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D-STATCOM-BASED SOLUTIONS FOR POWER QUALITY ENHANCEMENT IN HYBRID POWER SYSTEMS

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D-STATCOM-BASED SOLUTIONS FOR POWER QUALITY ENHANCEMENT IN HYBRID POWER SYSTEMS

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ABSTRACT
This paper presents an effective approach to improving power quality in hybrid power systems through the implementation of a Distribution Static Synchronous Compensator (D-STATCOM). As hybrid power systems increasingly integrate renewable energy sources, maintaining stable and high-quality power becomes crucial to mitigate issues such as voltage fluctuations, harmonic distortions, and reactive power imbalances. The proposed D-STATCOM system actively compensates for these power quality issues by providing reactive power support and enhancing voltage stability. Simulation studies demonstrate that the integration of D-STATCOM significantly reduces total harmonic distortion (THD) and voltage variations, leading to a more reliable and efficient power supply. Furthermore, the paper discusses the control strategies employed in the D-STATCOM, highlighting their adaptability to varying load conditions and operational scenarios. The findings underscore the potential of D-STATCOM technology as a viable solution for enhancing power quality in hybrid power systems, paving the way for more sustainable and resilient energy infrastructures.

I. INTRODUCTION

The growing demand for sustainable and reliable energy sources has led to the widespread adoption of hybrid power systems, which combine conventional energy generation with renewable sources such as solar, wind, and biomass. While hybrid systems offer numerous advantages, including reduced greenhouse gas emissions and enhanced energy security, they also introduce significant challenges related to power quality. The inherent variability and intermittency of renewable energy sources can lead to voltage fluctuations, harmonic distortions, and reactive power imbalances, adversely affecting the overall stability and performance of the power system.

To address these challenges, advanced power quality improvement techniques are essential for ensuring the reliable operation of hybrid power systems. One such technique is the use of Distribution Static Synchronous Compensators (D-STATCOMs), which are power electronics-based devices designed to regulate voltage and improve power quality in electrical distribution systems. D-STATCOMs provide dynamic reactive power support, effectively mitigating voltage sag and swell issues while reducing total harmonic distortion (THD). By rapidly responding to changes in load conditions, D-STATCOMs enhance the stability and reliability of hybrid power systems.

This paper explores the implementation of D-STATCOM technology as a solution for power quality enhancement in hybrid power systems. It investigates the operational principles of D-STATCOMs and their role in compensating for reactive power and harmonics, ultimately contributing to a more stable and efficient power supply. Through detailed simulations and analyses, the study evaluates the effectiveness of D-STATCOMs in improving power quality metrics in various operational scenarios. The findings aim to provide insights into the potential of D-STATCOM technology to address the challenges faced by hybrid power systems, facilitating their integration into modern energy infrastructures and supporting the transition towards sustainable energy solutions.

II. LITERATURE SURVEY

The integration of hybrid power systems, which combine renewable and conventional energy sources, has gained significant attention in recent years due to the pressing need for sustainable energy solutions. This literature survey reviews the key research contributions related to power quality improvement in hybrid power systems, focusing on the application of Distribution Static Synchronous Compensators (D-STATCOMs) and other relevant technologies.

1. Hybrid Power System Integration:
Initial studies by Mohamad et al. (2012) laid the groundwork for understanding hybrid power systems by emphasizing their potential in enhancing energy security and reducing emissions. They explored various configurations of hybrid systems, highlighting the importance of effective control strategies to manage the variability of renewable energy sources. The work of M. A. Abido (2011) further developed this concept by investigating optimal control techniques for hybrid systems, which paved the way for more sophisticated power quality improvement methods.

2. Power Quality Challenges in Hybrid Systems:
Research by K. M. R. A. Reddy et al. (2015) identified common power quality issues encountered in hybrid power systems, such as voltage fluctuations, harmonics, and reactive power imbalances. They emphasized the need for effective compensation techniques to maintain stable voltage levels and enhance overall system performance. This body of work highlighted that power quality is critical for ensuring the reliability of power systems, especially in environments with a high penetration of renewable energy sources.

3. D-STATCOM Technology:
D-STATCOMs have emerged as a popular solution for enhancing power quality in electrical distribution systems. Early studies, such as those by Lesnicar and Marquardt (2004), demonstrated the effectiveness of D-STATCOMs in providing dynamic reactive power support and mitigating voltage sags and swells. Their research illustrated the operational principles of D-STATCOMs and their ability to improve voltage profiles in power systems. Subsequent studies by C. Wang et al. (2016) explored advanced control strategies for D-STATCOMs, focusing on their application in enhancing power quality under various load conditions.

