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Reduced switch cascaded asymmetrical 27 level inverter-STATCOM with fuzzy logic controller

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ABSTRACT

In this study, a 27-level inverter with a reduced switch asymmetrical cascaded H-bridge (CHB) with fuzzy logic controller (FLC) is proposed. With series connections, a low voltage converter, a middle level voltage converter, and a high voltage converter make up the static synchronous compensator (STATCOM). The configuration of the asymmetrical inverter uses trinary DC sources. To acquire switching signals for the trinary inverter-based STATCOM to compensate for real power, load voltage, reactive power, load current, and power factor under load changing conditions, FLC is constructed. With fewer switches, the suggested arrangement produces greater voltage levels. The performance of the reduced switch asymmetrical cascaded H-bridge inverter-STATCOM with FLC is simulated using the MATLAB Simulink platform under both static and dynamic load conditions. When compared to reduced switch asymmetrical cascaded H-bridge inverter-STATCOM with traditional proportional integral (PI) controller, the FLC result demonstrates efficient unbalanced load compensation. The FLC in the proposed inverter also lowers the total harmonic distortion.

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1. INTRODUCTION

The most popular devices used in power systems to improve the quality of the power are called flexible AC transmission system (FACTS) devices. The FACTS device with the highest usage during the past ten years is static synchronous compensator (STATCOM). It is possible to use a multilayer inverter in STATCOM, which improves efficiency and reduces harmonics in the inverter's output voltage the fuzzy logic controller (FLC) is employed to create a single-cascaded H-bridge seven-level inverter in [1]. The root mean square voltage value is attained in a closed loop with fewer harmonics. Haw *et al.* [2], stated that the STATCOM is built with five-level inverters. The inherent phase-locked loop (PLL) delay and voltage instability are reduced, and a reactive current reference algorithm is proposed. To create a five-level inverter, however, more switches are needed. The traditional voltage source inverter with two levels now features a three-phase modular setup. The sinusoidal pulse width modulation (PWM) approach can be used with the new inverter in [3]. The PWM generation is complex enough to produce the necessary gate signals under non-linear loads. A proposed vector autoregression (VAR) [4] compensating system at asymmetrical levels and reactive power compensation are used to regulate the DC link voltage at cascaded inverter-based STATCOM. Voltage and current, however, are not compensated for non-linear loads. In order to provide various modulation indices with direct current voltage level variants, a unique transformer-less STATCOM with a multi-level selective harmonic elimination pulse width modulation (MSHE-PWM) module is proposed in [5]. The proposed paradigm, however, is only appropriate for high-power applications. Low frequency switching and a unique modulation technique for the CHB inverter are used in [6]. The amount of voltage can be increased for DC links by using asymmetric voltage. High frequency switching is incompatible with the inverter.

The construction of radial micro grid systems with a single alternator using fuzzy logic controller-based STATCOM [7]. As a result, when compared to the proportional integral (PI) controller, the voltage profile with static and dynamic loads is improved; however, the load current changes with dynamic loads. The phase 21 protection function of a generator is achieved with improved performance using an FLC-related approach to show the effect of STATCOM [8]. In a grid-connected PV system, a cascaded two-level inverter with a single-stage multifunction multilevel inverters (MLI) is used; the two-level inverter system in [9] provides active and reactive power control. Different multilevel inverter topologies were compared in terms of capacitor, diode, inductor, and transformer counts with performance in [10]. The source type energy unbalanced harmonic is spotted on a multilevel active power filter inverter [11]. To suppress this, the carrier frequency optimization method is used. However, the harmonics in the load voltage and current in the non-linear loads were not compensated for the proposed technique.

In the multilevel inverter-based PV stand-alone system in [12], a vector control is suggested. The maximum power point of the solar panel is not monitored by the system in place, but this control regulates the DC link voltages and reference voltage to the maximum power utilisation of the solar panel. Different topologies for multilevel inverters are introduced in [13] and categorized into 5 sub modules and investigated with regard to the number of components, inherent negative voltage, regeneration mode of operation, and usage of a single DC source. Cascaded multilevel inverter based STATCOM with delta connection is discussed in [14] to compensate for unbalanced load conditions in real time. A three-phase, 5 level cascaded MLI with STATCOM [15] is employed without a transformer to meet the isolated H-bridge reactive power and voltage balance with a control programme of phase shift carrier (PSC). However, the number of switch reduction techniques with the proposed model is not discussed. The symmetric fly capacitor (SFC) multilevel inverter topology is discussed in [16] for applications of STATCOM. By keeping the capacitor voltage of the module balanced, the cost of switching and the losses have been minimized. Two modulation control techniques are used in a modular multilevel inverter [17]. This results in lower component numbers such as switching devices, capacitors, power diodes, smaller inverter footprints, and increased overall reliability. However, the total harmonic distortion (THD) and overall performance of the load parameters were not discussed. Fuzzy logic controller-based STATCOM is used to design radial micro grid systems with a single alternator [18]. This methodology makes the gate pulse for cascaded H-bridge multilevel inverter (CHB-MLI) without a look-up table and provides a gate pulse without a mediator. However, the fuzzy logic controller was not implemented in the PWM of the STATCOM.

