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Power Quality Enhancement of a Grid Connected Solar Wind Hybrid System using PID Controller and STATCOM

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Abstract- Electricity have an important role in both daily life and industries. Hybrid solar-wind systems extract the energy from renewable sources like solar and wind to produce electricity.Power quality is an important factor in determining the power status. When generating electricity, one of the most crucial factors is the quality of the electricity produced. High-quality electricity ensures efficient performance, stability in supply, and minimal disruption to electrical systems. It impacts both the reliability of power delivery and the longevity of the equipment using it. Factors like voltage consistency, frequency stability, and the reduction of harmonic distortions are all key to maintaining optimal electricity quality.Due to the changing behavior of the power generation in the wind power systems, the problem of high quality may arise. The proposed work presents the simulation and analysis of the solar-wind hybrid system and the power improvement of the synchronous static amplifiers through the control strategy and power transmission.The main objectiveof this work to use a STATCOM device that can improve power-system Performance. The proposed system integrates both solar and wind energy sources to enhance power generation reliability and efficiency while addressing power quality concerns. The system aims to improve power system performance through the utilization of a STATCOM (Static Synchronous

Compensator) device and advanced control strategies. The proposed model is designed using Simulink of MATLAB software.

Keywords- Renewable Energy, Solar System, Wind System, STATCOM, Power Quality

Introduction

In hybrid power system, the system uses solar panels and a small wind turbine generator to produce electricity. The working of a hybrid solar-wind system is a combination of both the solar and wind energy systems. Solar systems use solar panels to extract the sun's energy to produce electricity.

Wind energy is another form of renewable energy that can be extracted by installing wind turbines and generators. The wind used for ship navigation in countries around the world. The windmill was built in the seventh century AD. The first English-language record is the wind turbine data from 1191 AD pointed out that in 1439 the Netherlands built the first corn grinder. The first electricity in Denmark was generated by wind turbines. In 1890, a wind turbine with a diameter of 23 meters was used [1]. In 1910, Denmark had 5 to 25 kW wind turbines in operation. In the mid-1970s, people had a strong understanding of unconventional energy. At the time, people worried that the environmental impact of fossil energy was similar. Explained that technology in wind turbine development in the last 25 years has become a recognized technology in this century [2].

Proposed Methodology

A The maintenance of generating power and the fulfillment of customer needs are the main objectives of this work to use a STATCOM device that can improve power-system Performance. The proposed system integrates both solar and wind energy sources to enhance power generation reliability and efficiency while addressing power quality concerns. The system aims to improve power system performance through the utilization of a STATCOM (Static Synchronous Compensator) device and advanced control strategies.

Given the variable nature of wind power generation, maintaining power quality becomes a challenge. To tackle this issue, the article suggests employing simulation and analysis techniques to optimize the filtering, rotation, and power enhancement capabilities of synchronous static amplifiers. These amplifiers, coupled with effective control strategies, can mitigate power fluctuations and improve overall system stability. The integration of solar and wind energy into the power system involves multiple steps, including power generation, transmission, and distribution. The main objectives of this work are to ensure the continuous supply of electricity to meet customer needs while maximizing the efficiency of power generation.

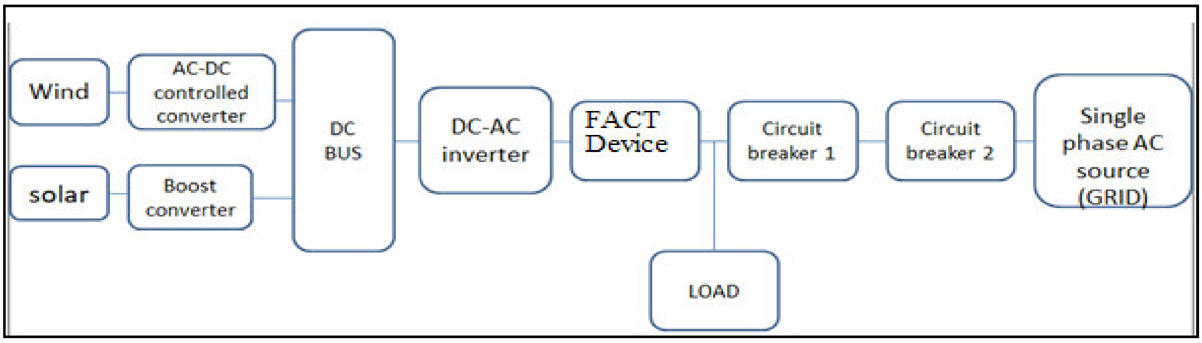

Figure 1: Block Diagram for the Proposed Work

Solar and Wind Unit: The hybrid module focuses on harnessing renewable energy to generate electricity.

