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Optimizing Power Quality with a Five-Level Modified CHB Inverter-Based STATCOM Using ANN Controller

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Abstract:** This project focuses on an advanced strategy for optimizing power quality using a Five-Level Modified Inverter-Based Static Synchronous Compensator (STATCOM) Cascaded H-Bridge (CHB) combined with an Artificial Neural Network (ANN) controller. The system is designed to address prevalent power quality challenges such as harmonic distortions, voltage sags and reactive power discrepancies, which are crucial in contemporary power grids. The CHB inverter is engineered to minimize Total Harmonic Distortion (THD) while enhancing power conversion efficiency. To optimize its performance further, the ANN controller adjusts the operations of the STATCOM in response to real-time grid conditions. In contrast to traditional controllers, the ANN controller learns from past data, modifying its reaction to varying load and fault situations, ultimately improving voltage stability, reducing harmonics, and ensuring a quick response from the system. Simulation outcomes illustrate the effectiveness of the ANN-based STATCOM in delivering enhanced harmonic mitigation and voltage regulation when compared to standard control techniques. This method proves to be particularly advantageous for smart grids, industrial power systems, and the integration of renewable energy, where sustaining high power quality is critical. The study concludes that the integration of ANN control with the modified CHB inverter-based STATCOM presents a highly effective and adaptable solution for enhancing power quality in intricate electrical networks.
***Keywords:** power quality, five-level inverter, harmonics, modified CHB STATCOM, ANN controller.*

I. INTRODUCTION

The increasing number of dispersed generating units, renewable energy sources, and nonlinear and dynamic demands has made power quality one of the biggest problems facing contemporary electrical power networks. Electrical networks' stability, effectiveness, and dependability can all be negatively impacted by reactive power imbalance, harmonic distortion, and voltage fluctuations brought on by poor power quality. A number of compensation strategies have been developed to solve these problems, and the Static Synchronous Compensator (STATCOM) has shown to be a successful means of controlling reactive power and regulating voltage.

In recent times, multilevel inverter (MLI) configurations, particularly Cascaded H-Bridge (CHB) inverters, have attracted significant interest for STATCOM applications due to their capacity to deliver high-quality output voltages with decreased switching losses and Total Harmonic Distortion (THD). The implementation a Five-Level Modified CHB inverter further improves the quality of the voltage waveform and decreases the necessity for large filters, thereby enhancing both system efficiency and dynamic response. Nevertheless, achieving optimal control of STATCOM amidst changing load and grid situations poses a significant challenge. Conventional control methods, such as PI or fuzzy controllers, frequently have difficulty adjusting swiftly to nonlinear and time-varying behaviours of the system.

To address these challenges, controllers based on Artificial Neural Networks (ANN) are being introduced as intelligent and adaptive solutions. ANN controllers possess the ability to learn the dynamics of the system., predict control actions, and self-adjust based on real-time data, resulting in faster response, improved stability, and enhanced harmonic mitigation. An ANN controller and a Five-Level Modified CHB inverter-based STATCOM work together to sustain exceptional power quality in contemporary grids. This arrangement mitigates voltage sags and swells, lowers harmonic distortion, and efficiently adjusts reactive power. These developments are especially important in industrial power networks, smart grids, and systems of renewable energy where steady and superb quality electricity its essential.

