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REVIEW ON FUZZY LOGIC BASED POWER QUALITY IMPROVEMENT BY USING DSTATCOM BASED CASCADED MULTILEVEL INVERTER

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A B S T R A C T

ABSTRACT

Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy. All electrical devices are prone to failure when exposed to one or more power quality problems. It is necessary for engineers, technicians, and system operators to become familiar with power quality. In this paper the solution is given by Static Compensator (STATCOM) with the desired reference current for Multilevel inverter based STATCOM for distribution system is employed. An investigation of multilevel inverter-based Distribution static compensator (D-STATCOM) with FLC in Power distribution System (PDS) for compensation of reactive power and harmonics mitigation. Cascaded H-bridge inverters having several advantages over conventional swathing devices are low harmonic distortion, reduced number of switches there by suppression of switching losses. The advantage of CHB Inverter is reducing the number of switches and thus switching losses. Hence in our paper we have proposed a DSTATCOM based Cascaded multilevel inverter by sing fuzzy logic controller to mitigate the switching losses, harmonics, and to compensate reactive power.

1. INTRODUCTION

Reliability analysis of power systems has been attracting increasing attention. Regulatory agencies establish reliability standards that, if infringed, result in costly fines for the utility suppliers (Babel & Hosseini, 2019). Power Quality (PQ) related issues are of most concern now days. The widespread use of electronic equipment, such as information technology equipment, power electronics such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting etc. led to a complete change of electric loads nature. These loads are simultaneously the major causers and the major victims of power quality problems (Benhabib & Saadate, 2005). Due to their non-linearity, all these loads cause disturbances in the voltage waveform. The FACTS devices offer a fast and reliable control over the transmission parameters, i.e. Voltage, line impedance, and phase angle between the sending end voltage and receiving end voltage. On the other hand, the custom power is for low voltage distribution, and improving the poor quality and

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reliability of supply affecting sensitive loads. Custom power devices are very similar to the FACTS. Most widely known custom power devices are DSTATCOM, UPQC, DVR among them DSTATCOM is very well known and can provide cost effective solution for the harmonic mitigation, compensation of reactive power and unbalance loading in distribution system. (Benysek & Pasko, 2021)

Modern power system is a complex dynamic networks, where large number of generating stations and loads are interconnected through long power transmission and distribution networks. Even though the power Generation is fairly reliable; the quality of power is not always so reliable the base reason for this is contingencies which are undesirable. Power distribution system should provide with a reliable flow of energy at smooth sinusoidal voltage at the contracted magnitude level and Frequency to have reliable power to all customers. In whole of PS network especially distribution system has large number of nonlinear loads, which significantly affect the quality of power. Apart from nonlinear loads, events like capacitor switching, motor starting and unusual faults could also inflict power quality (P-Q) problems. P-Q problem is defined as any manifested problem in voltage Incurrent or leading to frequency deviations that result in failure or maloperation of costumer equipment's. Voltage sags and swells are among the many P-Q problems the industrial processes have to face.

Fuzzy controllers are uses for controlling consumer products, such as washing machines, video cameras, and rice cookers, as well as industrial processes, such as cement kilns, underground trains, and robots. Fuzzy control is a control method based on fuzzy logic. Just as fuzzy logic can be described simply as computing with words rather than numbers„„; fuzzy control can be described simply as control with sentences rather than equations. A fuzzy controller can include empiric al rules, and that is especially useful in operator-controlled plants (Babel & Hosseini, 2019).

DSTATCOM is defined as the STATCOM when it is connected to the distribution system. It has the same configuration but small modification is there. It can exchange both active and reactive power with the distribution system by varying the amplitude and phase angle of the converter voltage with respect to the line terminal voltage (Jing & Cheng, 2013).