STATCOM (Static Synchronous Compensator): It helps stabilize voltage fluctuations and enhance grid stability [15].

Machine Side Converter (MSC): MSC is a converter used in variable speed wind turbines, such as DFIG systems. It controls the power flow between the wind turbine generator and the grid by adjusting the voltage and frequency.

DC link: The DC link is a component in power electronic systems that connects the converters or inverters to the DC power source. It serves as an interface for transferring power between different parts of the system.

Grid Side Converter (GSC): GSC is another converter used in variable speed wind turbines.

It interfaces between the wind turbine generator and the AC grid, controlling the power flow and maintaining grid stability[16].

AC Grid: The AC grid refers to the electrical grid infrastructure that distributes alternating current (AC) electricity to consumers. It comprises transmission lines, substations, and distribution networks[17].

PID (Proportional-Integral-Derivative): PID is a control algorithm used in various applications, including power electronics. It adjusts the control inputs based on the error between the desired set point and the actual system output, helping maintain stability and accuracy[18].

LOAD: Load refers to the electrical devices or equipment connected to the power system that consume electricity. It includes residential, commercial, and industrial loads such as lighting, appliances, and machinery[19].

Simulation Results-

In a MATLAB/Simulink simulation of an electrical power system, the results show that with a STATCOM, the system maintains stable voltage levels, effective reactive power compensation, and improved power quality by reducing harmonics and mitigating voltage sags and swells. The STATCOM also ensures smooth operation of circuit breakers during islanding detection, preventing instability when CB1 and CB2 open. Without a STATCOM, the system experiences significant voltage fluctuations, higher Total Harmonic Distortion (THD), and less efficient reactive power management, leading to potential instability and degraded power quality during disturbances.