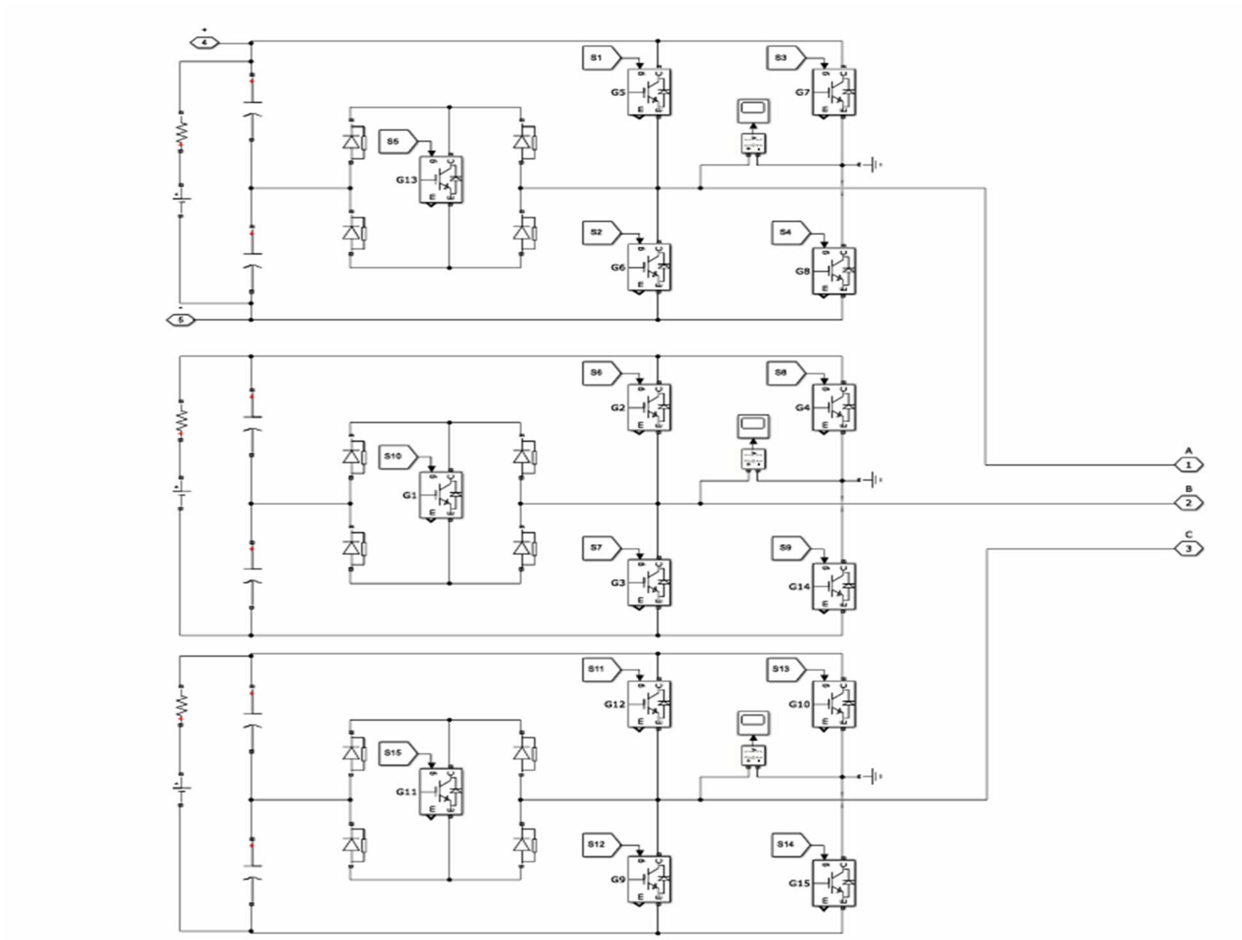

Figure 1: Modified CHB inverter setup with five levels

This project centers on the design and simulation of a Modified Five-Level CHB STATCOM that is Inverter-Based managed by an ANN to enhance power quality. The proposed approach showcases better voltage regulation, reduced THD, and quicker dynamic responses than traditional methods making it a viable option for power systems applications in the future.. Numerous researchers have explored different inverter structures and control mechanisms to improve the performance of STATCOM systems. Certain studies have concentrated on the use of multilevel Current Source Inverter (CSI)-fed STATCOMs, resulting in better harmonic performance compared to conventional techniques. The modulation approach outlined in [1] indicated substantially lower Total Harmonic Distortion (THD) values in comparison to standard carrier with a phase shift Modulation of Sinusoidal Pulse Width (SPWM) methods. In addition, the viability of utilizing Modular Multilevel Converters (MMC) for STATCOM applications was investigated in [2], highlighting their high energy-handling capacity, greater efficiency, and enhanced reliability for grid-connected reactive power compensation. A one-cycle control technique for STATCOM was proposed in [3], showing minimal steady-state error and quicker transient response than classical methods. controllers. Numerous other control algorithms and inverter structures have also been proposed in the literature [4-6], primarily aimed at improving system dynamic characteristics and reducing harmonic content. The five-level modified CHB STATCOM design presented by Yamnaz [7] focused mainly on reactive power compensation, while the harmonic mitigation aspect remained unaddressed. In a separate study, Mengi [8] achieved voltage THD and current THD values of 4.94% and 4.17%, respectively utilizing a five-level STATCOM configuration. The multilevel inverter Cascaded H-Bridge (CHB) topology offers several advantages, such as uniform distribution of switching losses, modular design, and improved output voltage quality [9]. Motivated by these benefits, this work proposes a modified five-level CHB. Figure 1 illustrates the configuration of a multilayer inverter designed to minimize the quantity of semiconductor switches utilized in traditional multilayer inverters. This modified CHB inverter is then put into use into STATCOM to enhance harmonic compensation performance. The effectiveness of the proposed configuration will be validated through comparative analysis with existing innovative methods reported in literary works.

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II. CHB STATCOM MODIFIED FIVE LEVEL