2. LITERATURE REVIEW

2.1 Distribution network issues

With the use of modern high-tech microprocessor-based technology in industrial systems for various applications, electrical distribution and power generation through renewable energy systems, the power quality is being polluted. To produce the quality of products, the power supply should be of high quality. With the use of modern high-tech microprocessor-based technology in industrial systems for various applications, electrical distribution and power generation through renewable energy systems, the power quality is being polluted. To produce the quality of products, the power supply should be of high quality. Quality is a perception (Gosh & Ledwich, 2002), and if consumers are happy with the things/service delivered to them, then one can say that things/service is of good quality. In respect of electric power, the consumers had less awareness and information 30 years ago. Now, as more and more people are using electrical gadgets, for various reasons, Power Quality is a major expectation from all section of people. Most of the consumers are worried about scheduled/unscheduled load shedding, low voltage, Flickering (Brownouts), High voltage and Transients. The interest in Power Quality (PQ) is related to all three parties concerned with the power i.e. utility companies, equipment manufacturers and electric power consumers, and involves huge loss to the utilities and consumers (Gosh & Ledwich, 2002).

2.2 Multilevel inverter with multiple pwm techniques

The multilevel converter has drawn tremendous interest in the power industry. The general structure of the multilevel converter is to synthesize a sinusoidal voltage from several levels of voltages, multilevel voltage source converters are emerging as a new breed of power converter options for high power applications. The cascaded H-bridge multilevel Inverter uses separate dc sources (SDCSs). The multilevel inverter using cascaded-inverter with SDCSs synthesizes a desired voltage from several independent sources of dc voltages, which may be obtained from batteries, fuel cells, or solar cells (Allmeling, 2004). The advent of the transformer less multilevel inverter topology has brought forth various pulse width modulation (PWM) schemes as a means to control the switching of the active devices in each of the multiple voltage levels in the inverter (Jing & Cheng, 2013).

When utilized at low amplitude modulation indices, existing multilevel carrier-based PWM strategies have no special provisions for this operating region, and several levels of the inverter go unused. This paper proposes some novel multilevel PWM strategies to take advantage of the multiple levels in both a diode-clamped inverter and a cascaded H-bridges inverter by utilizing all of the levels in the inverter even at low modulation indices. Simulation results show what effects the different strategies have on the active device utilization. A prototype 6-level diode-clamped inverter and an 11-level cascaded H-bridges inverter have been built and controlled with the novel PWM strategies proposed in this paper (Tzung-Lin et al., 2013).

2.3 Harmonic mitigation techniques

Reduces harmonic content in the network which further reduces disturbances in telecommunication network, misbehavior in control equipment's and relay protections, measuring errors in metering system it Reduces network losses, reduces equipment overloading & stress on insulation, reduces cost and generates higher revenue for the customer, Reduces unplanned outages and increases power availability. In Modern distribution systems have very complex networks connected with linear and nonlinear loads. Nonlinear loads are primary thing for harmonic distortion in a power system these harmonic distortions will be eliminated by using MLI and SRF Technology. The internal view of Synchronous Reference Frame Theory (SRF) control strategy for STATCOM is used In this control strategy the SRF-based STATCOM control technique is used to generate gate pulses for controlling of STATCOM. Here from the control strategy is designed with abc frame to d-q frame conversion block, PLL block, HPF, PI controller, DQ to ABC conversion block and hysteresis controller (Rao et al., 2000; Ren et al., 2009; Sensarma et al., 2001; Iyer et al., 2005).

2.4 Reactive power compensation techniques

Shunt compensation of reactive power can be employed either at load level, substation level or at transmission level. Compensation should be provided as close as possible to the consumption point to avoid having to distribute this power in the other part of network. The DSTATCOM is also coming by the STATCOM scheme; it may operate under the distribution system. Here presents the operating principle of the intended DSTATCOM which is basically one of the shunt FCATS devices. The same kind of the STATCOM is the so-called operated in distribution networks is called as distributed compensator. The key components of the DSTATCOM are a power VSI module, which is based on the high-power semi-conductor device (Gupta & Mahanty, 2015; Zhou et al., 2004).

3. RESEARCH METHODOLOGY

3.1 Basic structure

The CHBMLI (Figure 1) topology utilized for DSTATCOM offers both modularity and flexibility, corresponding to a change in the voltage level and switching frequency. The basic circuit of the three-phase CHBMLI is shown in Figure 2, considering generalized m- levels. The circuit consists of (m − 1)/2 cascaded cells in each phase. Each CHBMLI cell requires an isolated DC source/capacitor for the generation of a synthesized output ac voltage. The generalized system equations, as in Equations (1)–(4), are for the DC voltage and output ac voltage of CHBMLI.

