of STATCOM to the grid with five level converter.

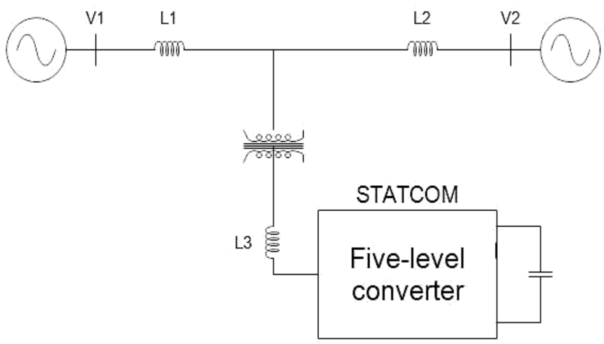

Fig. 1: STATCOM connected to the grid

Due to increased growth of load and transmission limitation, voltage instability problems could be more dynamic in nature. These problems can be mitigated using STATCOM with Magnetic Energy Storage system [14]. Using multilevel technology have many more advantages like higher power rating, lower total harmonic distortion and higher efficiency as compared to two level conventional converter technology [15]. Conventional converter faces the low switching frequency problem of the Thyristor and Gate Turn off (GTO). Use of multilevel converters eliminates these problems as well as cost effective and gives high performance [16]-[18]. Every power plant should have reliable reactive power source otherwise it would have negative impact on stability of the power system.

II. MULTILEVEL VSC TOPOLOGIES FOR STATCOM

Conventional two level converters are replaced by multilevel converter due to their modular structure and low total harmonic distortion (THD). Multilevel converters are of three types:

A. Diode clamped multilevel converter
B. Flying capacitor multilevel converter
C. Cascaded H-Bridge multilevel converter

Components required per leg of multilevel converter topologies are shown in TABLE I. Letter 'm' in the TABLE I indicate the no of levels in the output voltage waveform.

TABLE I
Components required for multilevel converters

Converter type	Diode-clamped	Flying capacitor	Cascaded H-bridge
Main switches	(m-1)2	(m-1)2	(m-1)2
Clamping diodes	(m-2)(m-1)	0	0
Main diodes	(m-1)2	(m-1)2	(m-1)2
Balancing capacitors	0	(m-2)(m-1) /2	0
DC bus capacitors	(m-1)	(m-1)	(m-1)/2

A. *Diode clamped multilevel converter*

Requirement of more no of diodes and DC link voltage balancing are the two major problems with this type of converters. Space vector pulse width modulation (SVPWM) [16] and virtual vector based modulation [15] are the two algorithms has been proposed for balancing DC link capacitor voltage. Output voltage of STATCOM is controlled by neutral point sub-controller and terminal voltage sub-controller. Two more different controllers are required to maintain DC capacitor voltage [16]. In diode clamped multilevel converter, for balancing of DC link voltage, an auxiliary capacitor based technique is adopted [19], [20].

The switching of capacitor is in order to balances the DC link voltage also boosts the output voltage [20], [21]. Cost and size of converter reduces as less number of diodes used in the converter [22]. These types of converters are mostly used in wind and solar energy applications. Multilevel converters are mostly designed for DC link voltage balancing and for reducing switching frequency [23]-[25]. Circuit diagram of five level diode clamped multilevel converter is shown in Fig. 2 [22]. Diodes are used as clamping device in this type of converters. For three phase converter three legs are connected to one common dc source.

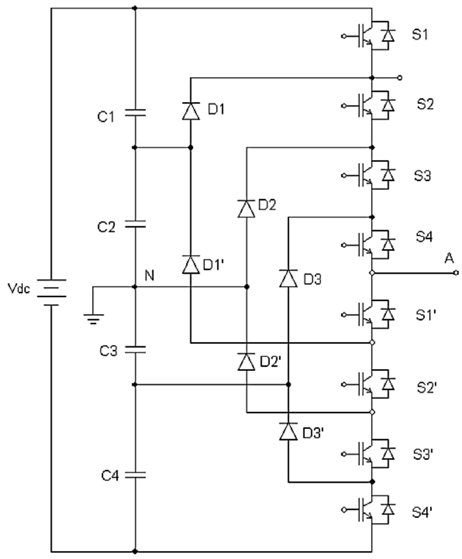

Fig. 2: Five-level diode clamped multilevel converter

B. *Flying Capacitor Multilevel Converter*

It is a well-known multilevel topology. It is quite similar to diode clamped multilevel inverter. This type of inverter requires capacitor to be pre-charged. Although basically this topology can be designed for infinite levels, but due to practical limitations it gives up to six level output voltage. Each cell consists of one capacitor and two switching devices. Mostly switches are transistors and anti-parallel connected diodes.

