Power Quality Improvement in Hybrid Power System using STATCOM

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Abstract— Meeting the escalating electricity demands posed by population growth and industrial expansion presents a significant challenge. Utilizing renewable energy sources like wind, biomass, and hydro co-generation has become imperative to satisfy energy requirements. In this proposed framework, a model featuring a grid-integrated wind energy generation system and nonlinear load is developed using MATLAB/Simulink. Integrating wind energy into the power grid impacts electricity quality, notably manifesting in voltage fluctuations, harmonics, flicker, and poor power factor at the source. The efficacy of a wind turbine and, consequently, electricity quality are assessed. To enhance power quality, the project advocates for the implementation of a STATCOM control strategy in grid-connected wind power systems. A bang-bang controller, based on hysteresis current control, is devised for STATCOM. Integrating STATCOM with the Point of Common Coupling (PCC) mitigates power quality issues. In this envisioned scheme, the FACTS device STATCOM is linked with battery power storage (BESS) at the PCC to alleviate power quality concerns. Incorporating Battery Energy Storage Systems aids in stabilizing the real power source during wind power fluctuations and facilitates the rapid injection of reactive power at the PCC.

Keywords: ***Wind energy, Solar Energy, STATCOM, Electric grid, IGBT, PWM.) etc.***

I. INTRODUCTION

In everyday observations, voltage dips emerge as a significant factor disrupting power quality attainment. These dips, lasting from 10 ms to 1 minute, occur when the root mean square voltage magnitude reduces, characterized by depth/magnitude and duration parameters. Their magnitude ranges between 10% to 90% of the nominal voltage, lasting from half a cycle to 1 minute, impacting both phase-to-ground and phase-to-phase voltages in a three-phase system. Large load current surges, such as motor startups or transformer energization, induce faults in the utility system, resulting in voltage drops across the network impedance, nearly zeroing the faulted phases at the fault location. Voltage dips, occurring frequently, lead to severe problems and economic losses, manifesting in disturbances, flicker, harmonics, etc., from end-user equipment, highlighting them as the primary power quality issues. Overhead line faults due to lightning are common culprits behind voltage dips. In cases where losses from voltage dips are considerable, suggested mitigation actions prove beneficial for customers and utilities. However, each action necessitates careful planning and evaluation, as there is no one-size-fits-all solution.

To address voltage dips, swells, and interruptions in transmission and distribution systems, a variety of advanced technologies and flexible controllers leveraging power electronics components are available for custom power applications. Among these, distribution static compensators and dynamic voltage restorers, employing the Voltage Source Converter principle, are highly effective. Power quality issues related to wind energy generation, transmission, and distribution networks, including voltage sag, swells, flicker, and harmonics, are prevalent. Integrating wind generators directly with the grid via induction generators, while introducing network disturbances, offers cost-effectiveness, robustness, and necessitates reactive power for magnetization. Fluctuations in wind speed impact active power variation, necessitating a trusted control scheme for proper control over active power production. Battery energy storage systems are essential for compensating wind turbine-generated fluctuations.

This paper proposes a STATCOM-based control technology for commercial wind turbines to enhance power quality, enabling technical management of associated power levels. The proposed STATCOM control scheme for grid-connected wind energy generation aims for unity power factor at the source side, STATCOM-exclusive reactive power support to wind generators and loads, and a simple bang-bang controller for STATCOM to achieve fast dynamic response. Modern wind turbine systems employ pulse-controlled inverters, enhancing switching techniques to ensure sinusoidal voltage and current at the point of common connection, thereby improving power quality at PCC.

II. LITERATURE SURVEY

- *Mallikarjuna Golla et. al. 2020,* These papers delve into enhancing grid power quality through the integration of wind energy systems with Flexible Alternating Current Transmission Systems (FACTS) devices. Renewable energy sources, such as wind energy, often exhibit fluctuations due to environmental conditions, impacting power quality when connected to the electric grid. The performance of wind turbines and, consequently, power quality are evaluated based on measurements and compliance with guidelines outlined in the IEC-61400 standard by the International Electro-technical Commission (IEC). Key power quality metrics include active and reactive power, voltage sag, voltage swell, flickers, harmonics, and the electrical behavior of switching operations. To address these issues, the proposed scheme involves connecting a Static Synchronous Compensator (STATCOM) to a Point Of Common Coupling (PCC) alongside a battery energy storage system (BESS). Simulation of this scheme is conducted using MATLAB/SIMULINK within the Sim Power System block set.