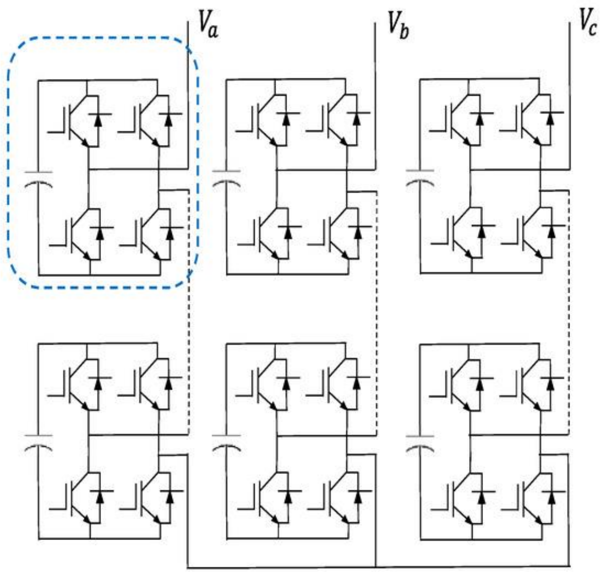

Figure 1. Three-phase cascaded H-bridge multilevel inverter (CHBMLI) structure.

For the DSTATCOM application, the CHBMLI bandwidth must be decided upon, based on the highest level of harmonics which need to be compensated. In the case of CHBMLI, the increased level of inverters has a linear relation with the number of H-bridge cells and dc sources/capacitors required for the implementation of the system. However, the improvement in the output voltage performance does not follow the linear relation and there will not be a considerable improvement in the performance corresponding to increased levels.

3.2 Implemented system

A five-level CHBMLI-based DSTATCOM is analyzed and investigated, and connected to the grid via an LCL filter. The CHBMLI (acting as the VSC) for the DSTATCOM application offers control capabilities similar to those of the traditional three-leg inverter. The only difference between these inverters is that more gate signals are required by the earlier invertor, but one of the advantages of the proposed system is that a reduced total harmonics distortion (THD) can be achieved in the converter voltage. The application of an appropriate control scheme with an optimum inverter level produces a voltage source inverter that can generate an alternating voltage in phase with the source voltage.

Each phase of this voltage is fed to the distribution line through a coupling inductance, to form a shunt-connected DSTATCOM, as shown in Figure 1, where Vsa, Vsb, and Vsc are the source phase voltages that are connected to a nonlinear load or reactive load. Ls is the per phase line inductance, and ILa, ILb, and ILc represent the per phase load currents. As shown in Figure 2, the CHBMLI is connected in shunt configuration to the load, and thus, at the point of common coupling (PCC), Kirchhoff's law can very easily be applied.

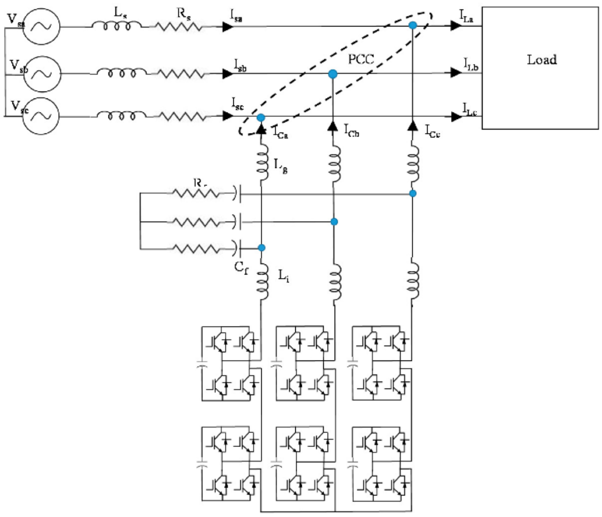

Figure 2. Shunt-connected distribution static compensator (DSTATCOM) system

The focus of this paper is on the analysis and effects of different parameters on the design of a DSTATCOM for reactive power and harmonics compensation. As shown in Figure 2, the system configuration used is the CHBMLI-based DSTATCOM . Linear, nonlinear, and unbalanced loads are connected to the system, and draw lagging or leading, distorted and unbalanced load currents from the source, respectively. The shunt-connected device allows for the compensation of the reactive power and harmonics to be performed, and the avoidable component of the current is supplied by the DSTATCOM (Figure 3).