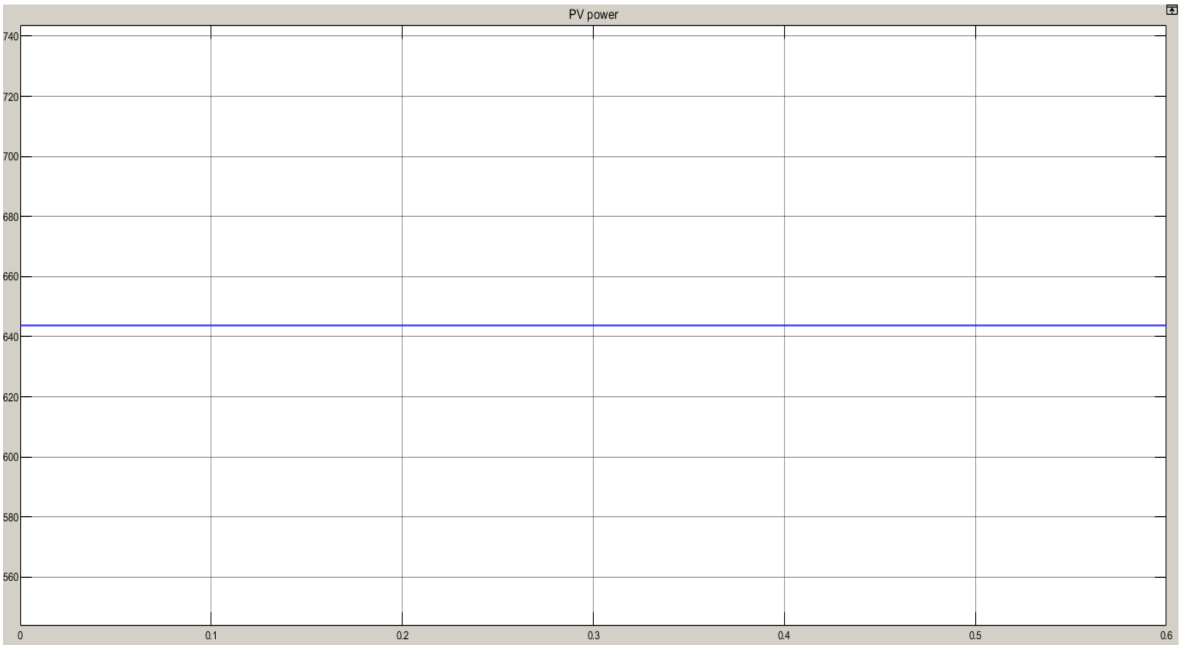

Figure 2: PV Power

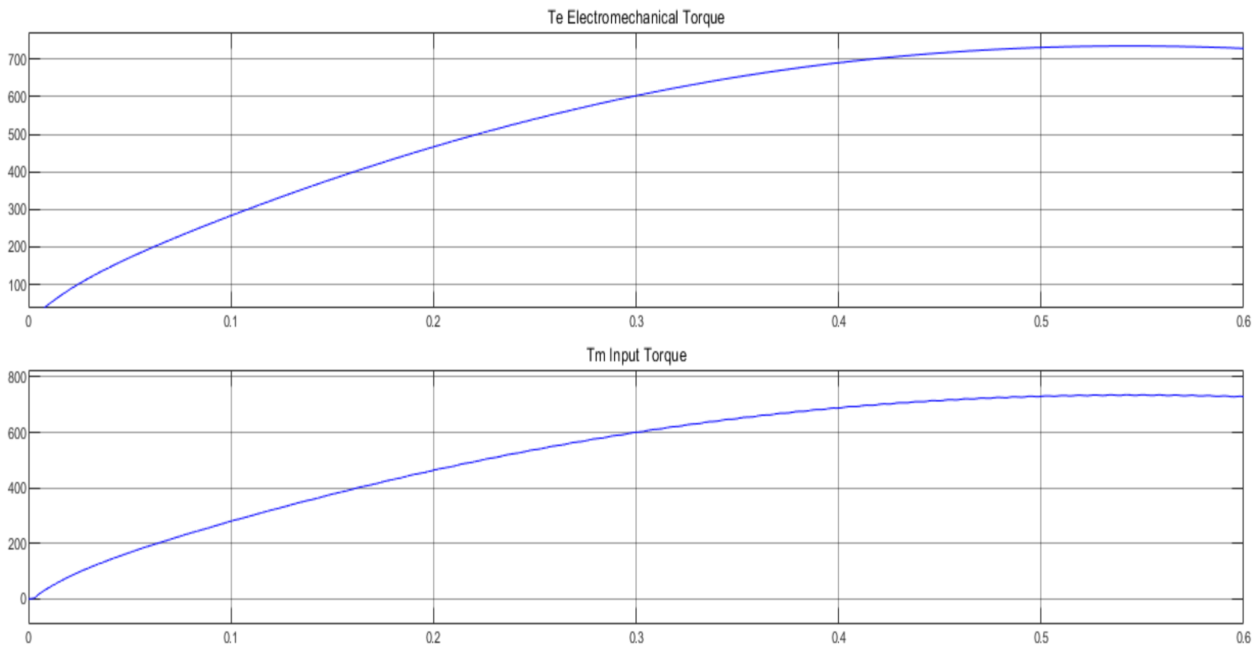

Figure 3: Electromechanical Torque (Te) and Input Torque (Tm)

