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REDUCTION OF VOLTAGE FLUCTUATIONS & IMPROVEMENT OF PQ IN DISTRIBUTION SYSTEM USING STATCOM

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Abstract

This article examines stability evaluation of multi-voltage converters based on static electricity component only (Static compensator). The major purpose of this study is to maintain the voltage balance by compensating the reactive power in electrical supply. By providing reactive power support and voltage stabilization, STATCOM helps mitigate voltage sags, flickers, and other power quality issues. It enhances the overall reliability and performance of the power system, reducing the likelihood of equipment damage or operational disruptions and it can indirectly help mitigate harmonics in the transmission system. The overall performance is also comparable using 110kV transmission with and without STATCOM. In this paper, a fuzzy logic controller approach is adopted to reduce total harmonic distortion (THD) and thus increase power efficiency.

Keywords: Fuzzy Logic Controller (FLC), Point of Common Coupling (PCC), STATCOM, STATCOM Controller, Total Harmonic Distortion (THD), Voltage Drips and Swells

1. INTRODUCTION

Electricity plays a crucial role in the present situation across various aspects of our lives. Electricity is the primary source of energy for lighting, heating, cooling, and powering appliances in homes, offices, and public infrastructure. It enables us to maintain a comfortable living environment, power essential equipment, and carry out daily activities. Electrical systems (if not all over the world) are those that connect electrical equipment in their region, connect to electrical grids, etc., for regional and international connections. Are widely interconnected. This is done for financial reasons to reduce energy costs and increase reliability. In the current plan, long-term changes and jobs are not uniform across devices. This makes it difficult to run continuously and change speed quickly [1]. In recent years, in the electrical grid, traditional power transmission cannot control the difference between different power and connected equipment in difficult areas. Therefore, these issues are issues of increasing stability and security. The electric generator is permanently connected to earth and this electric generator is the AC transmission transformer (FACTS) [2]. These FACTS devices are becoming the technology of choice for power management, active and passive power flow control, dynamic switching and steady state. Use this capability to analyze the efficiency of existing electrical equipment, reduce overall electricity and fuel consumption, and reduce operating costs.

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2. FLEXIBLE AC TRANSMISSION SYSTEM(FACTS)

The history of FACTS controllers can be traced back to the 70s when Hingorani came up with the idea of using electric current in electric charging [3]. Today, the demand for electricity is increasing day by day and it is necessary to transmit and control the flow of electricity by transmission. This leads to many load centers that can be changed many times, so it is very expensive to add new lines to increase the load on the system. As far as FACTS are concerned, equipment is the best job to accommodate the growing number of transmission lines. FACTS equipment has become more environmentally friendly; does not pose any danger. They do not pollute the environment and help to transmit electricity more economically using existing lines, reduce the cost of new lines and generate more electricity. FACTS technology has strong capabilities and its equipment is used for transmission line control and uses flexibility and performance, FACTS controllers are classified according to their connection, for example, connection and connection management, FACTS in general,

- Static Var Compensator (SVC)
- Static Synchronous Compensator (STATCOM)
- Thyristor-Controlled Series Capacitor (TCSC)

In transmission systems, using FACTS devices, existing transmission systems can be used to improve reliability, further improve engine power and stability, and improve electrical repair equipment in large industries.

3. STATCOM

The STATCOM (Static Synchronous Compensator) is a self-converting transformer that is fed from the power source and creates a system in which various voltages are regulated, which can be combined into AC electrical energy to change its true energy and work again.

3.1 Working Principle of STATCOM

The working principle of a STATCOM (Static Synchronous Compensator) involves the use of power electronics converters and control techniques to provide reactive power compensation and voltage regulation in power systems. The STATCOM measures the voltage at its point of connection in the power system using voltage sensors or phasor measurement units (PMUs). The most common converter topology used in STATCOM is the Voltage Source Converter (VSC). It consists of a series of insulated-gate bipolar transistors (IGBTs) or gate turn-off thyristors (GTOs) that can switch on and off rapidly. Finally, if equation (1) indicates V2 = V1, then no reactive power exchange takes place. The rate of change of reactive power is as follows:

$$Q = \frac{V1(V1-V2)}{Xs} \quad \text{………..} \ (1)$$

Among them

V1: the magnitude of the system voltage.