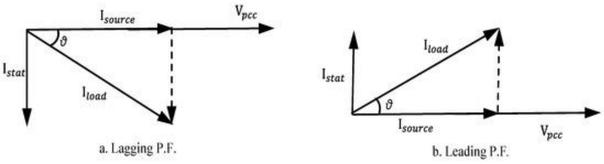

Figure 3. Phasor diagrams of DSTATCOM with (a) leading and (b) lagging power factor (PF) loads

3.3 Reduced switch modified MLI (RSM MLI)

Topologies without an H-bridge are considered in this section. Basically H-bridge topologies are more suitable for the low and medium voltage application. More voltage stress on the H-bridge switches of these topologies narrows down the applicability in high voltage application. In turn efficiency may reduce when used in high voltage applications.

These issues have lead to devise some new topologies which have inherent feature of polarity generation. Some recently developed topologies of this category are discussed in this section. A schematic of this topology has been illustrated in Figure 4(a). The main aim of the topology is to produce a large number of levels in the output by reducing the total component count. Total component count in this MLI is less than the conventional MLI topologies, but due to the use of bi-directional switches, the voltage stress and switching loss is more than few recently developed topologies discussed earlier in this work. Total voltage stresses across the switches, diodes, and the isolated dc sources of this topology are same as a CHB MLI topology. Furthermore, this topology possesses a limited number of redundant switching states as compared to the conventional topologies; hence the cells under fault condition can't be bypassed. It can be said that, modularity and the fault tolerant capacity of this topology is less than the CHB MLI topology.

Figure 4(b) depicts the circuit diagram of this topology. Author has validated the topology in both symmetric and asymmetric mode and found that the asymmetric mode produces a high-resolution output voltage waveform for the same number of basic block. The proposed topology requires a smaller number of switches as compared to the conventional MLIs, but not compared other recently proposed RS MLIs. Also, it requires large number of extra diodes to form a basic block which can be considered as a limitation of the topology. However, this topology is suitable in medium and high voltage applications. A new cascaded MLI topology was proposed in the literature. Figure 4(c) shows the generalized circuit topology of this MLI. The power circuit of this cascaded MLI consists of two dc sources, two different bridges and one auxiliary bi-directional current steering circuit. One among the two dc sources is split in two equal half by the auxiliary circuit, so in overall three dc sources are used in each power circuit. A carrier-based PWM strategy has been adopted for controlling the MLI and the superiority of this MLI has been validated through comparison with well-known MLI topologies disclosed in the literature.
The topology requires only one voltage source as shown in Figure 4(d). A number of capacitors are connected for the multiple level generations in the output. Availability of redundant switching states avoids the capacitor voltage balancing problem and improves the fault tolerant capability. An interesting control method based on phase-disposition PWM (PD-PWM) method has been analyzed for controlling the operation of MLI through capacitor voltage balancing.

Figure 4(e) depicts the generalized structure of the topology. Author had applied SHE-PWM technique to control the MLI by calculating optimum switching angles which results in low THD. Lower voltage stress on the switch and lower THD makes this topology suitable for high voltage and high-power applications. Figure4(f) shows the generalized structure of this topology. Four dc sources and twelve switches constitute a module and each module generates a seventeen-level output voltage. To achieve more levels the cascaded connection of modules can be made.

To generate higher levels, more semi half-bridge cells can be connected in series fashion. The generalized structure is formed by connecting the string of series connected semi half-bridge cells in crisscross manner through the switches as shown in Figure 4(g). This proposed topology is represented in Figure 4(h). The generalized structure consists of series connected cells, six main switches and one dc source with a proper arrangement. The combination of one dc source and two switches forms a sub-cell of this configuration.