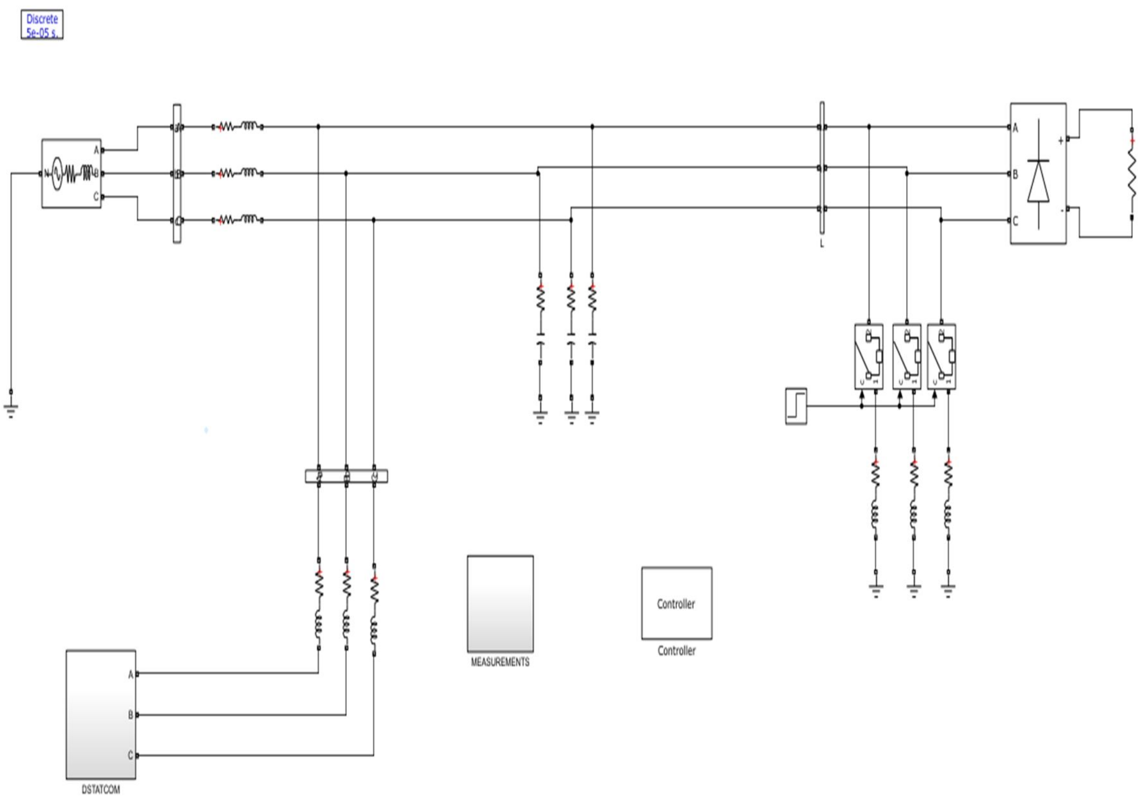

Figure 2: Configuration of STATCOM

STATCOM with five levels is suggested as shown in Figure 2. The control architecture is developed using the The theory of instantaneous reactive power, commonly referred to as the PQ theory, and further optimized with an Artificial To enhance power quality and mitigate harmonic distortions, A modified Cascaded H-Bridge (CHB) inverter-based Neural Network (ANN) controller, as illustrated in Figure 3. The basis of the PQ theory is the real-time calculation of reactive and active power components obtained from voltage and current data that were measured. The three-phase origin Initial measurements are made of load currents (Iabc) and voltages (Vabc). then converted into stationary reference frame components (α–β) using the Clarke transformation. These α–β elements are are employed to evaluate the instantaneous active and reactive power. Active power element processed through a to extract using a low-pass filter its non-oscillatory part. This filtered power is subsequently combined with the power loss component obtained from the DC-link voltage controller to keep the voltage balance across the inverter

The integration of the ANN controller significantly increases the system's resilience and adaptability. The ANN takes DC-link voltage error and other operating parameters as inputs and generates an optimized control signal that dynamically adjusts the compensating current. This intelligent control mechanism enables faster dynamic response, improved harmonic elimination, and better voltage regulation under varying load and system conditions compared to conventional linear controllers. Using the outputs from the ANN-assisted PQ control scheme, the reference current components (Iα*, Iβ*) is derived by merging the active power that is not oscillatory, the ANN-based loss of power term, and the reactive power (Q) components with the corresponding voltage components (Vα, VβThe three-phase (abc) is restored from these reference currents. domain through the inverse Clarke transformation. To provide the proper gating pulses for every IGBT switch in the improved CHB inverter, the generated sinusoidal reference signals are compared with high-frequency triangular carrier waveforms.This modulation process ensures accurate current injection, efficient reactive power compensation, and effective mitigation of harmonic distortions in the power system.