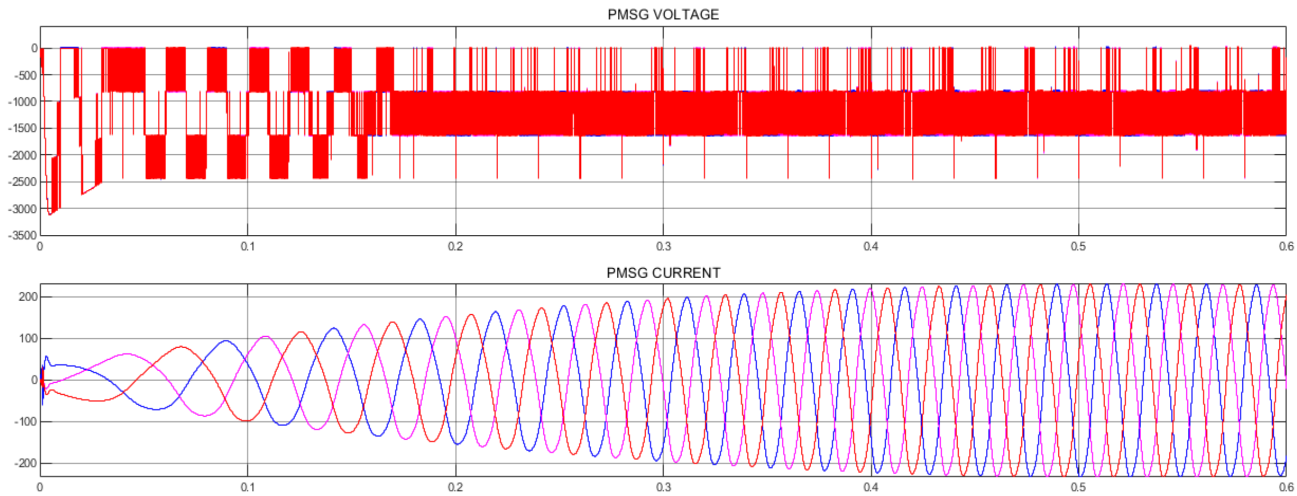

Figure 4: PMSG Current and Voltage

This figure illustrates the dynamic behavior of electromechanical torque (Te) and the mechanical input torque (Tm) in the power system. Electromechanical torque, represented by Te, is generated by the interaction of the stator magnetic field and the rotor in the generator. It reflects how electrical energy is converted into mechanical energy.

This figure 4 illustrates the current and voltage characteristics of a Permanent Magnet Synchronous Generator (PMSG) within the system

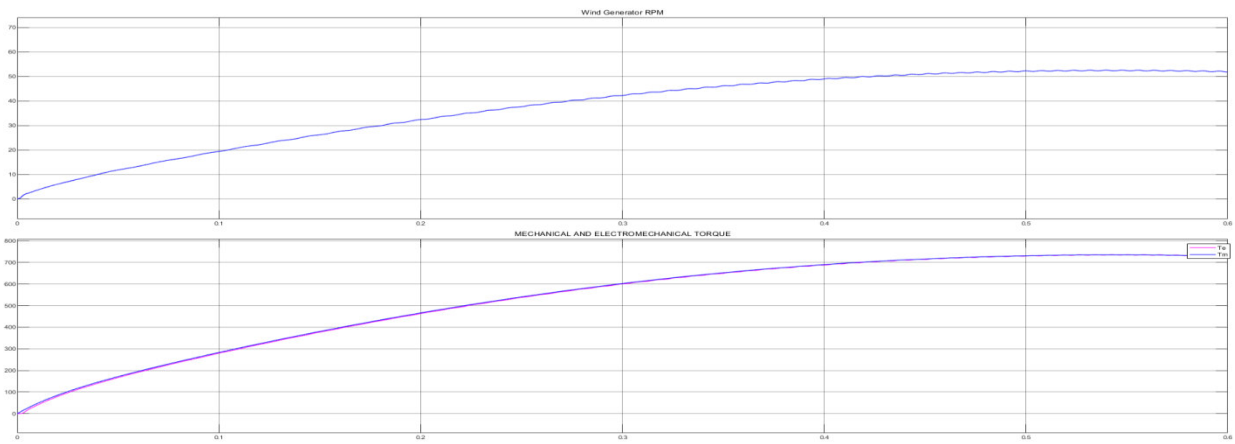

Figure 5: Wind Generation RPMand Mechanical and Electromechanically Torque

This figure 5 depicts the relationships between wind turbine generation RPM (Revolutions Per Minute), mechanical torque (Tm), and electromechanical torque (Te) within the power generation system.