A three-phase asymmetrical MLI is implemented with fewer swtiches [19]. The proposed inverter has an output voltage with enhanced power quality, reduced power loss, and reduced cost. However, STATCOM is not implemented in the proposed MLI. The distribution network is connected to a dynamic voltage restorer (DVR) in [20]. This results in enhanced voltage quality. The distributed network’s reactive power is managed using the DVR’s rational energy transformative optimisation algorithm. A modified wide-input switched quasi Z-source three-port (SqZSTP) DC-DC converter is recommended to connect a solar inverter in [21] with a distributed power producing system. The suggested SqZSTP DC-DC converter is constructed with a quasi Z-source impedance network and a three-winding high-frequency transformer, and it offers high voltage gain over a wide input voltage range.The output fluctuation is prevented by using a fuzzy logic controller. The grid connected five-level voltage source converter (VSC) is implemented with a double synchronous reference frame-PLL (DDSRF-PLL) based current controller in [22]. The proposed configuration results in reduced switching compared to five-level diode-clamped VSC and SFC-based VSC. Moreover, by increasing switching frequency, current THD was improved. The inverteris designed for an output voltage of 125 level, and it was verified with the DVR application. Moreover, the inverter is designed with FLC, which results in fewer switches and DC supplies. The suggested control approach improves the power quality and voltage profile of the self-excited induction generator in [23]. In this study, a control method for the self-excited induction generator (SEIG), which generates electricity for a remote area using a wind turbine, is developed. This control method enhances voltage synchronisation and power quality. To balance a reactive power challenges of SEIG under load disturbances, a modified second-order generalised integrator (SOGI) with quasi-impedance (QZ) STATCOM is employed in [24]. It has been suggested that a quasi impedance source based STATCOM with FLC will improve the active power flow. An 11-level multi-level inverter uses a black window optimisation algorithm approach. With various modulation indices and DC voltages, the proposed model in [25] is evaluated. Furthermore, the multicarrier alternative disposition PWM technique was used to test the suggested inverter. With the basics all literature reviews, reduced switch asymmetrical cascaded H-bridge inverter-

STATCOM with FLC is implemented and the results are compared with the reduced switch asymmetrical cascaded H-bridge inverter- STATCOM with conventional PI controller.

2. REDUCED SWITCH ASYMMETRICAL CASCADED TWENTY SEVEN LEVEL INVERTER

The main reasons why multilevel inverters are so popular are because of these benefits. The multilevel inverter features higher power handling, less switching, lower overall harmonic distortion, and better voltage stability. Single DC source inverters and multiple isolated DC source inverters are the two categories under which multilevel inverters fall. Additionally, two sorts of a single DC source can be distinguished: flying capacitor and neutral point clamping. The term "multilevel inverters" with cascading H-bridges refers to inverters with several isolated DC sources. The cascaded multilevel inverter can have equal DC sources for symmetry or uneven DC sources for asymmetry.

Trinary DC voltages are used in the planned CHB inverter because they offer a greater variety of voltage levels. For a trinary DC source, there are 3n output levels, where "n" denotes the number of H-bridges. The proposed model of MLI is depicted in Figure 1. For n DC sources, the output voltage level is 3n. Vdc1 equals V, Vdc2 3 V, and Vdc3 9 V. The single-phase, 27-level, asymmetrical cascaded-27-level inverter is shown in Figure 1. Different H-bridges in the proposed inverter are governed by various DC voltage sources. The center bridge has a middle-level converter with 105 V, the lower bridge is built with a high-voltage level converter with 315 V, and the upper bridge is envisioned as a low-level converter with 35 V.