- *R.S. Dhekekar et al. 2019*, This paper focuses on the real-time simulation and implementation of a PI controlled Voltage Source Converter (VSC) Static Synchronous Compensator (STATCOM) for a 750 km laboratory model of an artificial transmission line. The study investigates the effectiveness of PI controller and neural network control schemes. Through MATLAB simulation and actual testing, it is demonstrated that upon installation, these devices maintain the bus voltage at the reference voltage (sending-end voltage). The results obtained are significant and pave the way for the real-time implementation of the proposed control schemes. Moreover, the paper discusses the relative harmonic analysis for both schemes, further highlighting the feasibility of real-time implementation.

- *Jarupula Somlal, et. al. 2021*, This paper delves into the application of an Artificial Neural Network (ANN) controller-based Shunt Hybrid Active Power Filter (SHAPF) aimed at mitigating harmonics in the distribution system. To enhance the performance of the conventional Hysteresis controller and harness the benefits of intelligent controllers, a backpropagation algorithm-based feedforward-type ANN technique is integrated into the shunt active power filter to generate the controlled pulses required for the IGBT inverter. The proposed approach primarily relies on the energy stored by capacitors to stabilize the DC link voltage of a shunt connected filter, thereby reducing the transient response time during abrupt load variations. A comprehensive model of the proposed filter technique is developed in MATLAB to simulate the entire power system setup. The control algorithm devised is straightforward. Simulations conducted using MATLAB reveal a significant reduction in Total Harmonic Distortion (%THD) from 29.71% to 2.27% with the implementation of the ANN-controlled filter. The simulated experimental results demonstrate that the novel control method is not only computationally and practically feasible but also highly effective in harmonics reduction.

- *Sharad W. Mohod, et.al. 2020,* The paper investigates power quality issues arising from the installation of wind turbines connected to the grid. In the proposed solution, a Static Compensator (STATCOM) is linked to a point of common coupling along with a battery energy storage system (BESS) to address these power quality concerns. The integration of battery energy storage enables the stabilization of the real power source amidst fluctuations in wind power. Utilizing MATLAB/SIMULINK in the power system block set, the STATCOM control scheme for grid-connected wind energy generation systems is simulated. The efficacy of this approach alleviates the reactive power demand from the load and the induction generator, thereby easing the burden on the main supply source. Furthermore, the paper outlines the development of grid coordination rules and schemes aimed at enhancing power quality standards in line with the IEC-standard on the grid.

- *Priya Tare et. al. 2022*, This project introduces a STATCOM control scheme designed to enhance power quality in grid-connected wind energy systems. A bang-bang controller, employing a hysteresis current control scheme, is developed for the STATCOM. The STATCOM is integrated at the point of common coupling (PCC) to address power quality issues. Using MATLAB/SIMULINK in the power system block set, the proposed STATCOM control scheme for grid-connected wind energy generation systems is simulated. This scheme is designed to improve the power quality of the generated output.

- *Chi-Seng Lam* et. al. 2018, This paper presents a novel concept termed hybrid static synchronous compensator (hybrid-STATCOM) designed for use in three-phase power transmission systems. It offers a broad compensation range and operates at a low DC-link voltage, leading to significant cost reductions. The paper begins by outlining the circuit configuration of the hybrid-STATCOM, followed by an analysis and comparison of its V-I characteristic with those of traditional STATCOM and capacitive-coupled STATCOM (C-STATCOM). The design of system parameters is then discussed, considering the range of reactive power compensation and the prevention of potential resonance issues. Subsequently, a control strategy tailored for the hybrid-STATCOM is proposed, enabling operation under diverse voltage and current conditions, including unbalanced currents, voltage dips, and voltage faults. Finally, simulation and experimental outcomes are presented to validate the broad compensation range, low DC-link voltage characteristics, and excellent dynamic performance of the hybrid-STATCOM.

III. EXISTING SYSTEM

Using MATLAB/SIMULINK in the power system block set, the STATCOM control scheme is simulated to enhance power quality through the implementation of a PI controller. This approach aims to alleviate the burden on the primary power supply source and fulfill the reactive power requirements of the induction generator, thus contributing to improved power quality in the grid-connected wind energy generation system.