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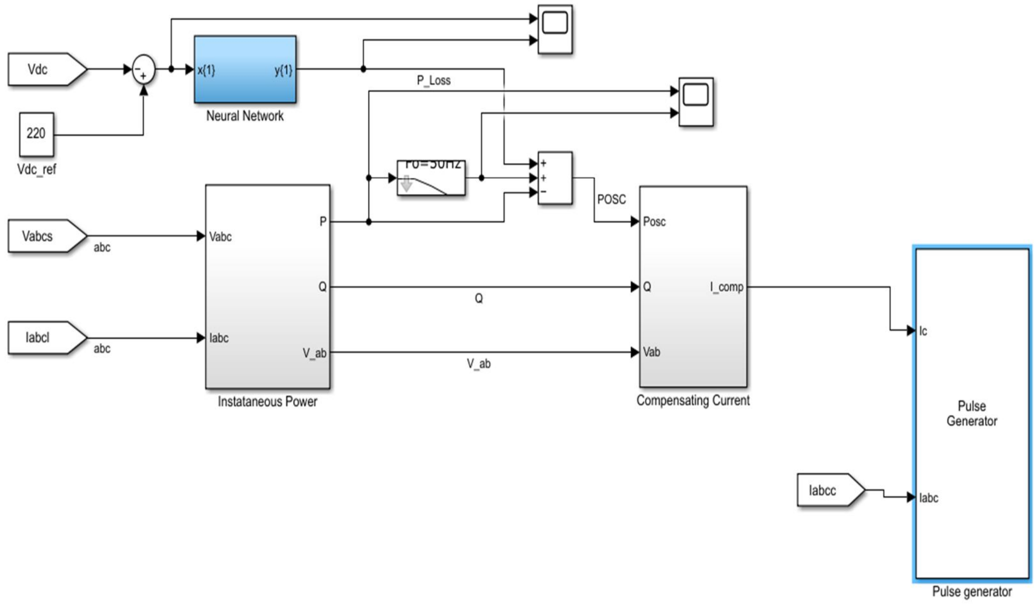


Figure 3. Control scheme of STATCOM with ANN controller

Table 1. Specifications of STATCOM

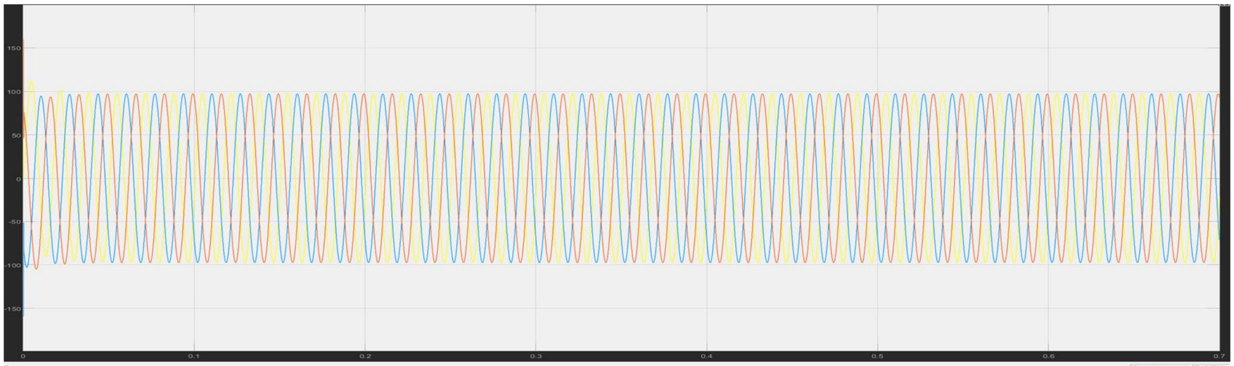
Source Parameters	Vrms (Ph-Ph) = 11 kV, Frequency = 50 Hz
Transformer Parameters	Winding 2 connection: Star grounded Nominal Power = 20kVA Frequency = 50 Hz V1 Ph-Phv\ (Vrms) = 11 kVV2 Ph-Ph (Vrms) = 400 V
Line & Load Parameters	RL Branch: Resistance R (Ohms) = 0.4, Inductance L (mH) = 3.55 Nonlinear Load: Resistance R (Ohms) = 15, Inductance L (mH) = 60
STATCOM Parameters	DC Link Voltage = 300 V Capacitance (μF), C_1=C_2=C_3=C_4= C_5= C_5= 1000 Switching Frequency (kHz) = 5 LC Filter: Inductance L (mH) = 150, Capacitance, C (μF) = 5000
Three Phase Circuit Breaker	Initial status: Open Switching times (s) = 0.4, Breaker resistance Ron (Ohm) = 0.001

III. RESULTS AND DISCUSSION

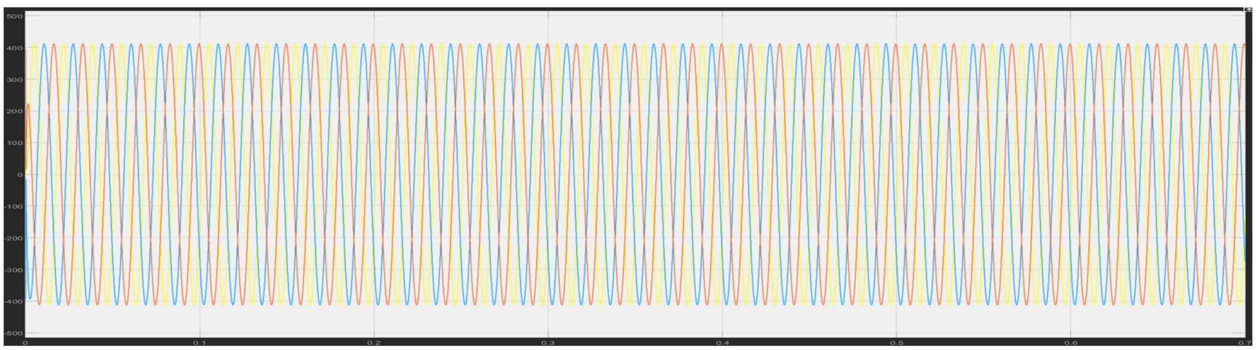
In the simulation, the STATCOM compensation is activated at 0.5 seconds, while the system operates without compensation from 0 to 0.5 seconds. During this initial period, The waveforms for voltage and current are recorded to evaluate of uncompensated system performance. The primary goal of the simulation is to assess the effectiveness Using the modified Cascaded H-Bridge (CHB) inverter-based five-level The STATCOM integrated with an ANN controller, in mitigating harmonics caused by a nonlinear load.