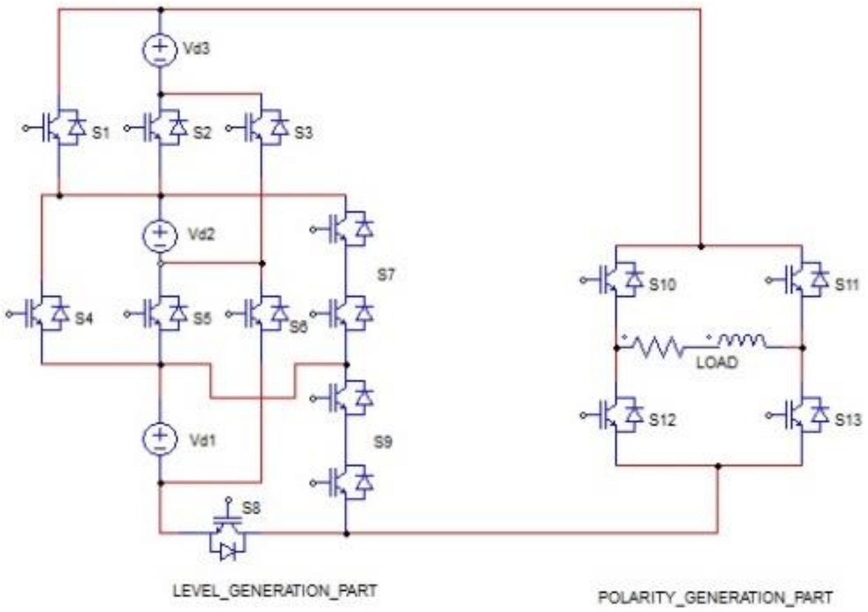


Figure 1. Proposed single-phase 27-level asymmetrical cascaded twenty seven level inverter

2.1. Modes of operation of 27-level inverter

There are two levels in the proposed model, one is level generation part (S1 to S9) and the other is polarity generation part (S10 to S13). The level generation part is implemented to generate the positive level of output voltage (S1 to S9). The polarity generation part is implemented to invert the output voltage (S10 to S13). When S10 and S11 are turned ON the output voltage is positive whereas when S12 and S13 is turned ON the output voltage is negative. The proposed model of MLI consists of trinary dc voltage for generating 27 levels of output voltage (13 level in positive half cycle, 13 level in negative half cycle and a zero level).

3. IMPLEMENTATION OF FUZZY LOGIC CONTROLLER

The FLC is implemented to obtain the switching angles for the STATCOM of 27 level MLI, with 3 voltage sources of 35 V, 105 V, and 315 V in the trinary asymmetric mode. Figure 2 displays the block diagram of the 27-level inverter-based STATCOM with a fuzzy logic controller. Isa, Isb, and Isc are three-phase source currents, Ila, Ilb, and Ilc are load currents, and Ica, Icb, and Icc are STATCOM currents at the point of common coupling. The FLC consists of four main blocks for the process, namely fuzzification, knowledge base, inference mechanism, and defuzzification. The FLC has two inputs; one is an error signal (e) and the other input is a change in error (Δe) signal of the output voltage. The control output (u) signal is compared with the triangular waveform to generate a pulse for the STATCOM.

The rules of fuzzy are based on certain rules such that the change of duty ratio is larger for the outputs that are far from their set point to make the output settle quickly. If the set point and output are close to the set point, then a small duty ratio is required. To avoid overshoots, the duty ratio is kept constant for the outputs very close to the specified set point. If the output is beyond the specified set point, the duty ratio is set to be negative and vice-versa. The error and change in error range [-25, 25] and [-25, 25], and the output ranges [0, 1]. Five linguistic variables are used to form 25 rules. Table 1 represents the fuzzy logic set rule base for generating the switching signals for the STATCOM.

A triangular membership function is employed for the FLC. Figure 3 presents the fuzzy logic plots for input and output membership function plots. The input and output have five fuzzy sets, namely: negative big (-BG), negative small (-SML), zero equal (ZEL), positive small (+SML), positive big (+BG). Fuzzification uses continuous universe discourse and Mamdani's mini operator, whereas defuzzification uses centroid methods. The control rules for the proposed system are formed by the trial and error method. For decision making rules, the min-max inference method is employed. Table 1 displays the fuzzy rule base.

