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Empowering Renewable Energy Systems: Enhancing Power Quality with Custom Power Devices

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Abstract — Recently, renewable energy sources have become more popular in the energy industry. These renewable energy sources should perform reliable operation, providing clean energy to the grid with minimal total harmonic distortion (THD). The paper contributes to the analysis of power quality parameters with and without the use of Custom Power Devices. The proposed analysis was performed for a hybrid system installed in an educational institution. An enhanced power quality strategy for a grid-connected wind farm system based on STATCOM. MATLAB was implemented to execute the simulation.

A Simulink model of a modified STATCOM as a shunt active filter is also presented to investigate and improvise system performance. In order to improve grid performance and deal with power quality concerns, the compensator has been designed to enable reactive power. The findings revealed a significant reduction in the current THD.

Keywords— Active power filter, Power Quality (PQ), Custom Power Devices (CPD) , Renewable Energ Systems(RES),Total Harmonic Distortion (THD)

I. INTRODUCTION

Pollution, global warming and greenhouse gas emissions from conventional energy sources, and environmental degradation due to increased industrial activity worldwide pose a challenge to clean, reliable, and natural conventional energy sources. The use of renewable energy sources (RES) to generate electricity is emphasized, and technological advancements are required to ensure optimal use of these energy sources, achieve higher efficiency, and reduce emissions.

The increasing integration of renewable energy into the grid raises concerns about power quality (PQ) in high voltage power transmission systems. Power electronics converters play a crucial role in integrating renewable energy systems into the grid but can also contribute to harmonic pollution and significant PQ issues if not implemented correctly As a consequence, evaluating a renewable system's performance in context with power quality analysis is crucial.

Recent advancements in interconnection equipment between distribution power systems and consumer appliances include the use of specialized power devices (CPDs) such as STATCOMs, DVRs, and combinations of series and shunt active power filters to mitigate reactive power and harmonic issues.

The voltage source converter (VSI) in the claimed compensator is composed of by proficient power semiconductor switches which provide adaptable voltage control for enhanced power quality. Applications in which load and power flow differ frequently are more appropriate for this method. The high-speed switching converter will generate an uninterrupted current with minimal harmonic content through high-frequency PWM switching. The article presents the modeling of an induction generator using MATLAB.

II. GRID-CONNECTED RENEWABLE ENERGY SYSTEMS

Power providers prioritize the integration of safety and quality components into your system. These components encompass switches designed to disconnect your system from the grid during power surges or blackouts, thus mitigating risks of electrocution for repair personnel. Additionally, power conditioning equipment is employed to align your output precisely with the voltage and frequency of the electricity circulating through the grid.

With a grid-connected system, you are able to utilize renewable energy to power your residence or small business wherever the sun shines, the water flows, or the wind blows both on a daily and seasonal basis. Any surplus electricity produced is seamlessly integrated back into the grid.

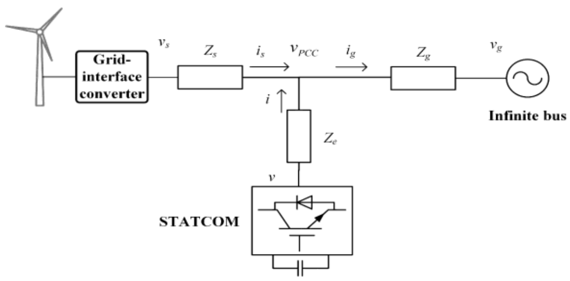


Fig. 1 Wind to Grid connection with STATCOM

III. POWER QUALITY MITIGATION TECHNIQUES:

There are various solutions to reduce power quality. The solution adopted will be principal and site specific.

The measures used in this paper to deal with power quality disturbances are,

1) Static VAR Compensator (SVC).
2) Static Synchronous Compensator (STATCOM).
3) Harmonic filters.
4) Increase arresters.

A widely employed method for managing harmonic distortion involves installing a passive shunt harmonic filter in proximity to the harmonic load carrier, which serves as the source of harmonic current. The key objective of the harmonic filter is to minimize the total amount of harmonic current that encounters the power system by transferring it through the filter and so minimizing the influence of harmonic current on the electrical load.

Filter is the inductance/capacitance (LC) configuration.

A. LC filter modeling to enhance Power Quality

In order to ensure that harmonic currents circulate between the load and the filters instead of flowing towards the power source and other elements in the power generation and distribution systems, harmonic filters are designed with low impedances.

Harmonic filters, often called "side" filters, are usually installed in parallel with the power system. They work by offering low-impedance paths to ground for currents linked to specific harmonic frequencies. In power applications, shunt filters are generally more economical compared to series filters.