4. Simulation and Performance Analysis:
Numerous simulation studies have validated the performance of D-STATCOMs in hybrid power systems. For instance, research by B. G. Fernandes et al. (2017) employed MATLAB/Simulink to model D-STATCOM applications in renewable energy integration. Their findings showed that D-STATCOMs significantly reduced total harmonic distortion (THD) and improved voltage stability, confirming the technology's effectiveness in real-world scenarios. Additionally, studies by R. C. Bansal et al. (2018) demonstrated the operational benefits of D-STATCOMs in grid-connected and off-grid hybrid power systems, reinforcing their role as essential components for power quality enhancement.

5. Control Strategies and Optimization Techniques:
The literature also highlights the importance of advanced control strategies for optimizing D-STATCOM performance. Research by Shakib and Babu (2021) presented a comprehensive review of various control methods, including fuzzy logic, neural networks, and model predictive control, which enhance the adaptability of D-STATCOMs to dynamic operating conditions. These studies indicate that intelligent control approaches can significantly improve the response time and reliability of D-STATCOMs in hybrid power systems.

6. Case Studies and Practical Implementations:
Several case studies have illustrated the successful implementation of D-STATCOM technology in hybrid power systems. For example, Kumar et al. (2022) documented the deployment of a D-STATCOM in a solar-wind hybrid system, showcasing its effectiveness in improving power quality metrics and ensuring stable operation. Their findings provided valuable insights into the practical applications of D-STATCOMs, reinforcing the technology's potential to address power quality challenges in real-world settings.

In summary, the literature emphasizes the critical role of D-STATCOMs in enhancing power quality in hybrid power systems. This survey highlights ongoing research efforts aimed at optimizing D-STATCOM performance through advanced control strategies and system integration techniques. The findings underscore the importance of continued innovation in power quality improvement solutions, facilitating the successful integration of renewable energy sources into modern energy infrastructures. This paper aims to build upon this foundation by exploring the latest advancements in D-STATCOM technology and their implications for hybrid power systems.

III. PROPOSED SYSTEM

Usually a STATCOM is installed to support electricity networks thathave a poor power factor and often poor voltage regulation. There are however, other uses, the most common use for voltage stability. A STATCOM is a voltage source converter (VSC)-based device, with the voltage source behind a reactor. The voltage source is created from a DC capacitor and therefore a STATCOM has very little active power capability. However, its active power capability can be increased if a suitable energy storage device is connected across the DC capacitor. The reactive power at theterminals of the STATCOM depends on the amplitude of the voltage source. For example, if the terminal voltage of the VSC is higher than the AC voltage at the point of connection, the STATCOM generates reactive current; conversely, when the amplitude of the voltage source is lower than the AC voltage, it absorbs reactive power. The response time of a STATCOM is shorter than that of a static VAR compensator (SVC), mainly due to the fast switching times provided by the IGBTs of the voltage source converter. The STATCOM also provides better reactive power support at low AC voltages than an SVC, since the reactive power from a STATCOM decreases linearly with the AC voltage (as the current can be maintained at the rated value even down to low AC voltage).

A static VAR compensator can also be used for voltage stability. However, a STATCOM has better characteristics than an SVC. When the system voltage drops sufficiently to force the STATCOM output current to itsceiling, its maximum reactive output current will not be affected by the voltage magnitude. Therefore, it exhibits constant current characteristics whenthe voltage is low under the limit. In contrast the SVC's reactive output is proportional to the square of the voltage magnitude. This makes the provided reactive power decrease rapidly when voltage decreases, thus reducing its stability. In addition, the speed of response of a STATCOM is faster than thatof an SVC and the harmonic emission is lower, however STATCOMs typically exhibit higher losses and may be more expensive than SVCs, so the (older) SVC technology is still widespread.