An investigation of total harmonic distortion (THD) is carried out for both The unreimbursed and compensated periods. Before recompense (0–0.5 s), the system exhibits high THD due to the presence of nonlinear load harmonics. After activating the STATCOM at 0.5 seconds, the inverter injects appropriate compensating currents, resulting in a noticeable improvement in waveform quality.

The voltage and current waveforms of the STATCOM are only active during the compensatory period, that is, starting at 0.5 s, illustrating dynamic response of the system. The simulation results demonstrate a significant reduction in THD, confirming the effectiveness of the ANN-based STATCOM in harmonic mitigation and reactive power compensation.

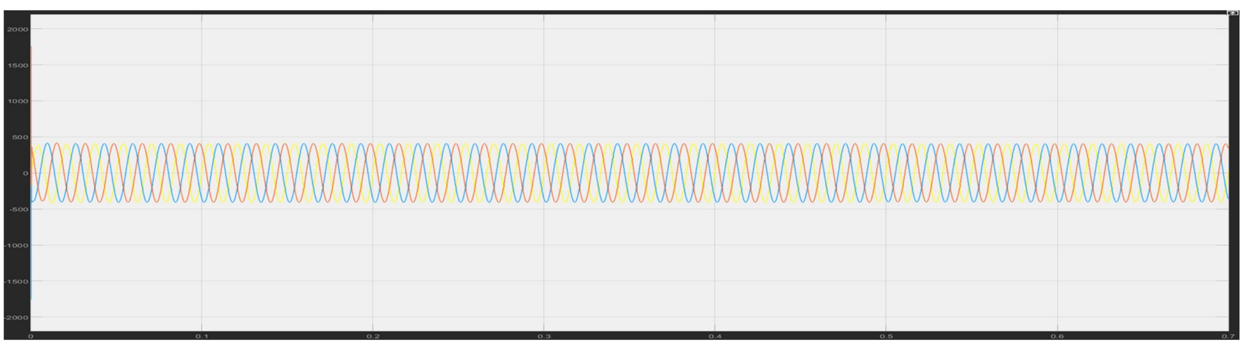


STATCOM VOLTAGE Vabcs

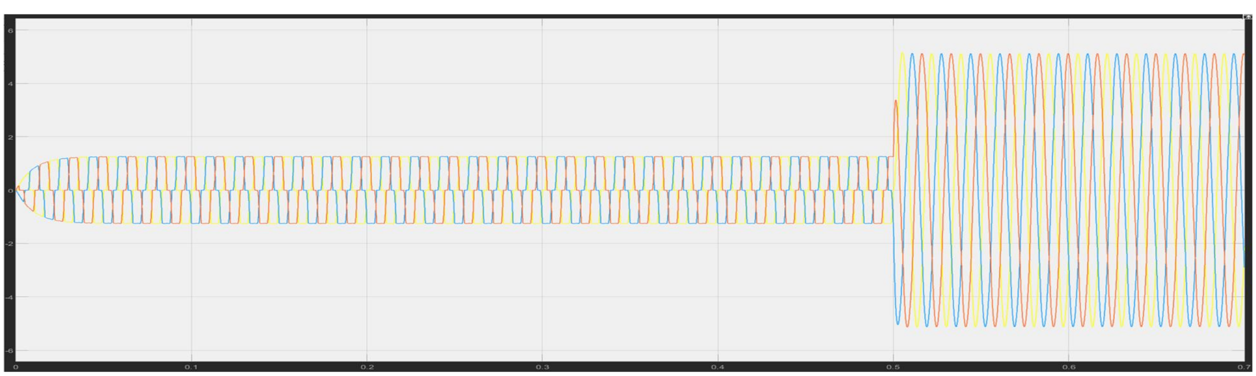


STATCOM CURRENT Iabcs

Figure 4: Voltage and current STATCOM



LOAD VOLTAGE



CURRENT LOAD

Figure 5: Current and voltage load

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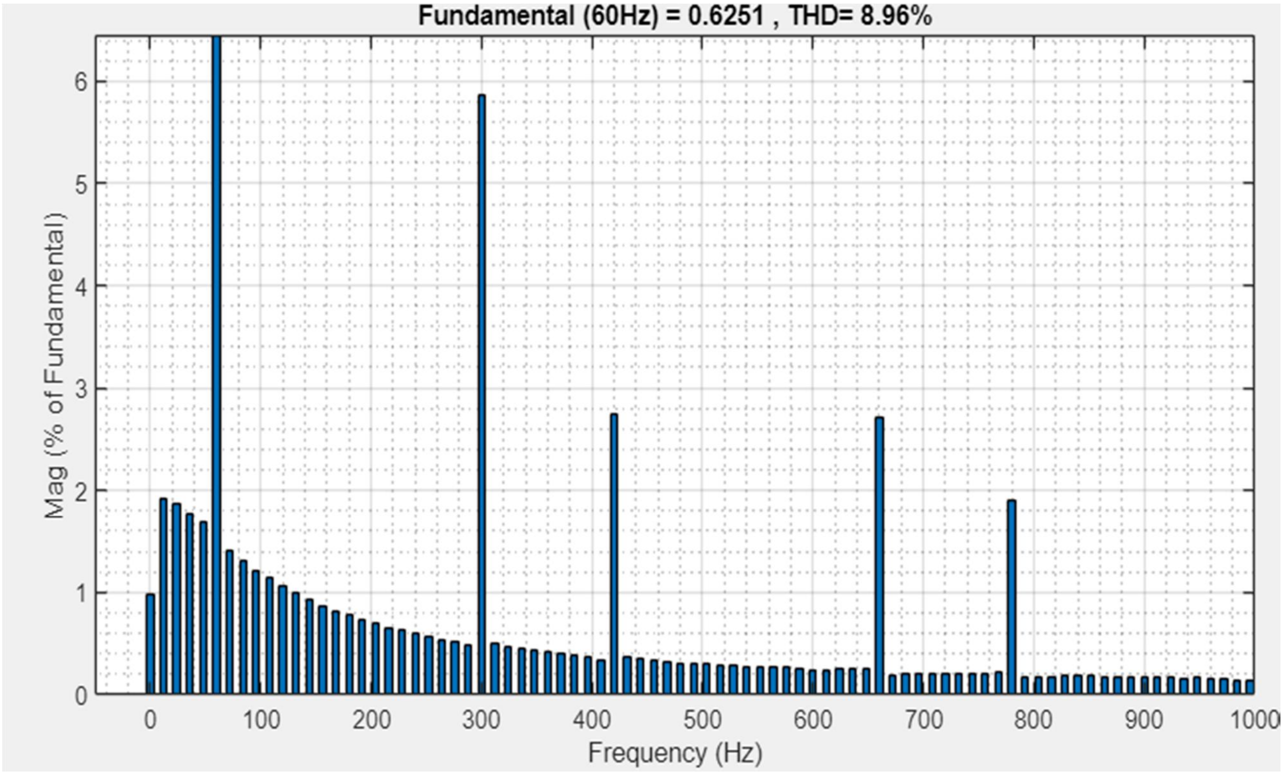
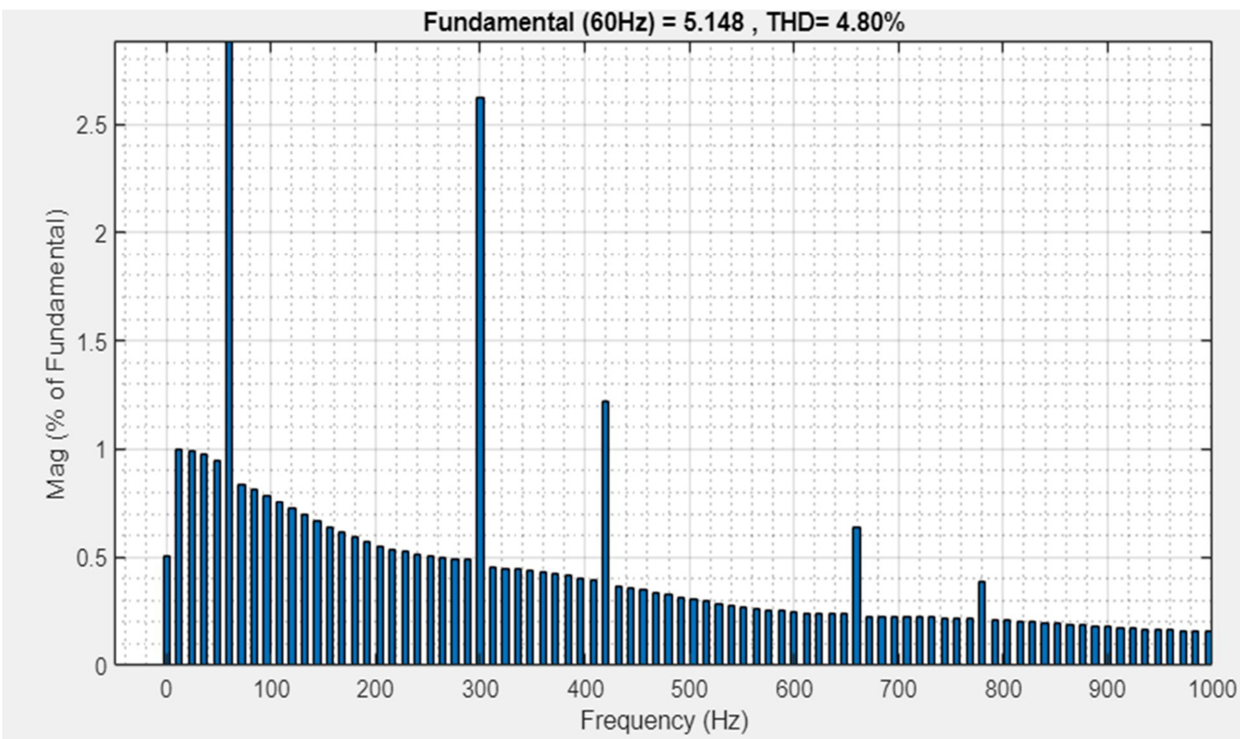
A. Analysis for PI CONTROLLER