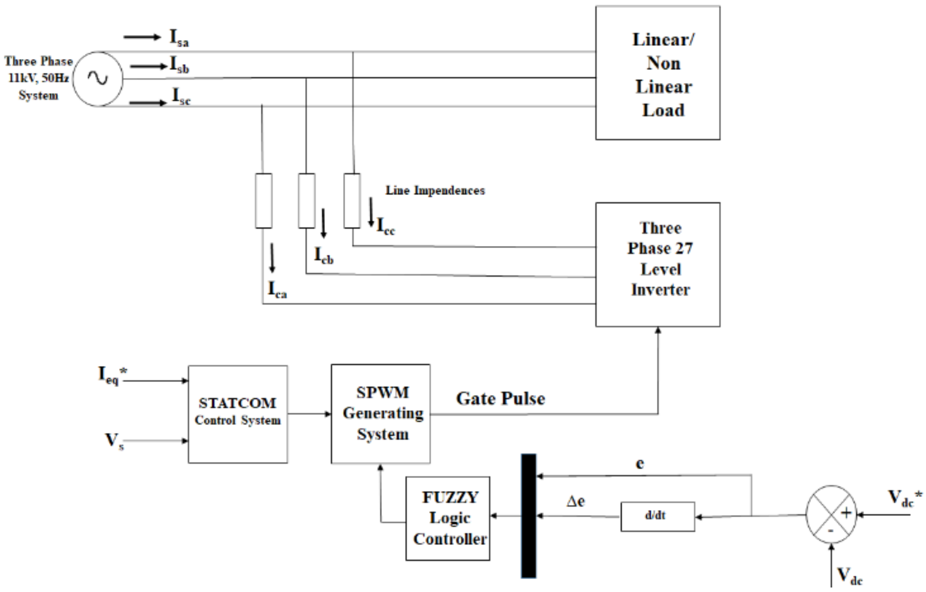


Figure 2. Block diagram of 27 level inverter based STATCOM with fuzzy logic controller

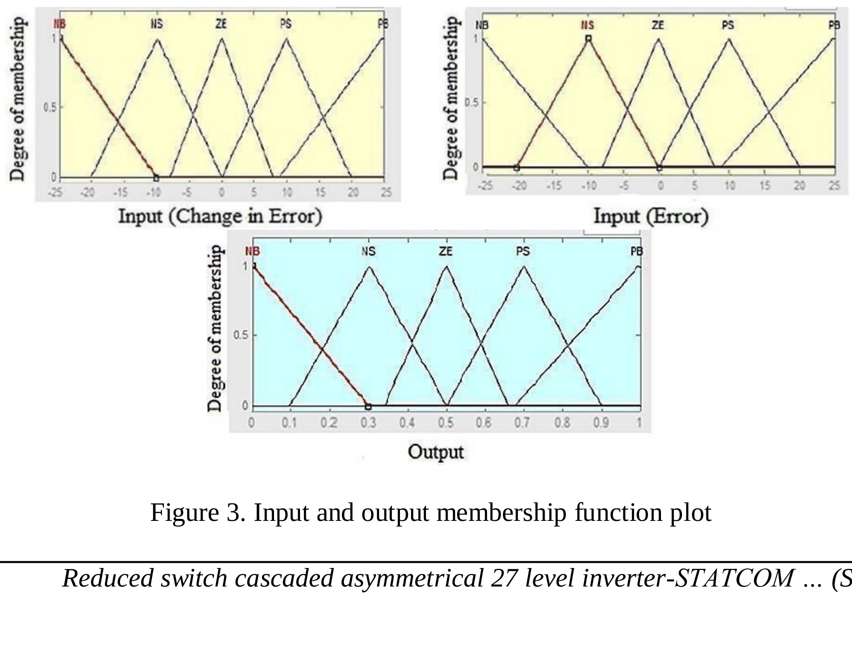


Figure 3. Input and output membership function plot

Table 1. Fuzzy rule base

e/Δe	–BG	-SML	ZEL	+SML	+BG
–BG	ZE	NS	–BG	–BG	–BG
-SML	–BG	ZE	-SML	–BG	–BG
ZEL	+BG	+SML	ZEL	-SML	–BG
+SML	+BG	+SML	+SML	ZEL	-SML
+BG	+BG	+BG	+BG	+SML	ZEL

4. RESULTS AND DISCUSSION

The asymmetrical cascaded multi level inverter (ACMLI) based STATCOM with FLC is developed on the MATLAB platform. Figure 4 shows the MATLAB simulation circuit diagram for the 27-level asymmetrical cascaded multilevel inverter-based STATCOM using a fuzzy logic controller. Table 2 Shows the system parameters of 27 level inverter with STATCOM.