Power harmonic filters are primarily employed to either obstruct the flow of harmonic currents within electrical power distribution systems or to isolate and eliminate them locally. These filters can be categorized into three main classifications.

(1) Passive,
(2) Active and
(3) Hybrid.

Passive filters are comprised of reactive elements, including capacitors, inductors, and resistors. These components are precisely tuned to provide a pathway of low impedance for specific currents linked to undesired harmonic frequencies.

Active filters utilize active power conditioning electronic devices to mitigate unfavourable harmonic currents but typically incur higher installation costs compared to passive filters. Hybrid filters, on the other hand, blend active and passive filter components, strategically employed in specialized applications to leverage the benefits of both filter types. An LC filter, a second-order passive filter, comprises two reactive components—an inductor and a capacitor. When properly designed, an LC filter diminishes the total harmonic distortion within the system while simultaneously enhancing its power factor.

IV. Results and Discussions

A. Analysis of Power Quality Parameters:

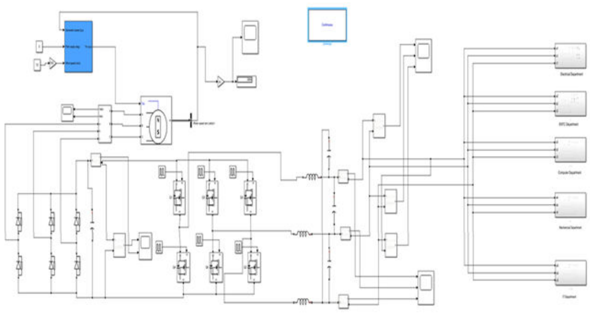


Fig:2: Simulink Model of Wind Generation System with Filter.

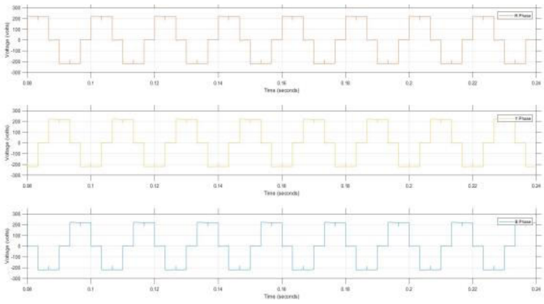


Fig:3: Three-phase Inverter Output Voltage Waveform without Filter.

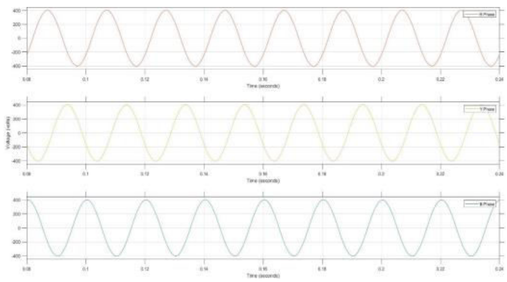


Fig: 4: Three-phase Inverter Output Voltage Waveform with Filter.

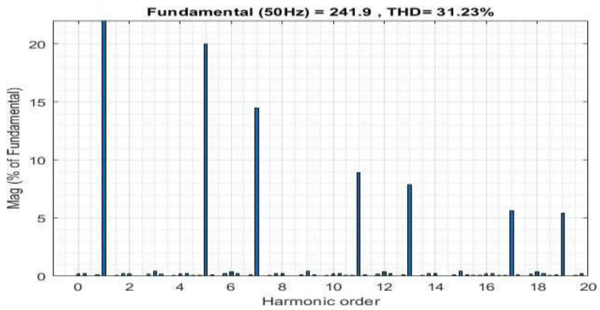


Fig: 5: Total Harmonic Distortion without Filter

Figure 2 depicts a Simulink model of a wind generation system integrated with a filter. The simulation outcomes are contrasted between scenarios with and without an LC filter. Figures 3 and 5 exhibit the system's response when the LC filter is not employed, while Figures 4 and 6 showcase the system's response with the LC filter implemented. In the absence of the LC filter, the waveform exhibits a non-sinusoidal, two-step response, contributing to a total harmonic distortion of 31.23%.After applying the LC filter, the observed response is a pure sine wave with harmonic reduction (THD) from 31.23% to 5.94%. It is also worth noting that the passive filter circuit filters only one harmonic.