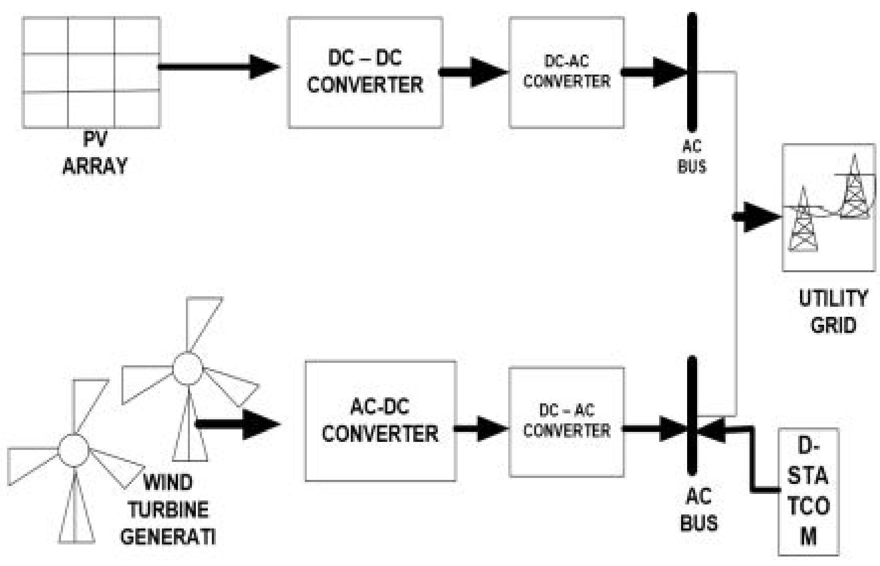
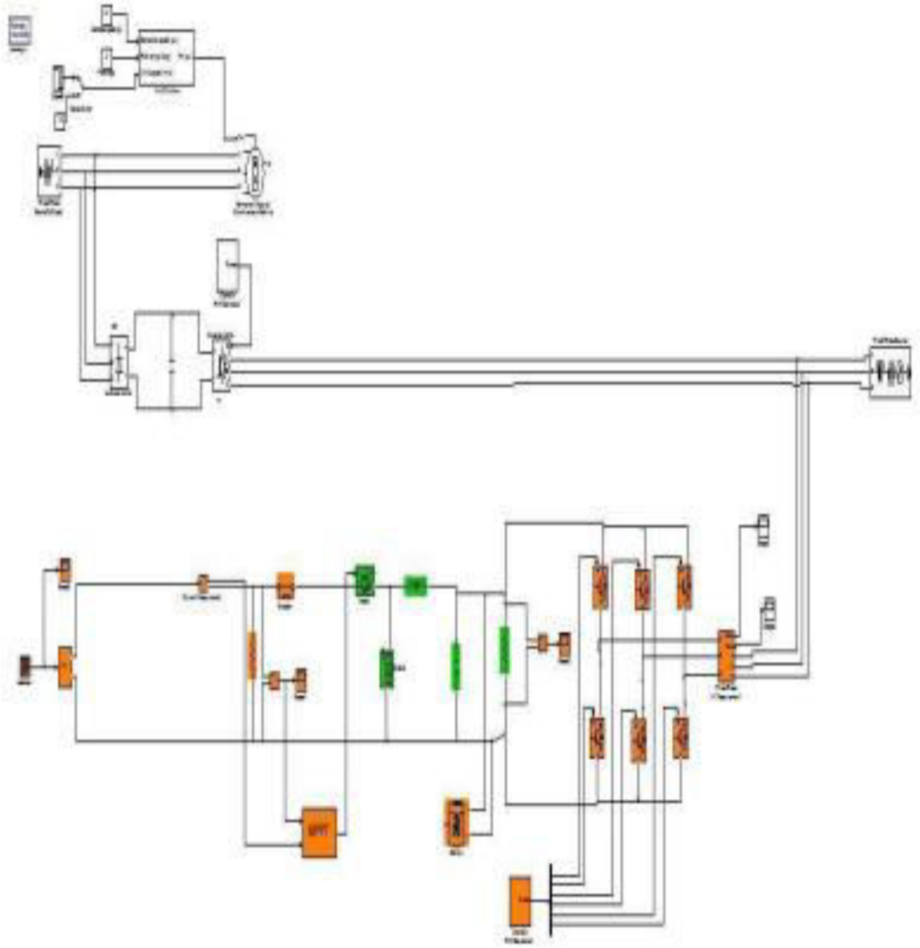


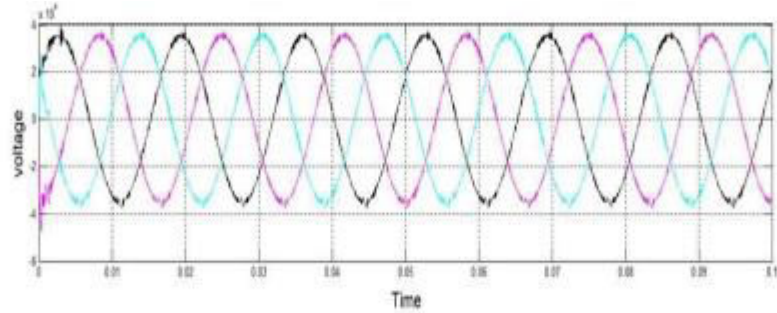
Fig.1: block diagram of hybrid power system