The control of converter and capacitor voltage balancing becomes more complicated with excessive number of storage capacitors [26], [27].

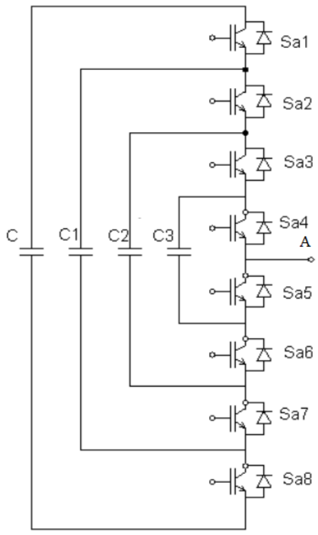

Fig. 3: Three-level flying capacitor multilevel converter

Series connected half bridge cells are used in place of clamping capacitors to improve the performance of the conventional multilevel converters [27]. The harmonic component and switching frequency can be reduced by proper selection of switching states. A sinusoidal pulse width modulation control (SPWM) with adjustable switching time is used for selection of switching state and elimination of selective harmonics [28]-[30]. Two low frequency switches are added in the configuration to improve the output frequency spectrum.

A semi-bridge rectifier topology is proposed which reduces the voltage stress on semiconductors and reduces the conduction losses. It cancels out the first carrier group switching harmonics which reduces the size of inductor in input filter [31], [32]. Fig. 3 shows the flying capacitor multilevel inverter topology. Each leg consists of switching devices which are generally thyristors. Each cell has a single capacitor and switching device. Use of converter is limited to four-cell because size and number of capacitor [33]. The use of synchronous reference frame control technique is proposed to control active and reactive power and regulates the DC voltage [34], [35].

C. Cascaded H-bridge multilevel converter

The cascade H-bridge converters has become more popular due to medium voltage high-power applications. Multiple numbers of single phase cells are connected to form multilevel converter. These cells are cascaded to achieve medium voltage operation and low switching distortion. For each cell different DC supply is needed i.e. each cell acts as the building block for cascaded H-bridge multilevel converter [36], [37]. A control scheme is implemented for 11 level converter which makes DC capacitor voltage equally charged and discharged [38]. If the traditional DC sources of equal voltage are replaced by sources with magnitude 1:2:4:8 then traditional 9-level converter can be switched to 31level converter [39].

A 31-level, six stage converter with 2 kV per step voltage compensator for railway power is designed and tested [40]. Coupling transformer is eliminated by generating high and medium voltage using converter [41]. Two structures of 81 level of 11 KV and 27 level of 33 KV are proposed in [42]. First one with all cells equal in size and another with selection of size of cell according to DC-link voltage. Considering losses, 27 levels 33 KV converter are far better than 81 levels 11 KV converter [42]. Dynamic performance of STATCOM installed for wind turbine is analyzed in [43]. Multiple loop controllers are used to control the DC link voltage of two cells. For maximum utilization of DC link voltage this control technique is used. This output of DC/AC converter has better quality with improved power factor [44].

To eliminate the voltage ripple a new technique of adding two controllable diodes in each cell is proposed [45]. The cascade H-bridge converter provides modular structure, lower switching losses. Fig. 4 shows Cascaded H-Bridge Multilevel converter. Cascaded h-bridge inverter requires (m-1)2 switching devices which are generally IGBT or MOSFET.