V2: The magnitude of the STATCOM output voltage.

The Seybold REPORT
ISSN 1533-9211
DOI 10.17605/OSF.IO/3S6EY

Xs: Equivalent impedance between STATCOM and system. [4]

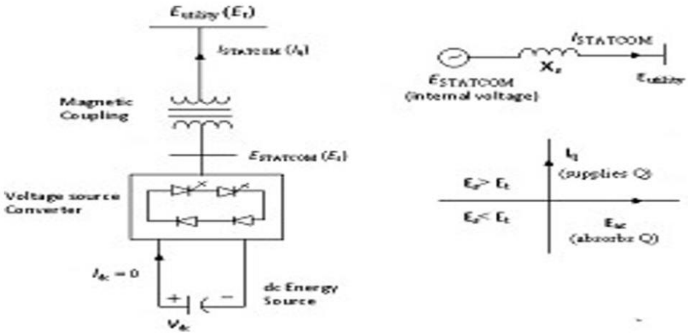

Figure 1: Schematic diagram of Static compensator

3.2 Cascade Multilevel STATCOM

Cascading multistage STATCOM (Static Synchronous Compensator) is an advanced configuration of STATCOM that uses multiple cascade-connected Voltage Source Converters (VSCs). It is designed to provide enhanced voltage and reactive power control capabilities for power system applications. The cascading multilevel converter circuit is shown in Figure 2. It is a three-phase VSC with a three-phase H-bridge connected in series at the same time. The three stages in the converter are star connected. Each single-phase H-bridge converter has two pairs of GTOs and two legs with antiparallel connected diodes. The Cascade Multilevel STATCOM is a sophisticated and high-performance solution for voltage regulation, reactive power compensation, and harmonic mitigation in power systems. Its advanced converter topology and control techniques contribute to enhanced system stability and power quality. The total output voltage of each level is a combination of the individual H-bridge voltages, as shown in Figure 2.

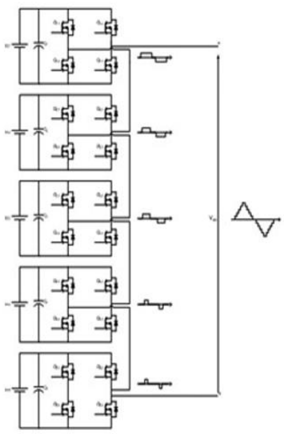

Figure 2: Single phase 9-level H-bridge inverter andswitching strategies

The output voltage waveform of the stepped N-phase STATCOM depends on the variation of the converter's change angle control. The angle of these changes can be chosen independently,

ISSN 1533-9211
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but changing the angle should produce good results on the voltage waveform. Using SHEM, the low frequency in the output waveform can be removed, as shown in equation (2), the amplitude of the single harmonic of the output voltage has 2N + 1 level, which indicates that the Fourier series method is used,