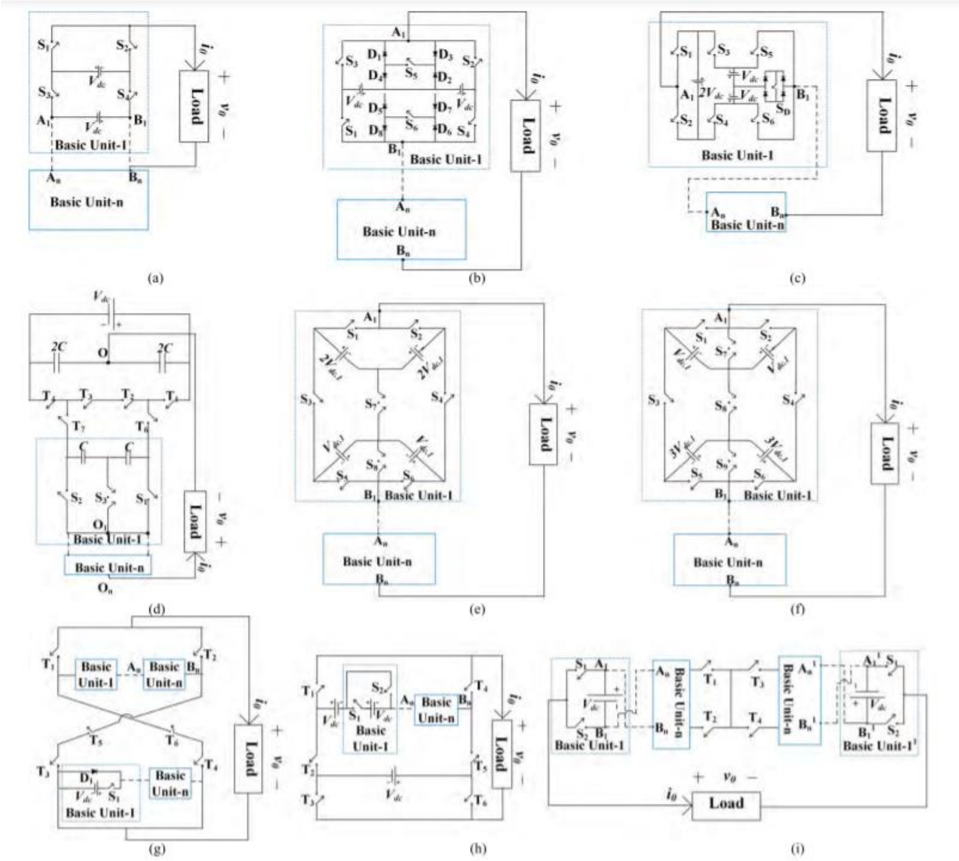

Figure 4. Generalized schematic of the RSM MLI topologies (a) RSM MLI 1. (b) RSM MLI 2. (c) RSM MLI 3. (d) RSM MLI 4. (e) RSM MLI 5. (f) RSM MLI 6. (g) RSM MLI 7. (h) RSM MLI 8. (i) RSM MLI 9

To reduce the voltage stress, inverter cost as well the installation area a novel cascaded MLI was analyzed which can operate in both symmetric and asymmetric mode requiring a smaller number of switches. Figure 4(i) unveils the proposed topology. Although the superiority of this topology is found over conventional CHB MLI in terms of reduced number of switches, but the standing voltage of the proposed topology is more as compared to CHB MLI restricting the application to low and medium voltage applications.

3.4 Fuzzy logic controller

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves membership functions, fuzzy logic operators, and if-then rules. Two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox are:

- Mamdani type
- Sugeno type.

Mamdani type inference expects the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It is possible, and in many cases much more efficient, to use a single spike as the output membership functions rather than a distributed fuzzy set. This type of output is sometimes known as a singleton output membership function, and it can be thought of as a pre-defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required by the more general mamdani method, which finds the centroid of a two-dimensional function. Rather than integrating across the two-dimensional function to find the centroid, we use the weighted average of a few data points.

Sugeno-type systems support this type of model. In general, Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant.