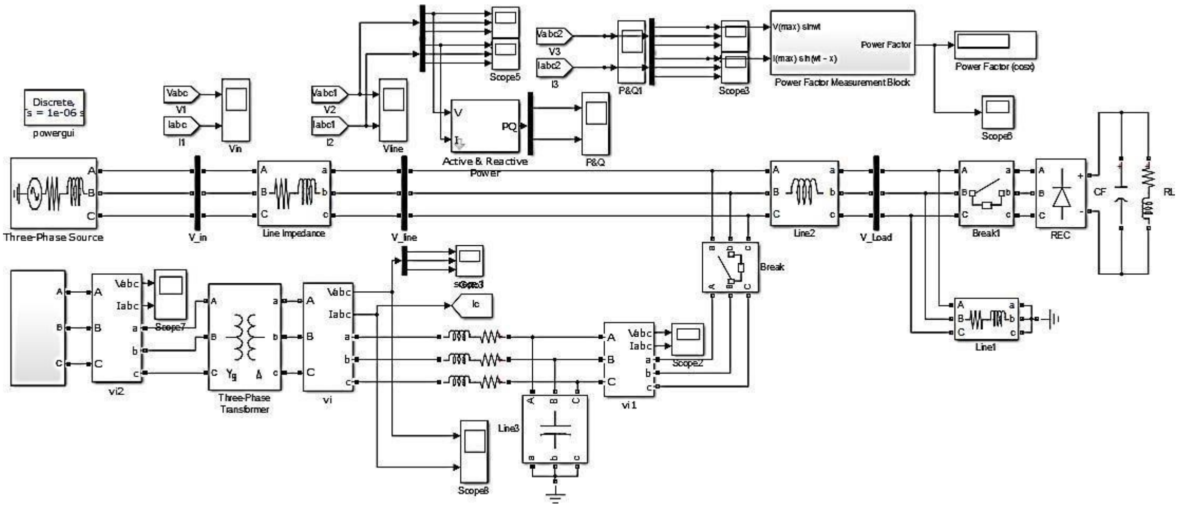


Figure 4. Simulation circuit of 27 level inverter based STATCOM control system with fuzzy logic controller

Table 2. System parameters of 27 level inverter with STATCOM

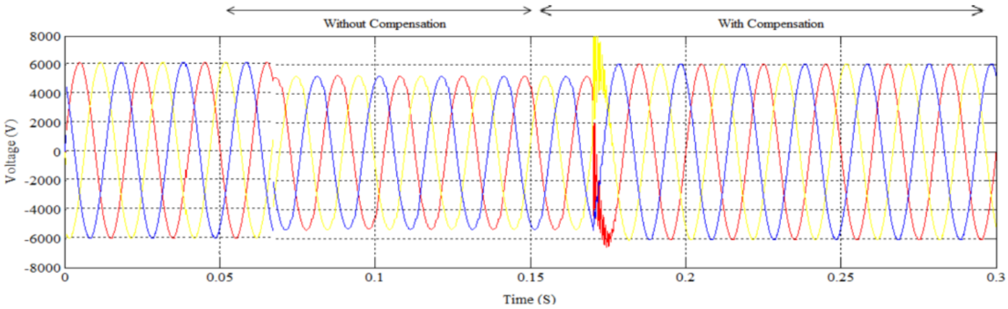
Proposed system parameters	Range
Proposed system voltage	11 kV
Proposed system frequency	50 Hz
STATCOM current	20 A
DC Voltages of 27 level inverter	35 V, 105 V, 315 V
Impedance (load)	500 Ω, 1 mH
Power rating of STATCOM	12 kVA
Carrier frequency	20 kHz

4.1. Comparison of results

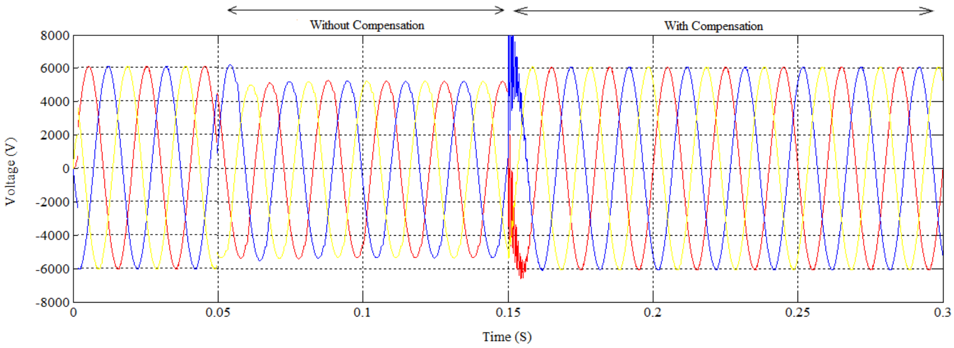
The system response is analyzed for 3 different intervals; i) linear load -0s to 0.05s, ii) non-linear load -0.05s to 0.3s, and iii) controller operation point -0.15s. Figure 5 shows the load voltage of 27 level inverter based STATCOM. Figure 5(a) shows the load voltage of 27 level inverter based STATCOM with PI controller and Figure 5(b) shows the load voltage of 27 level inverter based STATCOM with FLC. According to Figure 5(a) and 5(b), the load voltage in both controllers (PI and FLC) is 6 kV when a linear load is applied from 0 to 0.05s, and is lowered to 5 kV when a nonlinear load is applied at 0.05s. Both controllers have the compensator set to activate at 0.15s, but the PI controller's compensator replies to the disturbance at 0.17s, therefore the compensation is set to start at 0.17s due to the controller's slow reaction and settles the load voltage to 6 kV at 0.20s. It is obvious from Figure 5(b) that in FLC, the compensator is set to start immediately and the load voltage is set to 6 kV.