$$Vn1 = \frac{4Vdc}{n\Pi} \sum_{k=1}^{N} \cos(n\theta_k) \quad (2)$$

In the formula,

Vn is the magnitude of the nth voltage harmonic,

Vdc is the voltage across the capacitor,

N is the number of bridges per phase,

n is the number of odd harmonics,

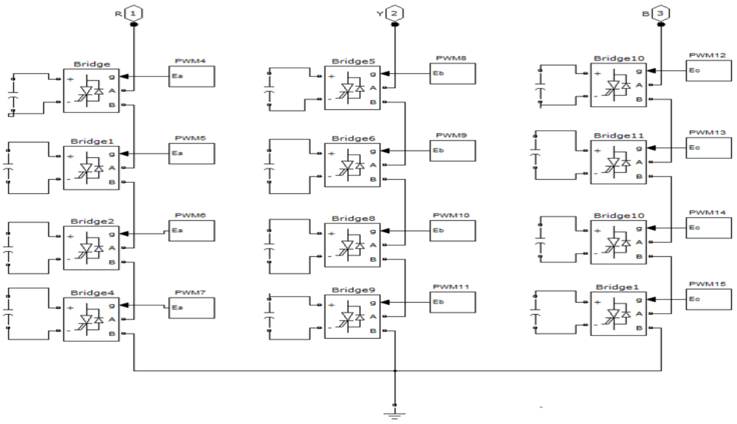

Figure 3: MATLAB design of 9 levels H-bridge inveter

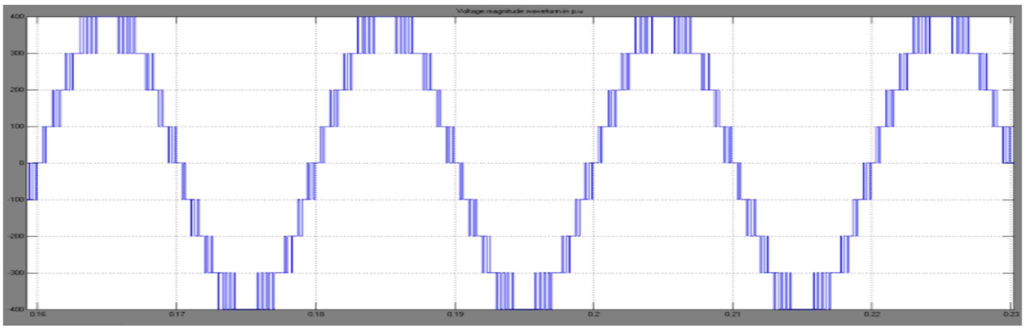

Figure 4: Output voltage of 9 levels VSC

3.3 Statcom Controller

A STATCOM (Static Synchronous Compensator) controller is a device used in power systems to provide reactive power compensation and voltage regulation. It is a type of Flexible AC

ISSN 1533-9211
DOI 10.17605/OSF.IO/3S6EY

Transmission System (FACTS) device that helps in maintaining the stability and reliability of electrical grids. The STATCOM controller consists of several key components, including a voltage source converter (VSC) and a DC capacitor. The VSC is responsible for converting the DC voltage from the capacitor into AC voltage and injecting it into the grid. The controller continuously monitors the grid voltage and adjusts the output of the VSC to maintain the desired voltage and reactive power levels. By varying the output voltages V2a, V2b and V2c, the STATCOM is controlled to supply inductive or capacitive current to electronic equipment. In the design of the STATCOM controller, the three-phase quantity (voltage and current) is first converted into four elements in the synchronously rotating reference frame.

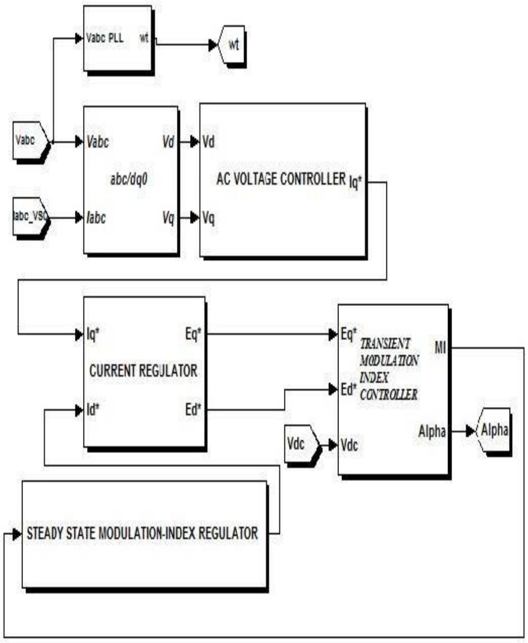

Figure 5: STATCOM Simulation controller

The control strategy of a STATCOM controller typically involves measuring the grid voltage and current, and using advanced control algorithms to regulate the converter's output. These algorithms are designed to respond quickly to changes in the system conditions and maintain voltage stability. Different control techniques, such as PI (Proportional-Integral) control, droop control, or model predictive control, can be implemented depending on the specific application requirements. As shown in Figure 5, the transient modulation index controller and the steady state modulation index regulator are designed to achieve the goals of good response and minimum state harmonics, respectively. Switching converter, state setting variable, phase measuring loop (PLL), abc to dqO conversion, AC voltage control, current regulator, PWM generator design as follows:

PLL: In an electrical transmission system, a phase-locked loop (PLL) can be used for various purposes, including synchronization, frequency generation, clock recovery, and phase modulation/demodulation. In addition to voltage synchronization and current control, the PLL