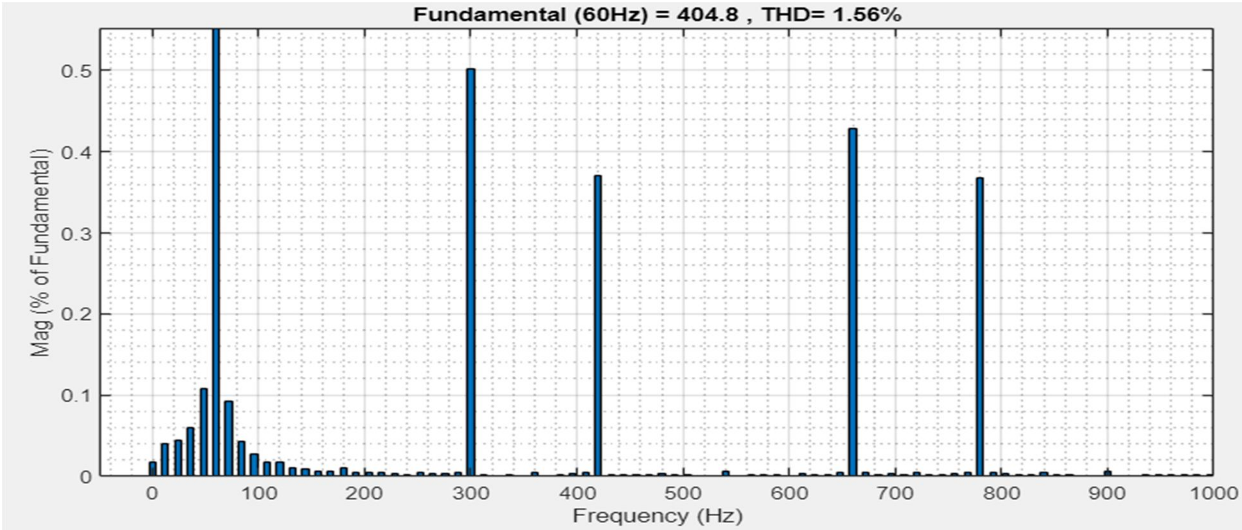
Without STATCOM, THD



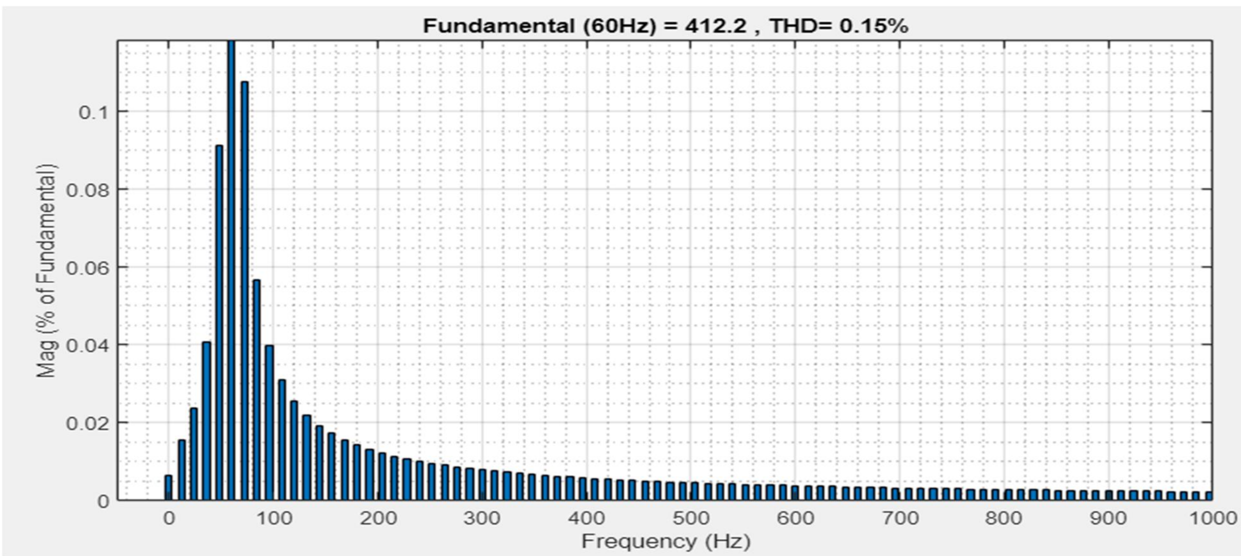
With STATCOM, THD

Figure 5. THD WITH & WITHOUT STATCOM

B. Analysis for ANN Controller



Without STATCOM, THD



With STATCOM, THD

IV. CONCLUSION

A new modified cascaded H-bridge multilevel inverter-based STATCOM for harmonic mitigation is presented in this study. PQ theory and an ANN controller are used to regulate the STATCOM configuration, which is constructed with fewer switches. Harmonics