IV. PROPOSED SYSTEM

The STATCOM operates by injecting current at a common coupling point, effectively compensating for both harmonic and reactive components present in the load and induction generator currents. This process ensures that the source current is devoid of harmonics and aligned with the source voltage, thus enhancing power factor and overall power quality. To achieve these objectives, the grid voltages at the point of common coupling are monitored and synchronized to generate a reference current for the inverter. The proposed integrated grid system is implemented in MATLAB/SIMULINK to enhance power quality at the point of common coupling (PCC), as illustrated in Fig. 1. The grid-connected system depicted in Fig. 1 comprises a wind power generation system and a battery power storage system equipped with STATCOM.

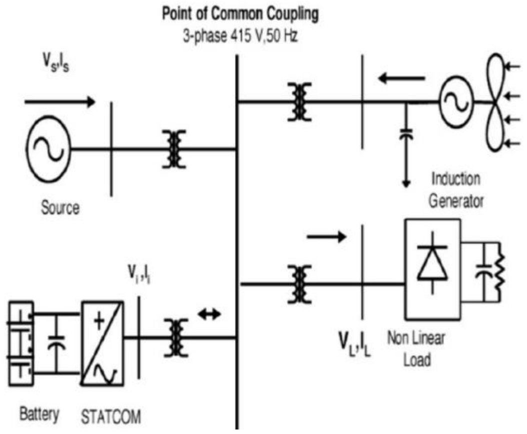

Fig.1: Grid-connected system for power quality improvement

A. Wind Energy Generating System

Wind generation relies on steady-state speed topologies with pitch-controlled turbines. The induction generator is favored for its modular circuit design, offering simplicity and eliminating the need for a separate field circuit. It can accommodate both constant and variable loads while providing inherent protection against short circuits. The current capacity of the wind energy system is illustrated in the provided data (1).

$$P_{wind} = \frac{1}{2}\rho A V_{wind}^3 \quad ....(1)$$

The air density, denoted as ρ (in kg/m^3), and A represents the area swept out by the turbine blade in meters. VWIND represents the wind speed in m/s. It's important to note that it's impossible to extract all the kinetic energy from the wind, so only a fraction of the wind's energy is consumed. This fraction is known as the power coefficient (CP) for the wind turbine and is typically denoted as CP (2).

$$P_{mech} = C_p P_{wind} \quad (2)$$

CP, representing the power coefficient, depends on the type and operating conditions of the wind turbine. It can be expressed as a function of the tip speed ratio and pitch angle. The mechanical power produced by the wind turbine is given by equation (3).

$$P_{mech} = \frac{1}{2}\rho \Pi R^2 V_{wind}^3 C_P \quad ... (3)$$

Where R is the radius of the blade (m).

B. BESS-STATCOM

The STATCOM is a three-phase voltage source inverter with a capacitor at the DC link, connected at a point of common coupling. It injects a controlled amount of compensating current at this point. Maintaining the DC link capacitor voltage constant is crucial for ensuring rapid injection or absorption of inverter current. To achieve this, a Battery Energy Storage System (BESS) is installed at the point of common coupling alongside the STATCOM. The BESS helps to stabilize the DC link capacitor voltage, enabling the STATCOM to effectively inject or absorb reactive power at the point of common coupling. Additionally, in the event of any power fluctuations in the system, the BESS facilitates the exchange of real power at the point of common coupling.

C. System Operation

The power network model of the proposed grid-connected system is illustrated in Figure 2. This system comprises a wind energy generation system and a battery energy storage system (BESS) with a STATCOM. The BESS serves as an energy storage element for voltage regulation purposes. By maintaining the DC capacitor voltage constant, the BESS is well-suited for the STATCOM, enabling rapid injection or absorption of reactive power to stabilize the grid system. Moreover, the BESS can mitigate power variations through charging and discharging operations. It is connected in parallel with the DC-link capacitor of the STATCOM.