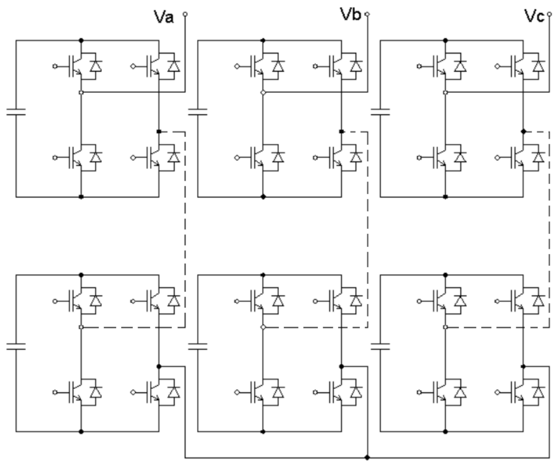

Fig. 4: Cascaded H-bridge multilevel converter

Comparison of different multilevel inverter shows that cascaded H-bridge inverter is most suitable for STATCOM application. Output voltage of cascaded H-bridge inverter is modified sine wave with minimum total harmonic distortion. No of switching devices required for cascaded H-bridge inverter are less as compared to flying capacitor and diode clamped converter. Diode clamped and flying capacitor inverter requires balancing capacitor and clamping diode.

III. CONTROLLER FOR MULTILEVEL INVERTER

Researchers are continuously working on control techniques to increase efficiency and performance of the system. Self-tuning proportional integral (PI), Fuzzy logic and root counting theory with Particle swarm algorithm are proposed by researchers instead of conventional PI controller, which improvers the performance of the controller.

Fuzzy logic controller based on error (e) and change in error (Δe) is proposed for STATCOM controller. The fuzzy logic controller is compared with conventional PI controller and it has been found that response of fuzzy logic controller is better than PI controller. Cascaded H-bridge multilevel converter topology for photovoltaic (PV) application gives better results as compared with the two-level converters [46]. Cascaded H-bridge multilevel converter with the use of fuzzy logic controller is proposed in [47], [48]. Fuzzy logic controller and H-bridge power sharing algorithm eliminates the use of pulse width modulation generator and PI controller. At low-medium power level, Fuzzy logic controller offers improved performance than conventional converters.

Advantages of using fuzzy logic controller over conventional PI controller are:

i. It can work with imprecise input.
ii. No need of accurate mathematical model.
iii. It can handle nonlinearities and robust in nature.
iv. Fuzzy logic controller is very sensitive to the input voltage change.
v. Fuzzy logic controller gives better stability for noisy signals.

The control strategies for STATCOM include DC link voltage control and inner current loop control. For smoothening DC link voltage Fuzzy-PI controller is used [49]. A comparative study is done in [50], between traditional PI controller and smooth sliding mode control (SMC) for voltage source converter. Both systems regulate the grid voltage by controlling reactive power at the PCC. An adaptive PI control scheme is used to self-adjust the control gain during abnormal conditions to match the desired performance [51]-[53].

Comparative study of double loop control, decoupled Fuzzy-PI based direct output voltage and Fuzzy-PI based direct output voltage shows that, maximum peak and settling time of decoupled Fuzzy-PI direct output voltage is decreased than double loop control. Also it can improve the dynamic performance of the system.

IV. CONCLUSION

After reviewing different publications on STATCOM and its control strategies, we can conclude that various FACTS controllers are available for improving the performance of the large interconnected power system. Various research and development activities are in progress in order to obtain high performance and good accuracy of FACTS devices. The trend is to use more and more advanced FACTS controller in different application. Various FACTS controllers, multilevel controller topologies and control strategies for STATCOM are brief summarized in this paper. Cascade H-bridge multilevel topology with Fuzzy-PI controller is best among all other controller topologies. Total harmonic distortion (THD) can be minimized by using cascaded H-bridge multilevel converter. It also improves the overall performance of the STATCOM.

For the further improvement in FACTS devices artificial intelligence based controllers can be used. Combination of fuzzy control system and proportional integral derivative controller can be used for controlling of the voltage source converter of STATCOM. Using multilevel converter with more number of steps harmonics in the output of multilevel converter can be minimized within limits. This reduces the size and cost of harmonics eliminating filter.

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