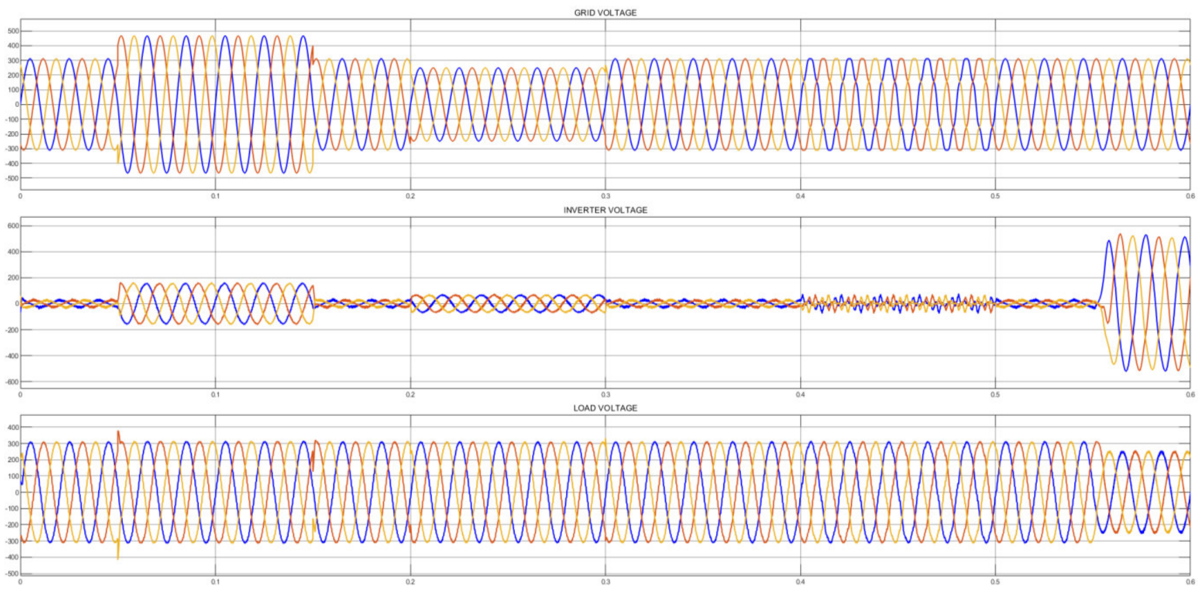

Figure 6:Grid Voltage, Inverter Voltage, Load Voltage

Analyzing Figure 6 provides insights into the interaction between the grid, inverter, and electrical load in a grid-connected renewable energy system

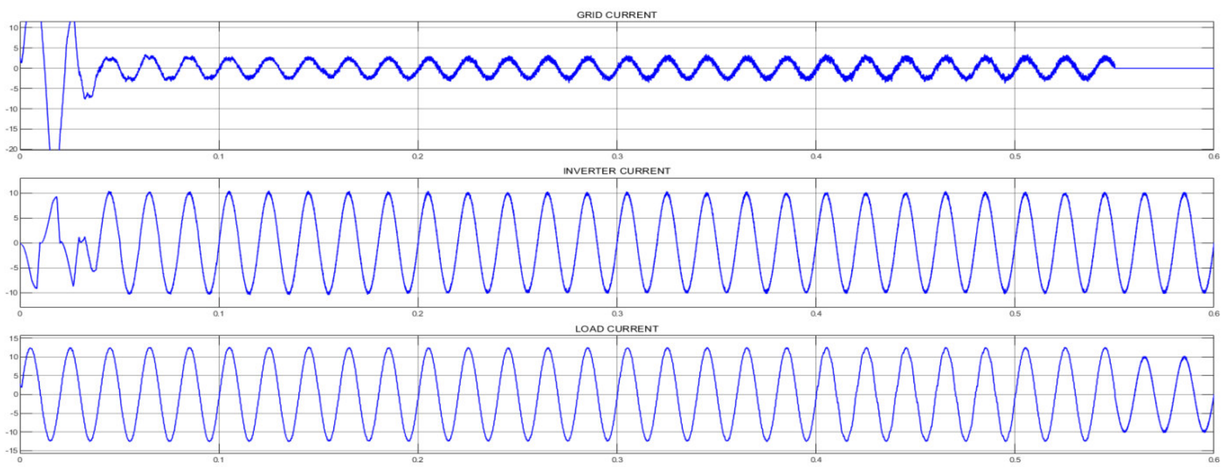

Figure7:Grid Current, Inverter current, Load Current

Figure 7 typically illustrates the current characteristics in a grid-connected power system with an inverter and electrical load. Analyzing these currents provides insights into the dynamics of power flow within the system, including how the inverter manages energy conversion and synchronization with the grid, and how load demands impact overall system operation and efficiency.