The load current of 27 level inverter based STATCOM is shown in Figure 6. The load current 27 level inverter based STATCOM with PI controller is displayed in Figure 6(a). The load current of 27 level inverter-based STATCOM with FLC is shown in Figure 6(b). Without compensation, the load current in both controllers is 300 A from 0 to 0.05s. The nonlinear load is applied to the system at time 0.05s, and it can be seen that the

PI controller responded to the disturbance at time 0.17s and balanced the reactive power by compensating the load with 320 A as shown in Figure 6(a). However, the FLC responded immediately to the disturbance at time 0.15s and did the same, as shown in Figure 6(b). To offset non-linear load reactive power, the STATCOM injects 20 A of current into both controllers.

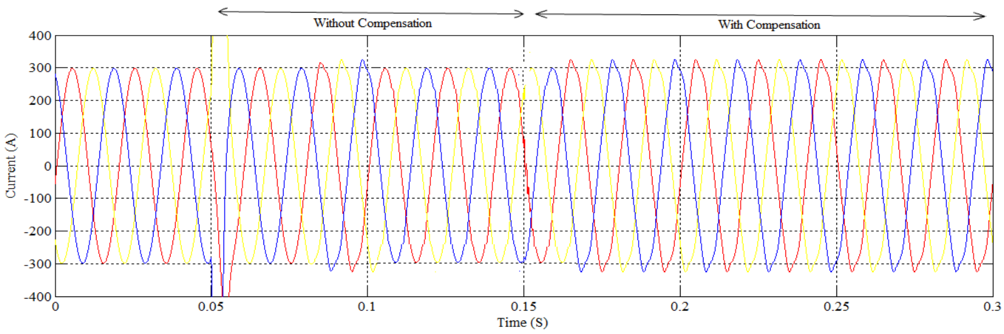


(a)

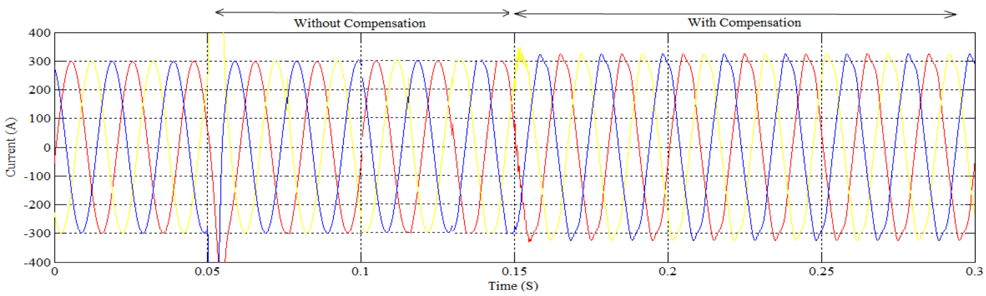


(b)

Figure 5. Load voltage of 27 level inverter based STATCOM (a) load voltage of 27 level inverters based STATCOM with PI controller and (b) load voltage of 27 level inverters based STATCOM with FLC