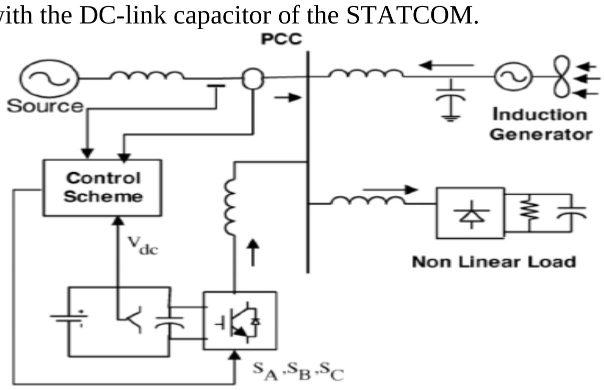

Fig.2: System operational scheme in grid system

The STATCOM, a three-phase voltage source inverter with a capacitance at its DC-link connection, is linked to the point of common coupling. It injects current with variable magnitude and frequency components at the common coupling bus. The shunt-connected STATCOM, along with the battery energy storage system, nonlinear load, and induction generator, is collectively connected at the point of common coupling in the grid system. The output of the STATCOM adjusts based on the control strategy to uphold power quality standards in the grid system. The current control methodology is an integral part of the control scheme, defining the role of the STATCOM in the power system. Utilizing an Insulated Gate Bipolar Transistor (IGBT) within the STATCOM enables the provision of reactive power support to the generator and nonlinear load on the grid system.

V. SIMULATIONS AND RESULTS

The proposed operation and control scheme is simulated in the power system block set using Simulink,

- ***Simulations And Results Grid With STATCOM***

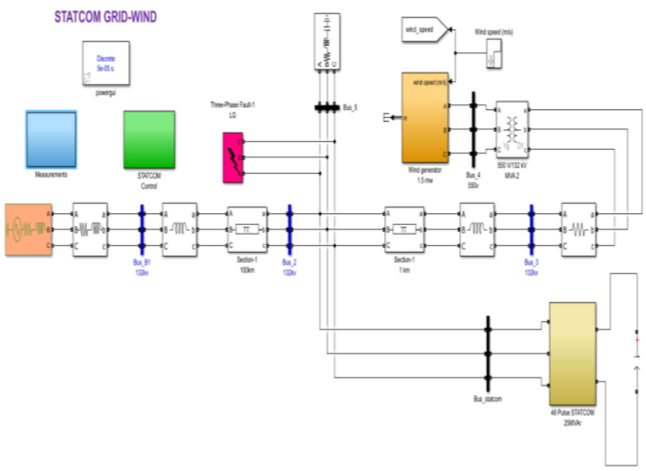

Fig. 3. SIMULINK model of the proposed scheme with STATCOM

In above simulation design, we have connected Three-Phase AC source with 100km grid line and Wind Generator with 1km grid line and RLC Load with fault for simulating disturbance at the end with STATCOM have 4 transformers and 8 universal bridge to simulate inverter operation for grid compensation. We have used STATCOM controller to control the STATCOM operation for injecting compensation power to the grid at specific time interval whenever occurred. To show the difference we have compared two conditions, Without STATCOM grid and With STATCOM grid. Both results can be compared through the scopes.

Voltage Source Current Control—Inverter Operation

The three-phase injected current from STATCOM into the grid eliminates the non-linear load and distortion generated by the wind generator. The IGBT-based three-phase inverter is connected to the grid via a transformer. The generation of signals switching from the reference current is simulated in the hysteresis band of 0.08. The narrow hysteresis band switching option in the system improves the current quality. Control signal of the switching frequency in its operating band 0.08 as shown in Fig.

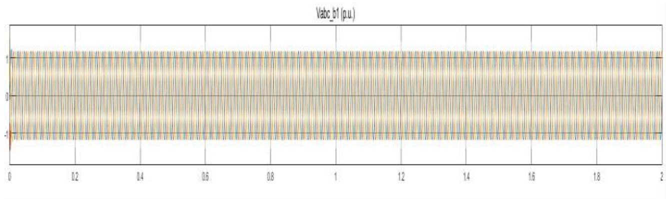

Figure 1 Three Phase AC-Source-Voltage in (p.u) with STATCOM

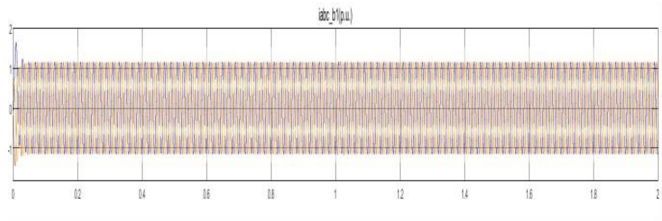

Figure 2 Three Phase AC-Source-Current in (p.u) with Statcom

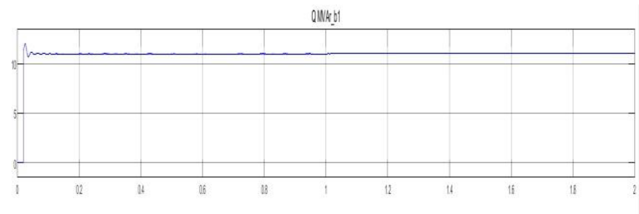

Figure 3 Three Phase AC-Source-Power in Reactive Power (Quality) in mega volt (MV) with Statcom