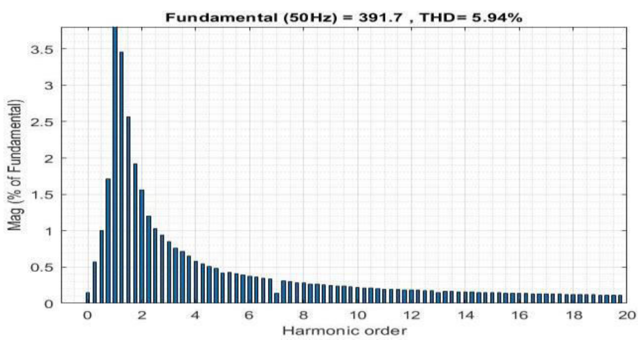


Fig: 6: Total Harmonic Distortion with Filter

There should be a separate filter for each settlement that needs to be filtered. Passive filters may have multiple switching steps for multiple frequencies. Passive filters may exhibit multiple steps targeting specific frequencies, often determined by the tuning frequency, capacitance, and network impedance, all of which influence the filter's effectiveness. Each harmonic necessitates a step to align with its desired frequency. Negative filters, however, lack the flexibility to adjust the filter level frequency in accordance with the current relationship, making them unsuitable for high-frequency filtering. Moreover, negative filtering can extend beyond the 3rd harmonic up to the 25th and beyond. Each filter must incorporate steps to counteract all potential lows, such as higher harmonics. Tuned passive filters are frequently utilized for this purpose, especially in commercial networks, where they are commonly tuned to harmonics of order ν = 5, 7, 11, 13, and so forth

B. *Design and development of STATCOM to improve Power Quality*

A STATCOM is a controlled reactive power source. Electronic processing of the voltage and current waveforms in the voltage source converter (VSC) provides all the necessary reactive power generation and absorption. A single-wire STATCOM power supply circuit is shown in Figure 3.6(a). Here the VSC is connected to the bus via magnetic coupling.

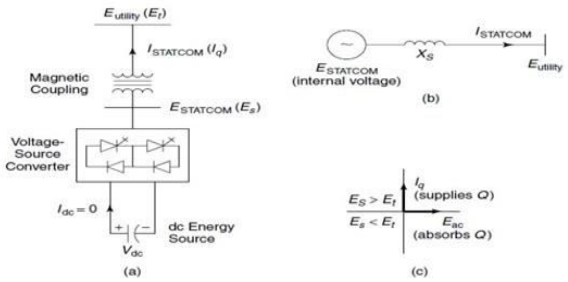


Fig: 7(a),(b),(c) STATCOM Power circuit, Equivalent circuit, Power exchange respectively

In Figure 3.6(b), the STATCOM is conceptualized as an adaptable voltage source positioned behind the reactance. This configuration eliminates the need for capacitor banks and shunt reactors for reactive power management, resulting in a compact design with minimal noise and magnetic interference. The exchange of reactive power between the converter and the AC system is controlled by adjusting the amplitude of the 3-phase output voltage. Fig. 7(a), (b), and (c) depict the STATCOM power circuit, equivalent circuit, and power exchange, respectively.

When the output voltage's magnitude exceeds the utility bus voltage (Et), current flows through the circuit from the converter to the AC system, generating capacitive-reactive power for the AC system. Conversely, if the output voltage amplitude falls below the utility bus voltage, current flows from the AC system to the converter, leading to the absorption of inductive-reactive power from the AC system by the converter.

C. *Case Study of An Educational System*

A case study of an Educational Institute with 25 KV/400V, 4 MVA distribution system is considered to analyse the impact of power quality parameters. Simulation with MATLAB Simulink has been presented here.

A STATCOM serves as a managed reactive-power source, achieving the desired reactive-power generation and absorption solely through electronic manipulation of voltage and current waveforms within a voltage-source converter (VSC).

TABLE I SYSTEM PARAMETERS

Sr. No.	Parameters	Values
1	Voltage of the transmission line	25KV
2	Rating of the transformer	25 kV / 400 V, 4 MVA
3	Fundamental frequency	50 Hz
4	Voltage	400V

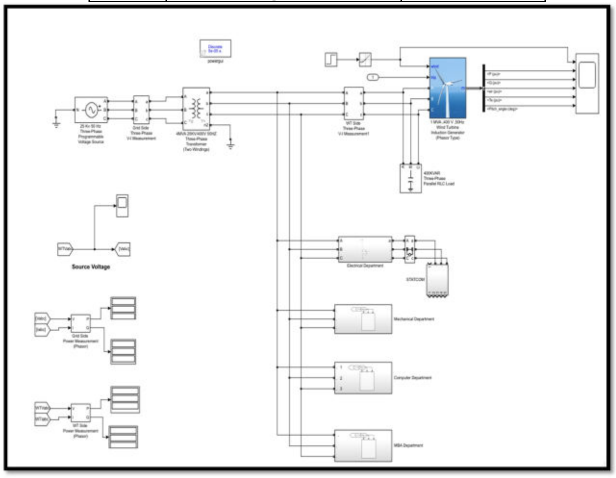


Fig.8 Simulation model of case study

Fig 8. depicts the simulation model of the case study, while Fig 9. showcases the three-phase voltage and current output of the inverter. Upon observing the inverter output voltage and current, it's evident that they do not exhibit a pure sinusoidal waveform but rather a non-sinusoidal waveform containing harmonics. This discrepancy is attributed to the power quality issue known as harmonic distortion. The system includes the connection of STATCOM and an LC filter, where the inductor is in series and the capacitor is in parallel. Fig.10 illustrates that the three-phase voltage and current outputs of the inverter transform into sinusoidal waveforms. This indicates a reduction in the harmonic content within the system due to the application of STATCOM. The displayed waveforms pertain to the D3 department.