ISSN 1533-9211

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in a STATCOM can be used for harmonic detection and compensation. By analyzing the phase and frequency of the grid current, the PLL can detect the presence of harmonic components. This information can be utilized to generate control signals that drive the power electronics within the STATCOM to actively compensate for the harmonics and mitigate their effects on the power system.

abc to dqo conversion: The abc reference frame represents the three-phase quantities as vectors in a stationary coordinate system, where the three axes are aligned with the three phases (a, b, c). On the other hand, the dq0 reference frame is a rotating coordinate system, also known as the Park's transform, in which one axis (d-axis) is aligned with the magnetic field of the machine, and the other two axes (q-axis and zero-axis) are perpendicular to the d-axis. The transformation equations for converting abc variables (a, b, c) to dq0 variables (d, q, 0) are as follows:

$$V_d = \frac{2}{3}\left[V_a \sin(\omega t) + V_b \sin\left(\omega t - \frac{2\pi}{3}\right) + V_c \sin\left(\omega t + \frac{2\pi}{3}\right)\right] \quad \ldots\ldots\ (3)$$

$$V_q = \frac{2}{3}\left[V_a \cos(\omega t) + V_b \cos\left(\omega t - \frac{2\pi}{3}\right) + V_c \cos\left(\omega t + \frac{2\pi}{3}\right)\right] \quad \ldots\ldots\ (4)$$

$$V_o = \frac{1}{3}[V_a + V_b + V_c] \quad \ldots\ldots\ (5)$$

Where ωt = rotating speed (rad/sec) of the rotating frame.

AC Voltage Controllers and Current Regulators:

The AC voltage controller converts Vd, Vq to reactive current 1 using a PI controller as shown in figure 5.

$$i_q^* = G_1(s)[V_{rms} - V_{rms}^*]$$

$$G_1(s) = k_1 + \frac{k_2}{s}$$

Likewise, the current controller uses the reference current Iq* and uses the DC current Id* and the PI controller to generate the DC voltage E/, Eq* respectively.

$$E_d^* = -\omega L_f i_q + V_{dc} - x_1 \quad \ldots\ldots\ldots\ (6)$$

Where

$$x_1 = G_2(s)[i_d^* - i_d]$$

$$G_2(s) = k_3 + \frac{k_4}{s}$$

Where,

L_f is leakage inductance

V_{dc} is capacitor voltage.

ISSN 1533-9211
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Transient Modulation Index Controller

The Transient Modulation Index Controller contributes to improving the dynamic performance of VSC-based devices, enabling them to respond effectively to transient events. By regulating the reactive power exchange, it helps stabilize the system voltage, mitigate voltage fluctuations, and maintain power quality during disturbances. The TMIC control strategy can be implemented in various power system applications, including STATCOMs, voltage regulators, and active power filters, to enhance system resilience and reliability.

$$MI = \frac{\sqrt{E_d^{*}+E_q^{*}}}{KV_{dc}} \quad \text{.........} \quad (7)$$

$$\propto = \tan^{-1}\left(\frac{E_q^{*}}{E_d^{*}}\right) \quad \text{.........} \quad (8)$$

Steady-State Modulation Index Tuner:

A "Stable state modulation index adjuster" shall refer to a control algorithm or technique for adjusting or optimizing the index of a VSC based system in steady state operation. It proposes to adjust the parameters of the measurement system to achieve a specific purpose or to improve the performance of the system in regular situations. As shown in Figure 5, the actual current I_d is generated by the steady-state modulation index editor as shown in equations (8) and (9).

$$i_d^{*} = G_3(s)[MI^{*} - MI] \quad \text{..........} \quad (9)$$

$$G_3(s) = k_5 + \frac{k_6}{s} \quad \text{..........} \quad (10)$$

By using continuous tuning of parameter and variable, less harmonic advantage can be kept constant. When the reactive power needs to be changed when the state changes, the actual MI is not equal to the state, using the value M equal to the current value. Therefore, MI deviates from steady state. However, where the content of the fit state is constant, the difference in this parameter is less significant because the change takes a very short time. With change.