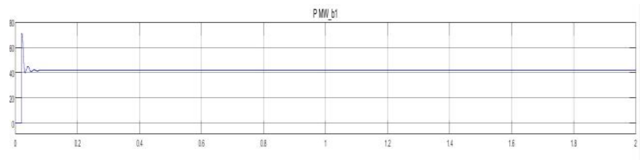

Figure 4 Three Phase AC-Source-Power in Mega Watt (MW) with Statcom

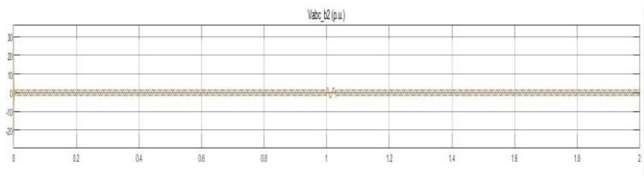

Figure 5 Three Phase AC-Line-Voltage (Vabc) in (p.u)

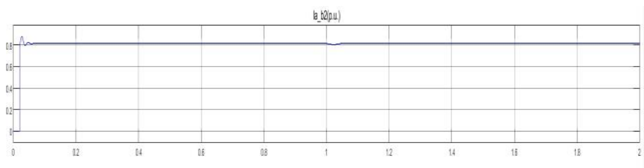

Figure 6 Three Phase AC-Line-A Current (Ia) in (p.u) with STATCOM

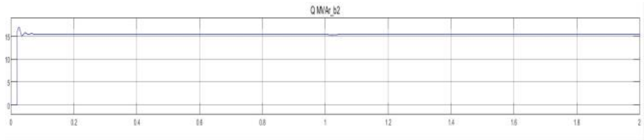

Figure 7 Three Phase AC-Line-Power in Reactive Power (Quality) in mega volt (MV)

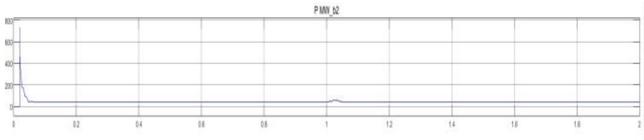

Figure 8 Three Phase AC-Source-Power in Mega Watt (MW)

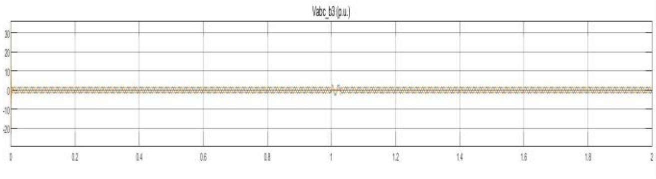

Figure 9 Wind Generator Ac grid line Voltage in (P.u) with STATCOM

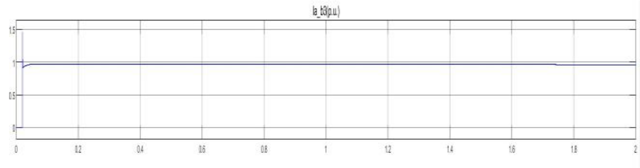

Figure 10 Wind Generator Ac grid line Current in (P.u) with Statcom

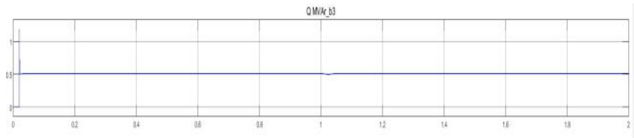

Figure 11 Wind Generator Grid Line-Power in Reactive Power (Quality) in mega volt (MV)