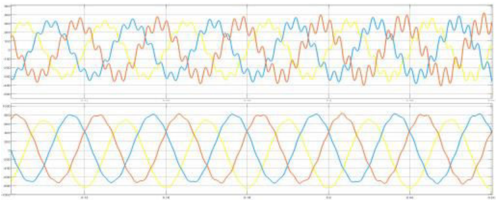
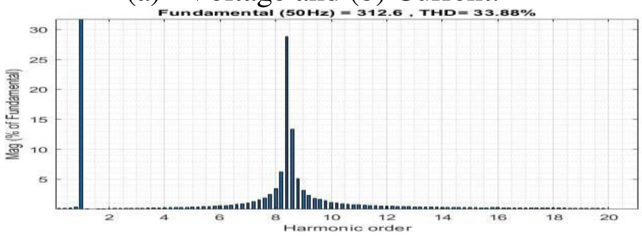


Fig 9 : Waveforms of the D3 Department in the absence of STATCOM: (a) Voltage and (b) Current.

Fig. 10 : Waveforms of D3 Department with STATCOM:
(a) Voltage and (b) Current.



Using Fast Fourier Transform (FFT) Analysis, we determine the Total Harmonic Distortion (THD) within the system. The following figures illustrate the THD values with and without the application of STATCOM.

Fig .11.Total Harmonic Distortion without STATCOM

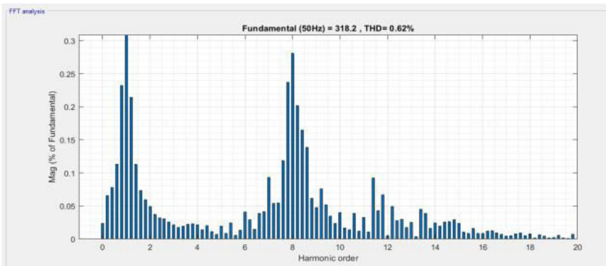
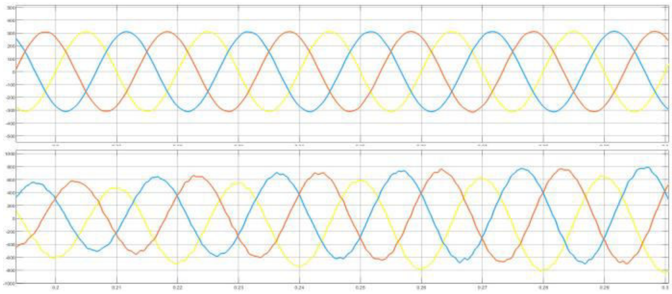


Fig .12. Total Harmonic Distortion with STATCOM



In Fig. 11(a), we observe that the THD (Total Harmonic Distortion) is 33.88% and it has been reduced to 0.62% In Fig. 12 with application of STATCOM. Likewise all the five departments are analyzed for power quality parameter of Total Harmonic Distortion especially in current. The results are tabulated in Table II given below.

TABLE II
THD ANALYSIS OF ALL DEPARTMENTS WITH AND WITHOUT STSTCOM

Department	Load	Total Harmonic Distortion Without STATCOM	Total Harmonic Distortion with STATCOM
D1	100 KVAR	13.38 %	0.61 %
D2	250 KVAR	25.79 %	0.52 %
D3	400 KVAR	33.88 %	0.62 %
D4	550 KVAR	40.59 %	0.55 %
D5	600 KVAR	41.52 %	0.48 %

V. CONCLUSIONS

The paper introduces a STATCOM-driven approach aimed at enhancing power quality in grid-connected wind generation systems. MATLAB/SIMULINK simulations illustrate the STATCOM's role in ensuring consistent power quality. The simulations reveal power quality issues arising after integrating wind plants with the grid. Through case studies across five different sections incorporating grid-tied wind power generation, the application of STATCOM reduces total harmonic distortion (THD) from 33.88% to 0.62% in section D3. Given THD's significant impact on power quality, efforts focused on reducing and maintaining it in accordance with IEEE 519 standards. Similar analyses were conducted across all departments, resulting in promising reductions in current THD levels.

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