are reduced from 8.96% to 4.80% with the PI controller and from 1.56% to 0.15% with the ANN controller, resulting in an improvement in power quality. It should be mentioned that the system takes fewer than three cycles to restore (respond) to the disruptions. The modified H-bridge based STATCOM has a lower THD value than the most advanced models [11,12,13].

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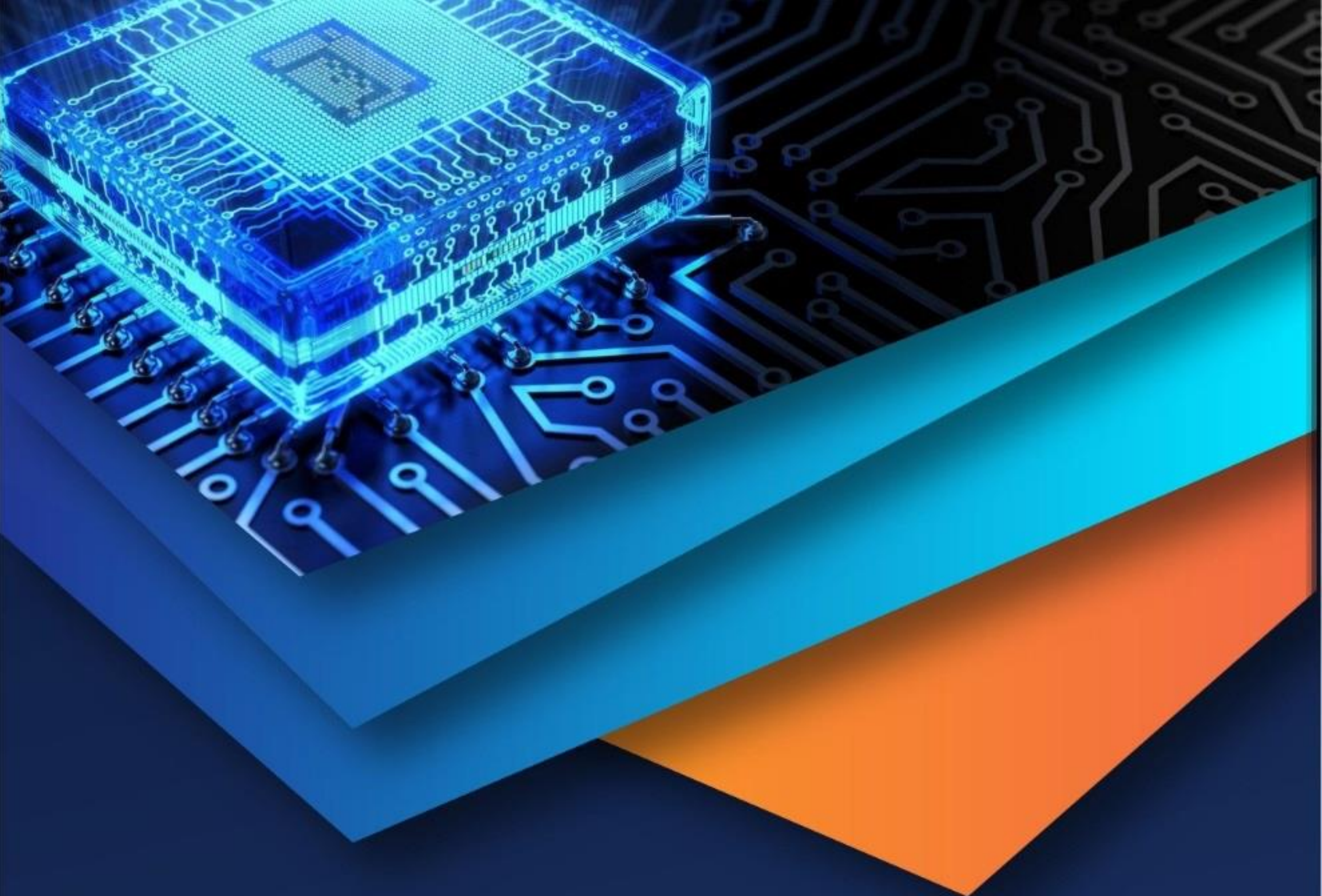

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