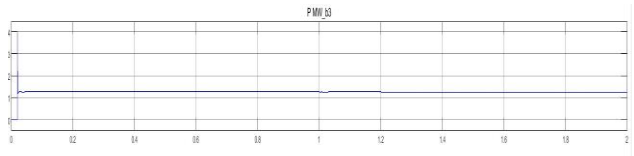

Figure 12 Wind Generator AC grid line-Power in Mega Watt (MW) with Statcom

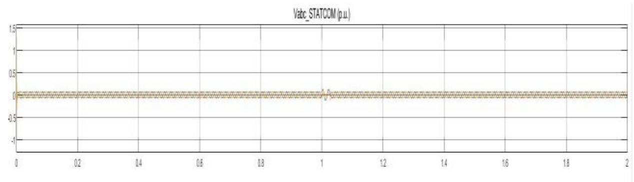

Figure 13 Statcom Connected Grid Line Voltage in p.u

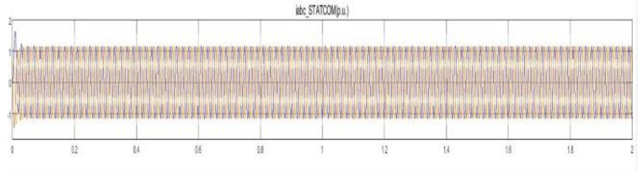

Figure 14 Statcom Connected Grid three phase Line Current in p.u

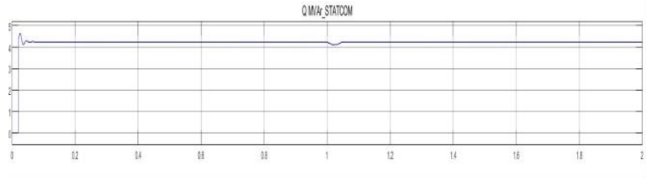

Figure 15 Statcom Connected Grid-Power in Reactive Power (Quality) in mega volt (MV)

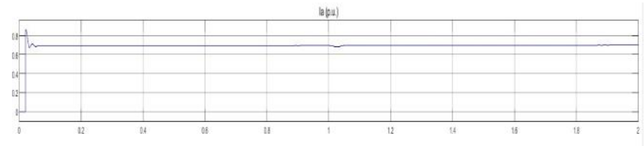

Figure 16 Wind Generator Source Output After STATCOM compensation Current in p.u

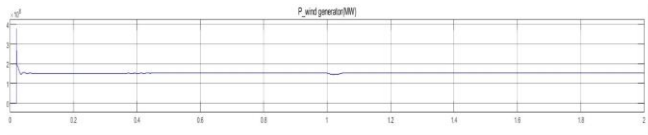

Figure 17 Wind Generator Sorce Output After STATCOM compensation Power in MW

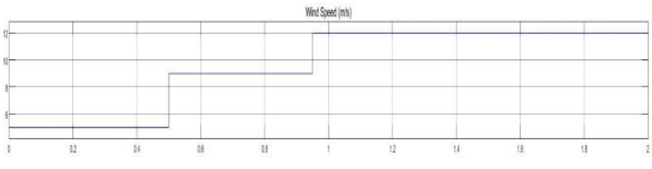

Figure 18 Wind Generator Source Output After STATCOM Wind Speed in m/s

From above figures we can analyze the result of the grid and wind generator with load, disturbance occurred due to fault at the load end get removed with compensation by STATCOM by successful injection. Power quality throughout the sources and grid line has been improved resulted in stable power flow.