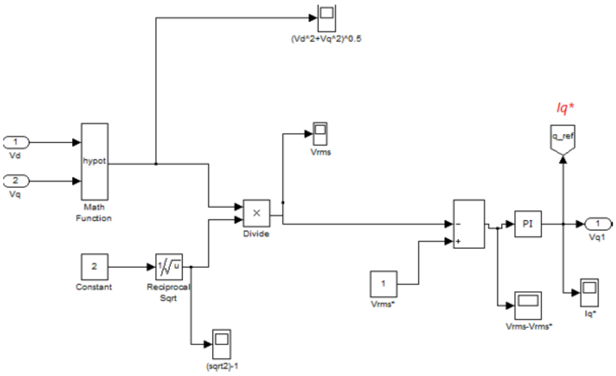

Figure 6: Proportional and Integral (PI) Controller

ISSN 1533-9211
DOI 10.17605/OSF.IO/3S6EY

PI Controller: The PI controller compares the set point with the measured values of reactive and active power and generates gate commands to drive the converter and compensate for errors. This is an essential part of the converter that generates changes that allow the converter to synchronize with the AC system to produce simple voltage waveforms with equal voltage amplitudes. As shown in Figure 6, attention should be paid to the internal control to limit the maximum voltage and current of the power transformer to ensure the stability of each connection.

4. FUZZY LOGICAL CONTROLLER

Fuzzy logic controller (FLC) is a controller based on fuzzy logic, which is a mathematical framework for modeling uncertainty and uncertainty in decision making. FLC is frequently used in many fields such as control, robotics and artificial intelligence to solve complex and uncertain problems. Fuzzy logic controllers are based on a process known in many languages as fuzzy rules, as shown in Figure 7. FLC is based on fuzzy logic describing the control strategy. Concepts for a fuzzy policy mapping system (eg.eg sensor measurement) for suitable control (eg signal output to actuators). These rules are usually expressed using IF-THEN statements, where the original (IF section) contains the conditional statement and the result (THEN section) represents the desired control.

Rules:

- If input-1 is negative, input-2 is negative then output is positive
- If input-1 is zero, input-2 zero then output is zero
- If input-1 is positive, input-2 is positive then output is negative

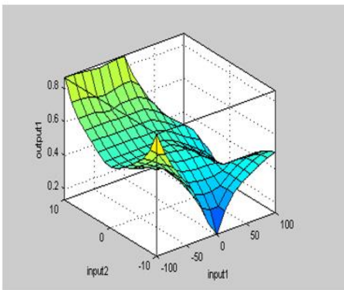

Figure 7: Surface of the fuzzy logic controller

Table I: Fuzzy Rules for Total Harmonic Distortion

	N	**Z**	**P**
N	P	Z	P
Z	N	Z	P
P	Z	N	N

ISSN 1533-9211
DOI 10.17605/OSF.IO/3S6EY

Fuzzy rules typically follow the IF-THEN structure and are expressed in linguistic terms. This method using 3×3 matrix will create nine rules as shown below,

IF input-1 is N AND input-2 is N THEN output is P

IF input-1 is Z AND input-2 is N THEN output is N

IF input-1 is P AND input-2 is N THEN output is Z

IF input-1 is N ANDinput-2 is Z THEN output is Z

IF input-1 is Z AND input-2 is Z THEN output is Z

IF input-1 is P AND input-2 is Z THEN output is N

IF input-1 is N AND input-2 is P THEN output is P

IF input-1 is Z AND input-2 is P THEN output is P

IF input-1 is P ANDinput-2 is P THEN output is N

5. SIMULATION AND RESULTS ANALYSIS

This article refers to the use of a 9-phase power converter as a static synchronous stabilizer (STATCOM). The main aim of the project is to ensure energy security by charging for renewable energy. Therefore, a new concept is proposed to reduce changes such as droop and swell states and to separate current and voltage harmonics in transmission.

A. Without STATCOM

In a 3Φ fault happened and the system is not equipped with a STATCOM and the system will be unstable. The voltage and current in the power transmission have a rapid rise and fall, and the load is not balanced. When the magnitude of the voltage and current in the power supply is not constant.

B. With STATCOM

There is a PI-based STATCOM installed on the system. The system is stable and the voltage and current are shown in Figure 8-10.