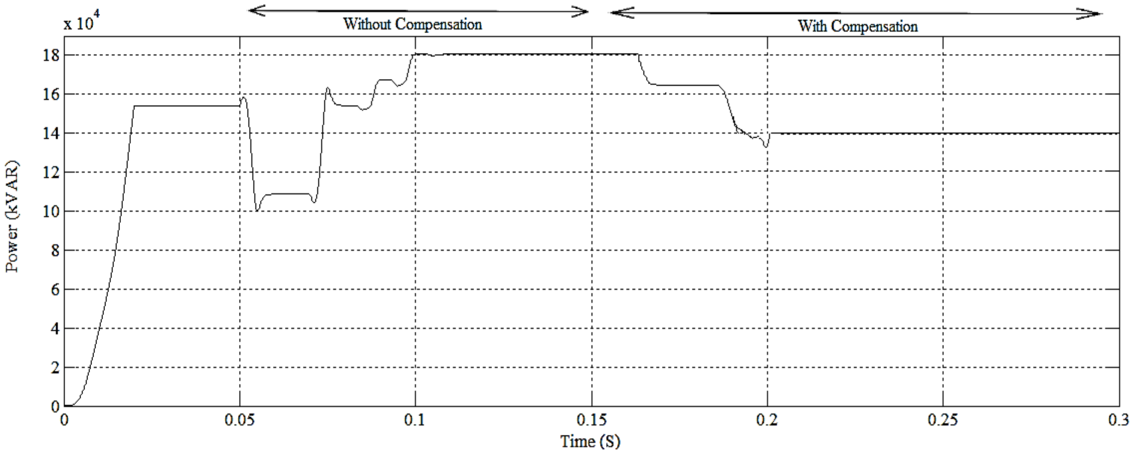
(a)



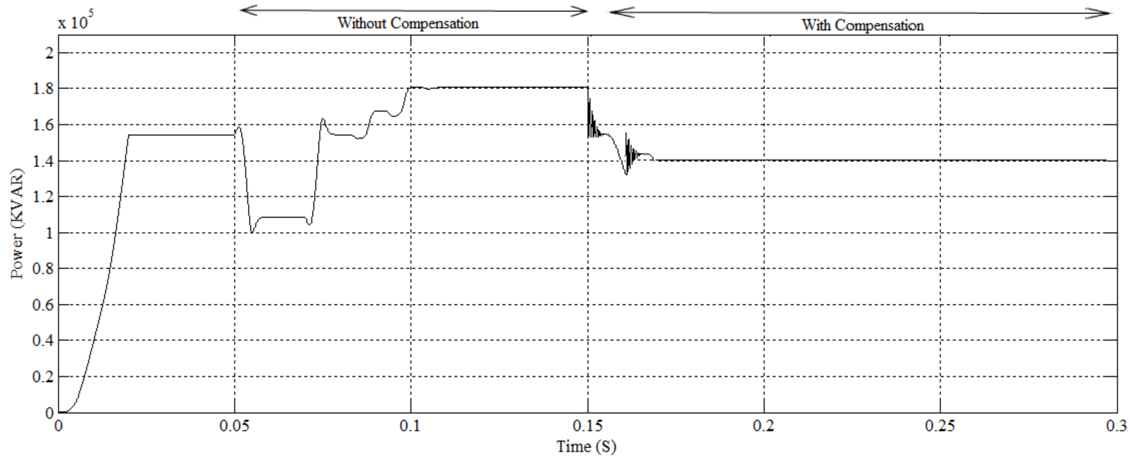
(b)

Figure 6. Load current of 27 level inverter based STATCOM (a) load current of 27 level inverters based STATCOM with PI controller and (b) load current of 27 level inverters based STATCOM with FLC

Reactive power of 27 level inverter based STATCOM is shown in the Figure 7. Reactive power of 27 level inverter-based STATCOM with PI controller is shown in Figure 7(a), while reactive power of 27 level inverter-based STATCOM with FLC is shown in Figure 7(b). It is clear that in both situations, the reactive power is 179.5 kVAR without compensation for the nonlinear load. The FLC responded quickly to the disturbance and settled the reactive power to 139.5 kVAR at 0.17s, while the PI controller responded to the disturbance at 0.17s and compensated the reactive power to 139.5 kVAR at 0.2s. In both controllers, the real power and power factor are kept constant under all loading conditions. Table 3 shows the comparison of PI controller and FLC.



(a)



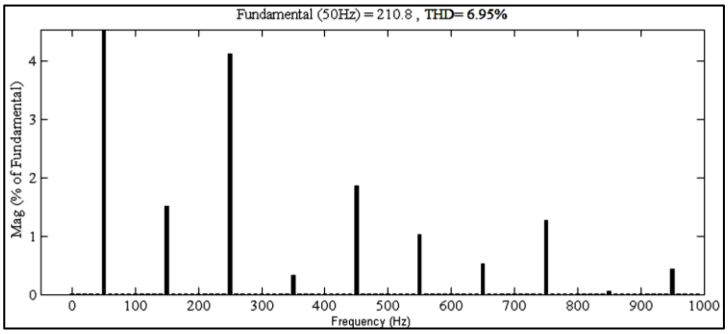
(b)

Figure 7. Reactive power of 27 level inverter based STATCOM (a) reactive power of 27 level inverter based STATCOM with PI controller and (b) reactive power of 27 level inverter based STATCOM with FLC