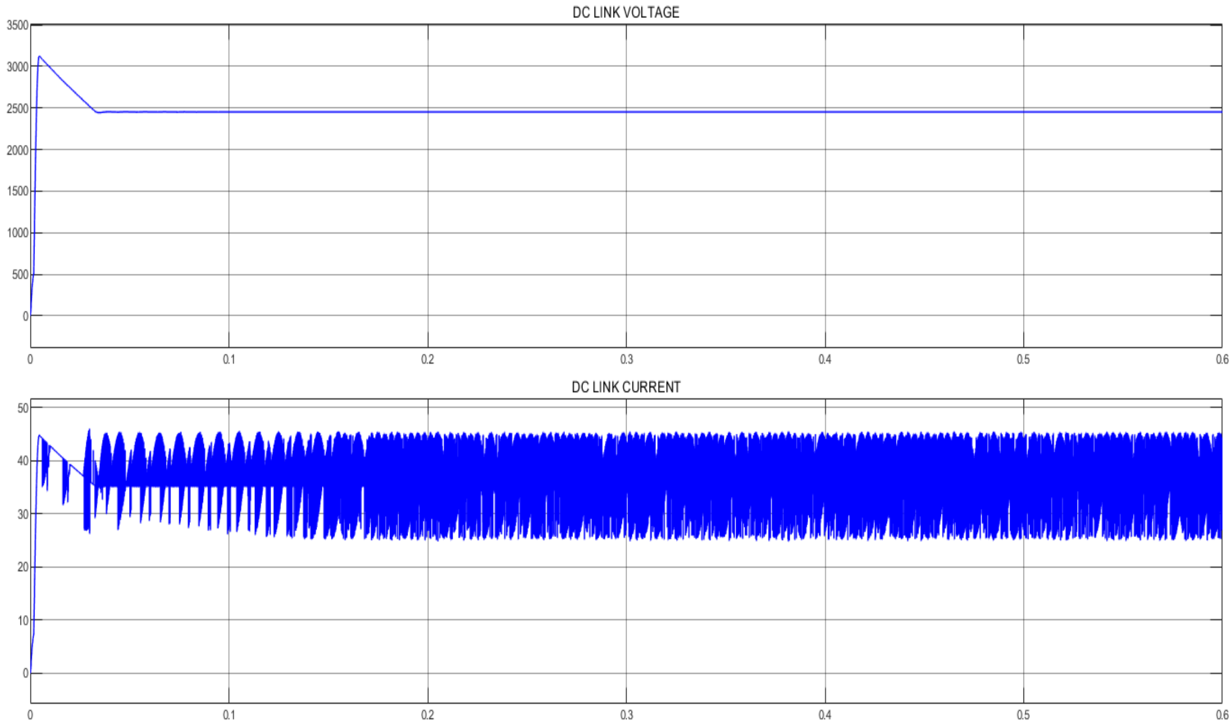

Figure8: DC Link Voltage and DC Link Current

Figure8 typically illustrates the relationship between DC link voltage and DC link current .