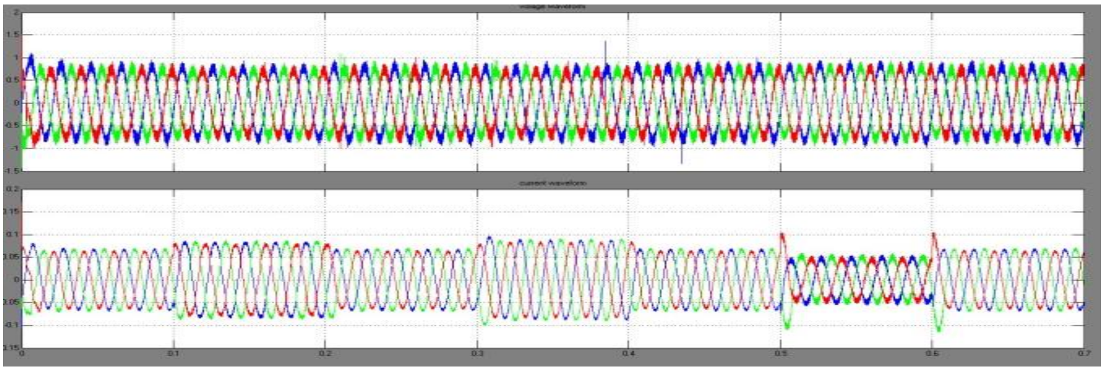

Figure 8: Output voltage and current of the power system

ISSN 1533-9211
DOI 10.17605/OSF.IO/3S6EY

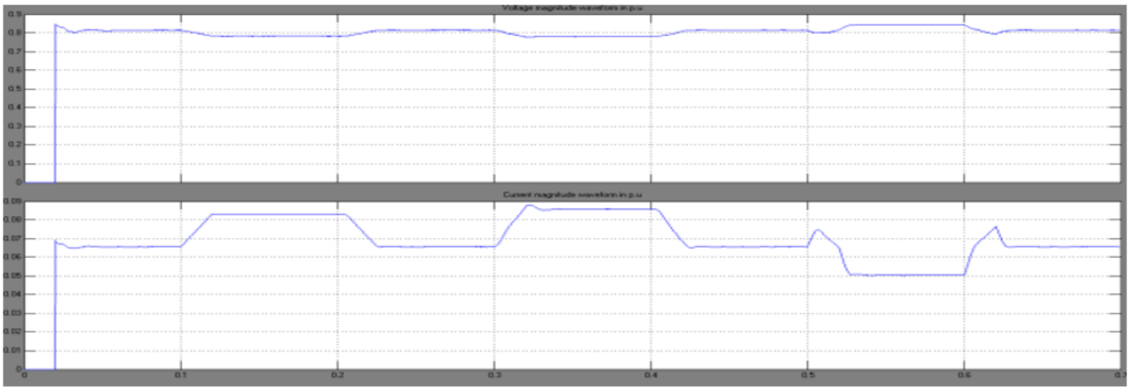

Figure 9: Voltage and current magnitude

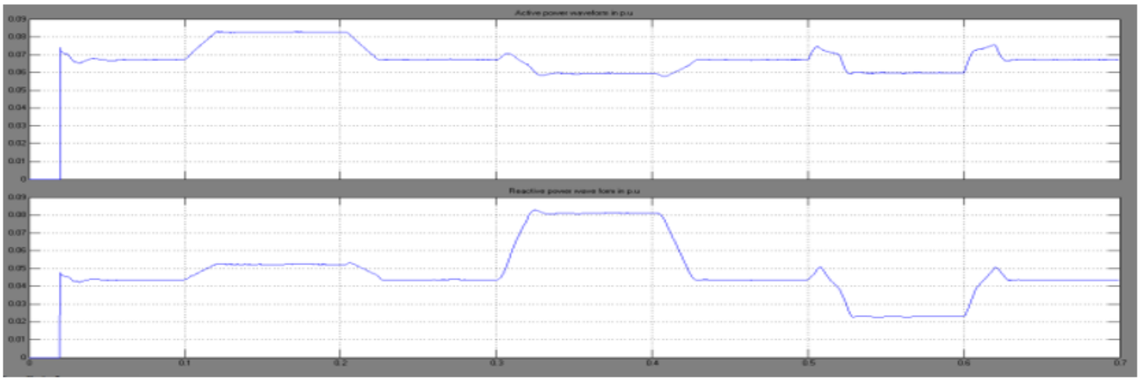

Figure 10: Real and reactive power

a) System Installed With Fuzzy Based StatcomController

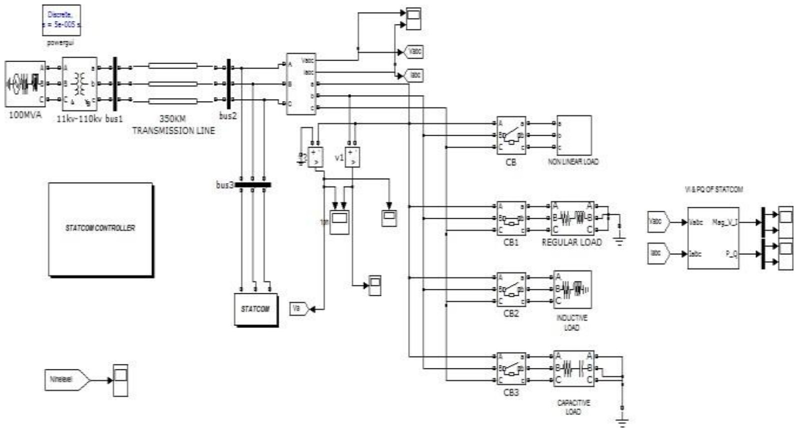

Figure 11: Simulation of fuzzy based STATCOM controller

Figure 11 above shows the fuzzy-based STATCOM simulation. Here the input is 100MVA and the main components are step-up transformers and bus bars. In 350 KM transmission line. 1

The Seybold Report
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and No. 2 buses, connection points of lines with STATCOM equipment and No. All 3 buses are connected by different modes of transport. The different loads are connected to the power supply. Comparison of FFT analysis of PI and FLC controllers is shown in figures 12 and 13.From the above figure, it can be concluded that FLC-based STATCOM is superior to PI-based STSTCOM in overall performance, especially in terms of reducing THD.

Comparison of FFT analysis of PI and FLC controllers

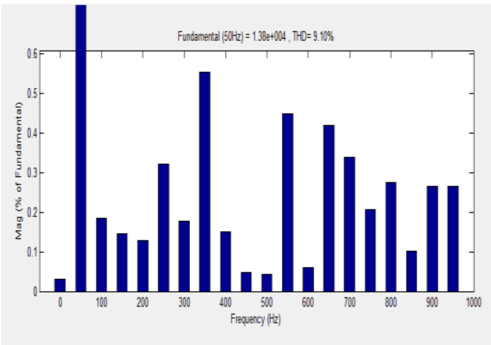