3.5 Basic Fuzzy Algorithm

In a fuzzy controller as shown in figure 5, the control action is determined from the evaluation of a simple linguist rules. The development of the rules requires a thorough understanding of the process to be controlled but it does not require a mathematical model of the system.

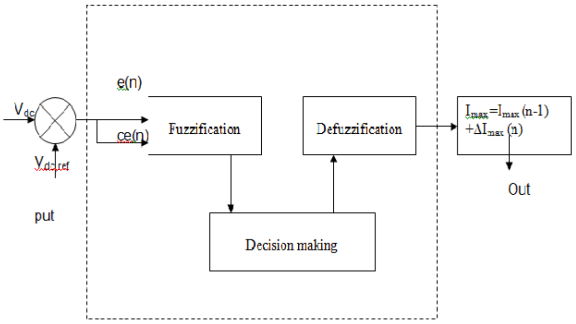

Figure 5. Schematic Diagram of FLC

A fuzzy controller consists of fourth stages: fuzzification, knowledge base, inference mechanisms, and defuzzification. The knowledge base is composed of a data base and rule base, and is designed to obtain good dynamic response under uncertainty in process parameters and external disturbance. The data base, consisting of input and output membership functions, provides information for the appropriate fuzzification operations, the inference mechanism, and defuzzification. The inference mechanism uses a collection of linguistic rules to convert the input conditions into a fuzzified output. Finally, defuzzification is used to convert the fuzzy outputs into control signals (Jing & Cheng, 2013). In order to implement the control algorithm of a SAPF in closed loop, the optimum value of K gain is calculated by a fuzzy inference system, which receives as inputs the slope of D.C. average bus voltage and D.C. voltage error. Both quantities (error and slope of DC voltage) are normalized by suitable values. Thus, each range is between -1 and 1 normalized unity. Taking into account that the value of K is quite near unity, we consider the range of the output weight membership function between 0.6 and 1.4.We have chosen to characterize this fuzzy controller by seven and five sets respectively for the error and slope inputs. The linguistic rules for the fuzzy logic controller are chosen, in most cases, depending only of the D.C. voltage error.

The desired switching signals, according to output inverter currents to follow the reference ones, a current control is made by fuzzy logic controller. The inputs variables for the necessary control action of active filter are the error and the rate change of error between the reference signal and the active filter output current. The current control method used in this thesis is related to fuzzy controller based PWM current controller. The switching signals are generated by means of comparing a carrier signal with the output of the fuzzy controller. The MATLAB/SIMULINK circuit of seven level cascaded multilevel inverter without distributed static synchronous compensator is shown in figure 6.