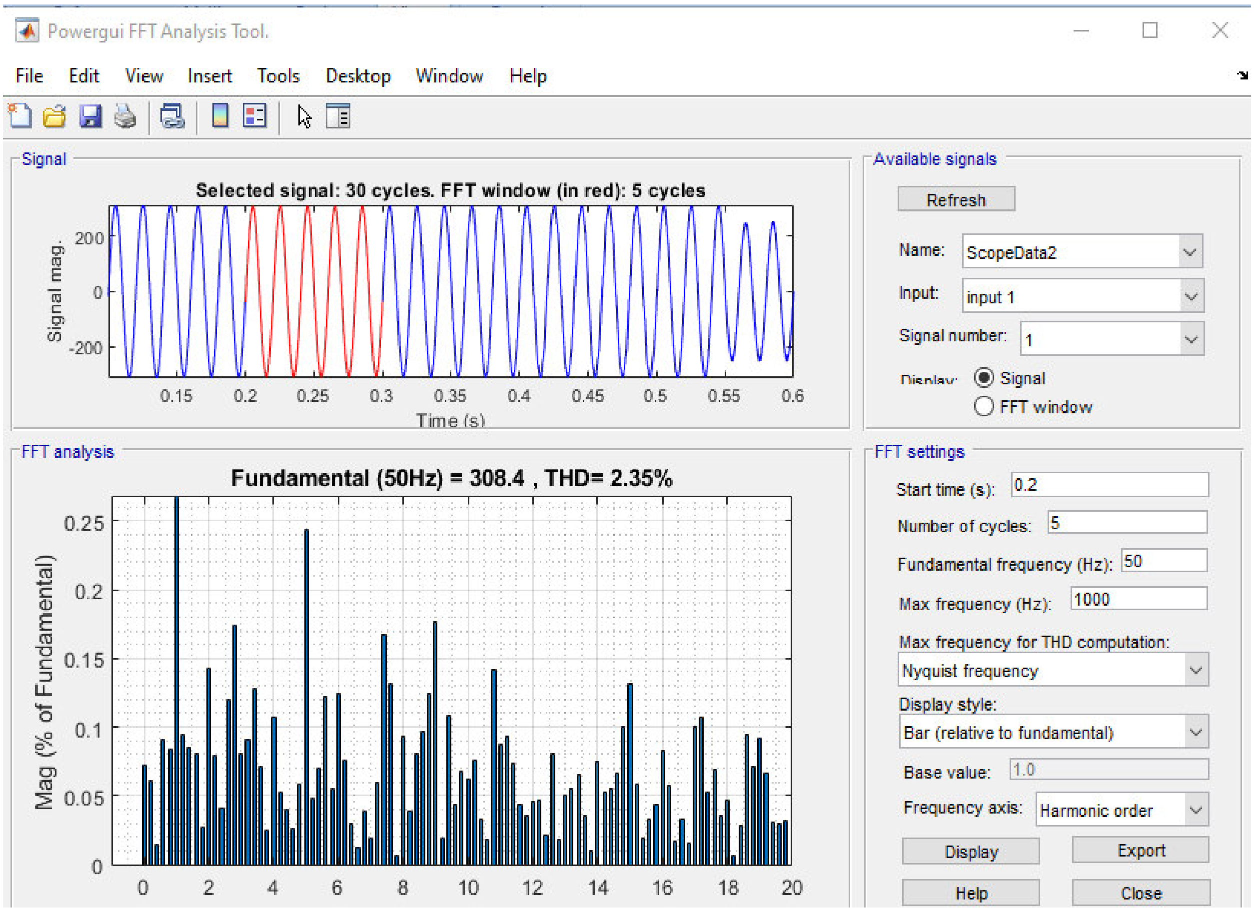

Figure9: THD with STATCOM

Figure 9 presents the Total Harmonic Distortion (THD) performance of a Simulink model, comparing the system's harmonic distortion with and without a STATCOM (Static Synchronous Compensator). The THD value without the STATCOM is 2.59%, indicating a higher level of harmonic distortion in the system's voltage or current waveforms. In contrast, the presence of a STATCOM reduces the THD to 2.35%, demonstrating its effectiveness in improving power quality by mitigating harmonic distortions. This reduction in THD signifies that the STATCOM enhances the overall performance of the electrical system by providing reactive power support and filtering out harmonics, leading to a cleaner and more stable power supply.

Conclusion

In this study, the proposed methodology focuses on enhancing power quality and system stability in renewable energy integration, particularly addressing the variability of wind power generation. Through simulation and analysis techniques, the research optimizes the filtering, rotation, and power enhancement capabilities of synchronous static amplifiers, complemented by the strategic deployment of a STATCOM device. Integrated within the MATLAB/Simulink environment, the STATCOM is configured with a PI controller to manage reactive power compensation effectively. Initial conditions such as wind speed profiles and solar irradiance are considered to simulate various operational scenarios, enabling the assessment of key metrics like voltage stability and power quality. This approach aims to improve overall power system performance while ensuring reliable electricity supply to meet customer needs.

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