Figure 12: FFT analysis of source current with waveform PI based STATCOM

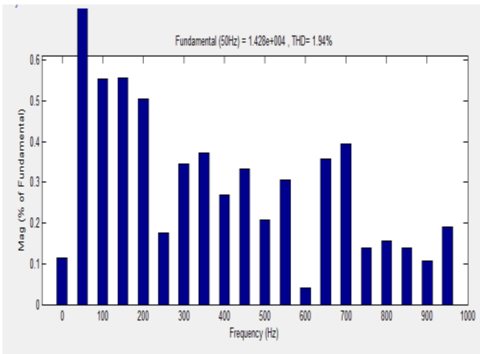

Figure 13: FFT analysis of source current waveform with FLC based STATCOM

6. CONCLUSION

This article presents the implementation of STATCOM in distribution systems offers significant advantages in terms of reducing voltage fluctuations and improving Power Quality. Its ability to regulate voltage, compensate for reactive power, mitigate harmonics, and enhance grid stability makes it a valuable tool for power utilities to deliver a reliable and high-quality power supply to consumers. The multi-level voltage source converter in the system overcomes all influences and delivers pure voltage, current, active and reactive power to the target (load). FLC-based STATCOMs have been found to improve power efficiency of current sources by reducing total harmonic distortion (THD). Comparison of PI controllers and fuzzy logic controllers. It is clear that STATCOM with FLC has better performance than STATCOM with PI device. Therefore, it can be concluded that FLC-based STATCOM works poorly in controlling voltage, measuring and eliminating correlation.

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