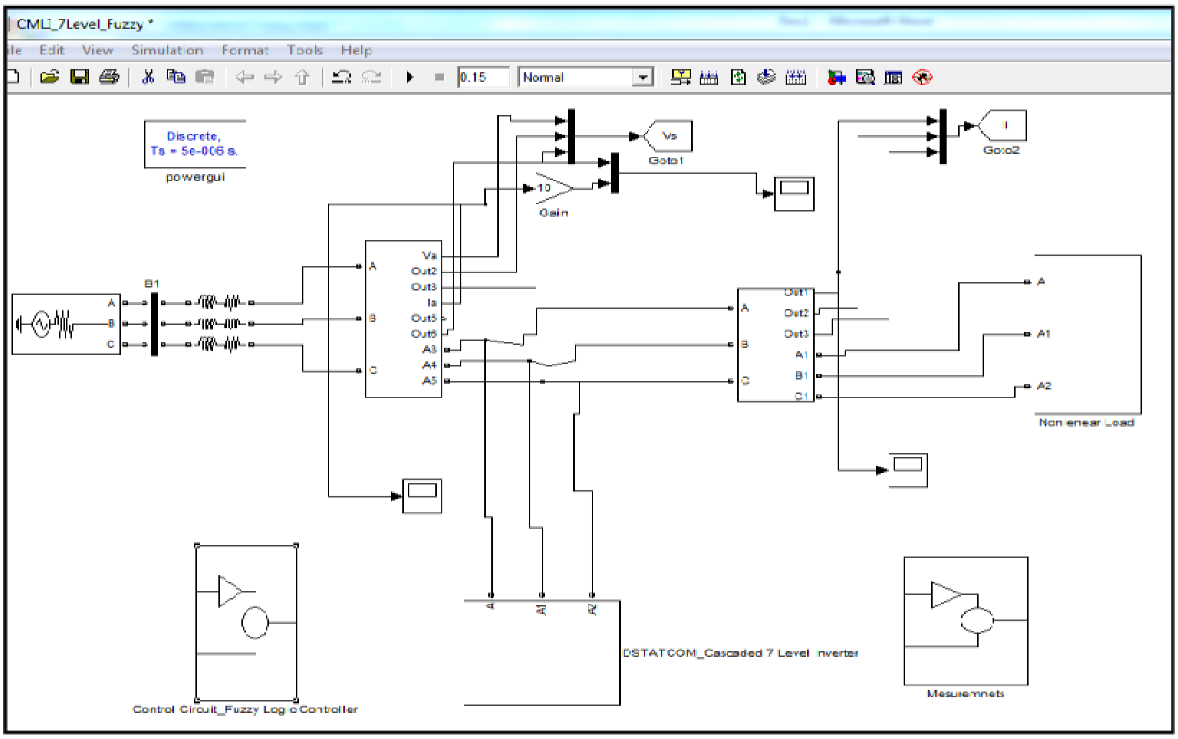

Figure 6. Circuit of CMLI and DSTATCOM Device Using Fuzzy Logic Controller

4. AIMS AND OBJECTIVES

Overall loss reduction and improvement in harmonic profile are the major objective of most of the control techniques.

The objective of the review is to cover most of the recently proposed MLI and the useful information has been effectively detailed through this review.

To provide low switching losses because the output voltage contains fewer switching ripples compared to the conventional two-level VSC.

5. LIMITATIONS OF THE STUDY

However, the reactive power production of wind turbines is limited, especially in the high-wind speed operation where large amounts of active power are delivered to the grid. In order to increase the reactive power capacity, a higher power rating of the GSCs of PMSG wind turbines has been suggested. Unfortunately, this increases the system cost. In addition, the power losses of the system are increased as well. Another scheme to improve the power quality of wind farms integrated with the grid using a STATCOM has been introduced. The STATCOM provides several advantages such as a fast response (1-2 cycles) and superior voltage support capability due to its nature as a voltage source. In addition, unlike shunt capacitor banks, the STATCOM is capable of generating reactive current for the grid under deep voltage sag conditions. However, the cost of the STATCOM is still high. By coordinating a large wind farm with a STATCOM for reactive power control, the power capacity of the STATCOM can be reduced. However, the reduction of the STATCOM capacity is not significant due to the limitations of the generator capacity for reactive power control during grid fault conditions. The coordinated control of a STATCOM and a DFIG-based wind farm for optimizing the power loss of the system has been presented. The limitation of this approach is that the coordinated algorithm only takes the power loss into account, without considering the voltage regulation.

6. CONCLUSION

MLI based topologies are evolved as a robust candidate for power industry for a number of key applications. With the rapid growth in power semiconductor technologies, many MLI topologies have been developed through research utilizing reduced number of components. New RS MLI topologies are still emerging for various advantages such as reduced cost, optimal size, lesser volume, reduced losses, and high efficiency. A number of RS MLI topologies are developed most recently for different application such as motor drives, renewable energy system integration, FACTs, power filtering, etc. Therefore, this review article has mainly focused on RS MLI topologies based on the three categories, i.e., symmetrical H-bridge based RS MLI, asymmetrical H-bridge based RS MLI, and modified RS MLI topologies. Each topology has been reviewed carefully based on the number of switch count, number of dc sources used, PIV, TSV, and applications. The performance of the CHBMLI-based DSTATCOM is evaluated for reactive power compensation, harmonic compensation, and load balancing under a linear load, Non-linear load, and unbalanced load condition. The power quality issues are investigated for a disturbance in the PCC voltage (voltage sag and swell) under an unbalanced load and load change condition. The source current THD under different load conditions (0.51% linear load, 0.79% unbalanced load, 4.59% nonlinear load) is achieved and is well within the IEEE-519 standards of 5%.

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