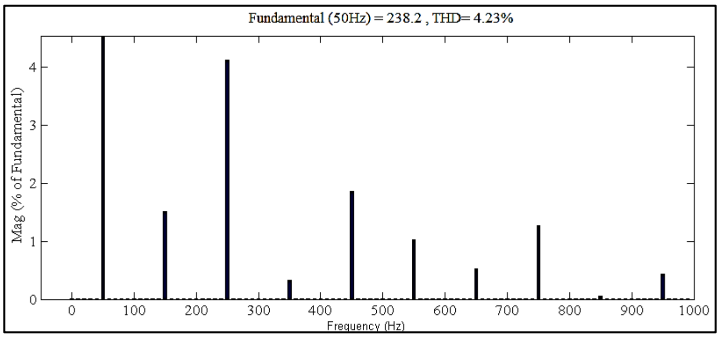
Table 3. Comparison of PI controller and FLC

Controller type	Response time (s)	Settling time (s)
PI controller	0.02	0.05
FLC	Nil (immediate)	0.01 to 0.02

Total harmonics distortion is shown in the Figure 8. The total harmonics distortion is 6.95% in Figure 8(a) for the voltage harmonics of 27 level inverter-based STATCOM with PI controller, and it is reduced to 4.23% in Figure 8(b) for the voltage harmonics of 27 level inverter-based STATCOM with FLC. Figure 8(c) shows the current harmonics of 27 level inverter based STATCOM with PI controller, the total harmonics distortion is 5.01% and Figure 8(d) shows the current harmonics of 27 level Inverter based STATCOM with FLC, the total harmonics distortion is reduced to 3.13% also tabulated in Table 4.



(a)



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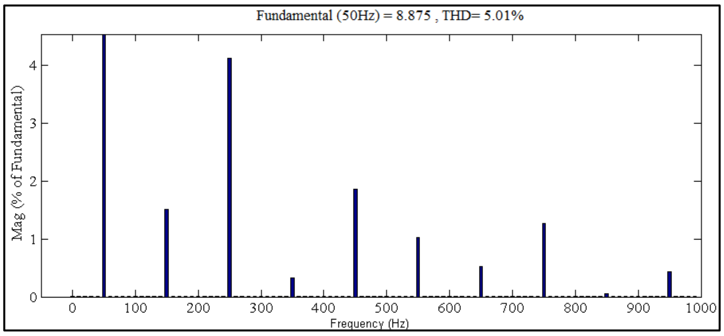
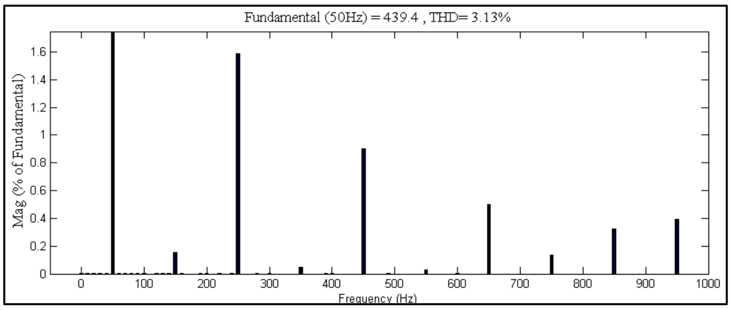


(c)



(d)

Figure 8. Total harmonics distortion; (a) voltage harmonics of 27 level inverters based STATCOM with PI controller, (b) voltage harmonics of 27 level inverters based STATCOM with FLC, (c) current harmonics of 27 level inverters based STATCOM with PI controller, and (d) current harmonics of 27 level inverters based STATCOM with FLC

Table 4. THD comparison of 27 level inverters based STATCOM with PI controller and FLC

THD of PI controller		THD of FLC	
Voltage harmonics	6.95%	Voltage harmonics	4.23%
Current harmonics	5.01%	Current harmonics	3.13%

5. CONCLUSION

This article deals with reduced switch 27 level asymmetrical cascaded h-bridge trinary MLI STATCOM with FLC. Compared to other MLI topologies, the trinary DC source offers higher voltage levels and fewer switches. The proposed design offers fewer switching components, higher output voltage levels, and enhanced harmonic performance. To give the switching angles for the trinary inverter-based STATCOM, fuzzy logic controller is designed. As compared to the PI controller, which has a slower response and settling time, the proposed STATCOM with FLC offers effective reactive power compensation under static and dynamic load shifting conditions. Additionally, it can be seen that the proposed STATCOM with FLC has lower THD of voltage and current than STATCOM with PI controller.

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