- ***Simulations And Results Grid Without STATCOM***

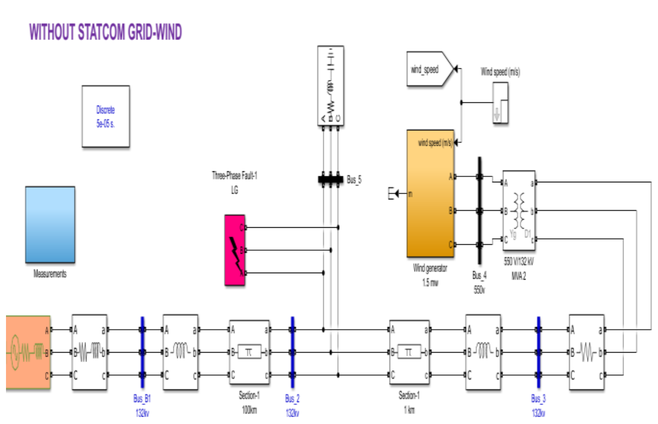

Figure 19 SIMULINK model of the proposed scheme without STATCOM

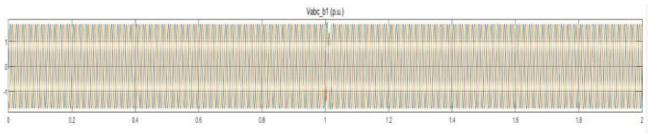

Figure 20 Three Phase AC-Source-Voltage in (p.u) without STATCOM

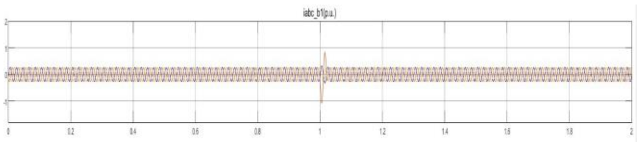

Figure 21 Three Phase AC-Source-Current in (p.u) without STATCOM

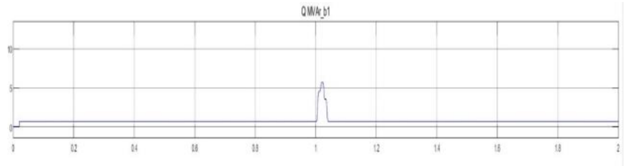

Figure 22 Three Phase AC-Source-Power in Reactive Power (Quality) in mega volt (MV) without STATCOM

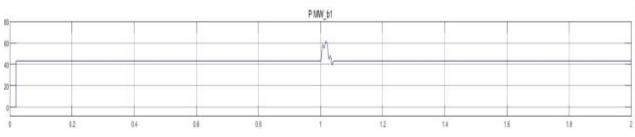

Figure 23 Three Phase AC-Source-Power in Mega Watt (MW) without STATCOM

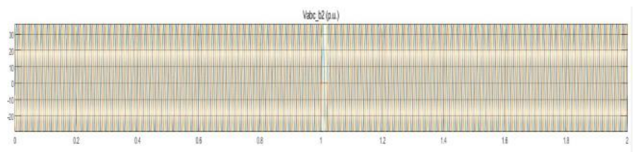

Figure 24 Three Phase AC-Line-Voltage (Vabc) in (p.u) without STATCOM

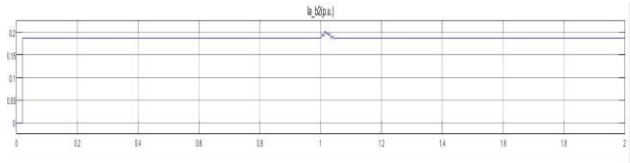

Figure 25 Three Phase AC-Line-A Current (Ia) in (p.u) without STATCOM

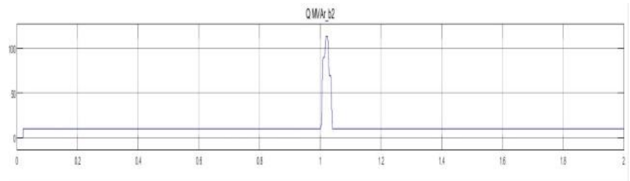

Figure 26 Three Phase AC-Line-Power in Reactive Power (Quality) in mega volt (MV) without STATCOM

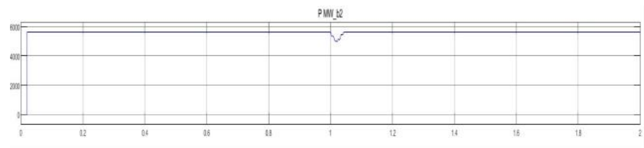

Figure 27 Three Phase AC-Source-Power in Mega Watt (MW) without STATCOM

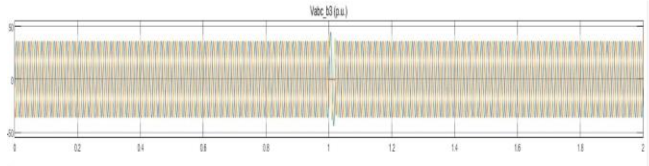

Figure 28 Wind Generator Ac grid line Voltage in (P.u) with STATCOM

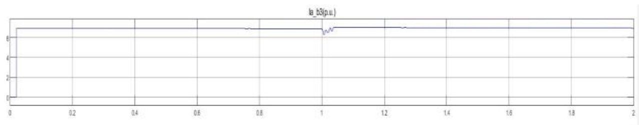

Figure 29 Wind Generator Ac grid line Current in (P.u) without STATCOM

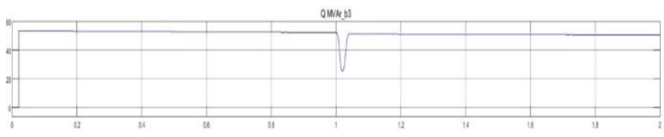

Figure 30 Wind Generator Grid Line-Power in Reactive Power (Quality) in mega volt (MV)

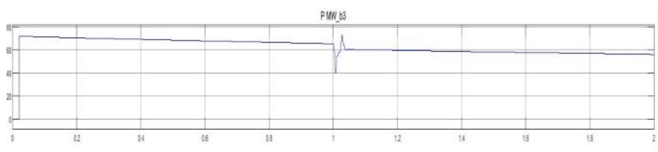

Figure 31 Wind Generator AC grid line-Power in Mega Watt (MW) without STATCOM

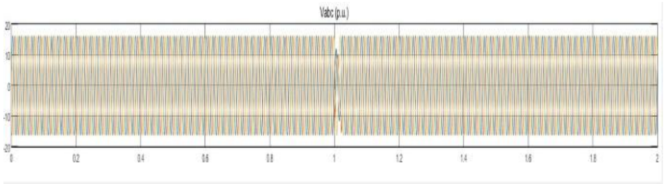

Figure 32 Wind Generator Source Output Voltage in p.u without STATCOM

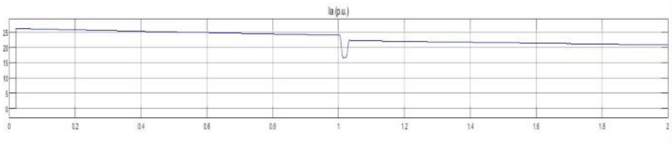

Figure 33 Wind Generator Source Output Current in p.u without STATCOM

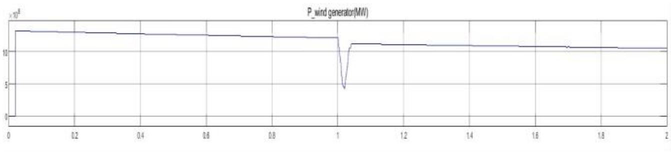

Figure 34 Wind Generator Source Output Power in MW without STATCOM

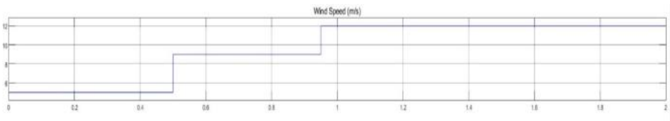

Figure 35 Wind Generator Source Output Wind Speed in m/s without STATCOM

We can compared the results from both the models that in grid without STATCOM has the disturbances at every end of the sources and load flow after connecting renewable source and three phase AC grid. But in the results of model with STATCOM, we are able to conclude that the STATCOM could remove the disturbances and improve the power quality throuout the grid from the Three Phase AC Grid to the Wind Generator and load. STATCOM can be used as one of the best performing FACT devices in the high voltage grid supply.

VI. CONCLUSION

The operation of control system developed for STATCOM-BESS on MATLAB / SIMULINK to protect power quality. It has the ability to cancel the harmonic components of the load flow. It maintains the source voltage and current phase and supports the reactive power demand for the wind generator and load on the PC in the grid system, thus giving it the opportunity to increase the transmission line consumption factor. Integrated Wind Generation with BESS and STATCOM showed excellent performance. Therefore, the proposed scheme in the grid-connection system satisfies the power quality.

The implementation of STATCOM technology in hybrid power systems represents a significant advancement in power quality improvement and grid stability. Through the integration of renewable energy sources such as solar and wind, hybrid power systems offer sustainable solutions for meeting the growing energy demands while reducing reliance on fossil fuels.

The use of STATCOM devices plays a crucial role in mitigating power quality issues such as voltage fluctuations, harmonics, and reactive power imbalance. By dynamically controlling voltage and reactive power levels, STATCOMs ensure smooth and stable operation of the grid, thereby enhancing system reliability and efficiency.

Furthermore, the flexibility and scalability of STATCOM technology allow for seamless integration into existing power infrastructure, making it suitable for a wide range of applications, from distribution networks to large-scale industrial facilities. The ability to respond rapidly to changing grid conditions and maintain optimal power quality levels makes STATCOMs an indispensable tool in modern power systems.

Overall, the implementation of STATCOMs in hybrid power systems not only improves power quality but also contributes to the transition towards a more sustainable and resilient energy infrastructure. Continued research and development in this field will further enhance the performance and effectiveness of STATCOM technology, paving the way for a cleaner, more reliable, and efficient energy future.

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