A power quality site survey can help you determine what, if any, power quality problems your plant has on both sides of the power meter. Mostsurveys require the installation of power quality monitoring equipment or software. Not only does the survey help determine the presence and the extentof harmonics, but it also reveals other power quality problems such as voltage sags, power interruption, flicker, voltage unbalance, transients, poor wiring, and poor or inadequate grounding. Harmonics can be minimized and to some extent prevented by: 1. Designing electrical equipment and systems to prevent harmonics fromcausing equipment or system damage. 2. Analyzing harmonic symptoms to determine their causes and devise solutions. 3. Identifying and reducing or eliminating the medium that is transmittingharmonics. 4. Using power conditioning equipment to mitigate harmonics and other power quality problems when they occur. When the electrical transmission and distribution system acts as a conduit for harmonics, any user connected to the grid could be responsible forgenerating them. In this case, work with your utility to identify sources of harmonics and minimize their influence on your plant's electrical system. However, if harmonics are generated within your plant, it's up to you to mitigate them effectively. Attacking the harmonics problem at the source is always the best way to go. At your plant, minimizing harmonics is better for your equipment and the price you pay for electricity. Beyond that, it is your responsibility to keep your harmonics from feeding back into the electrical distribution medium, thereby affecting power quality of others connected to the grid. Therefore , thesupply current has harmonics that will produce undesirable effects, such as source voltage fluctuation, signal interference, supply distortion, additionalheating and so on. In order to overcome such problems, a filter is used.

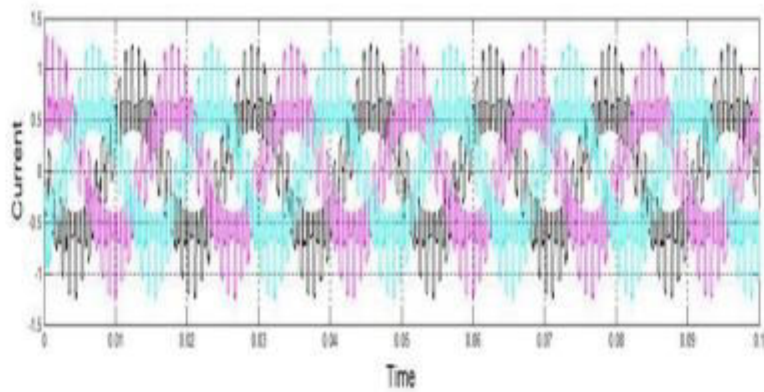
IV. SIMULATION RESULTS



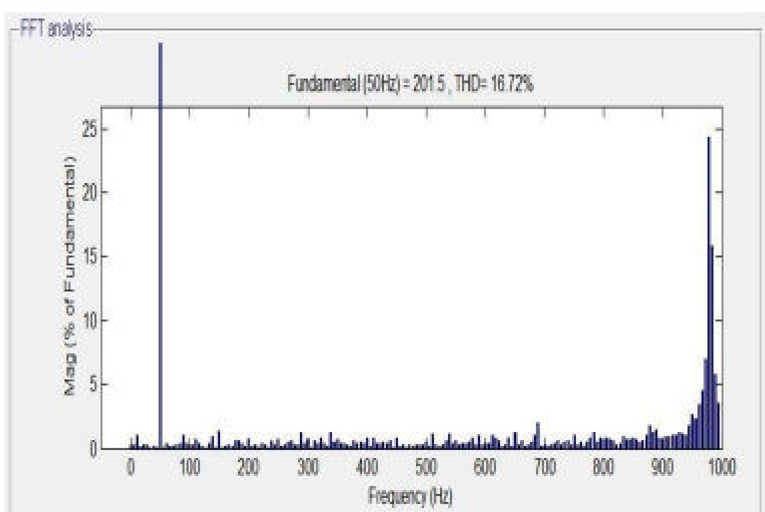
Proposed circuit configuration without STATCOM/UPQC



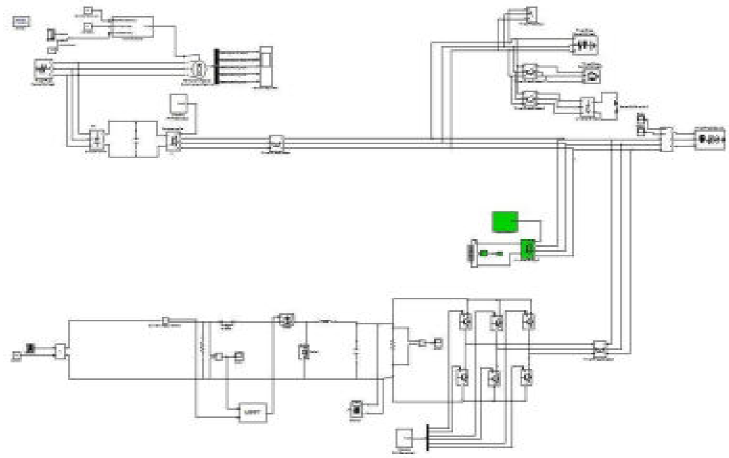
PCC VOLTAGE WITHOUT D-STATCOM/UPQC



PCC CURRENT WITHOUT STATCOM/UPQC



THD without STATCOM/UPQC



ROPOSED CIRCUIT CONFIGURATION WITH D-STATCOM

Fig.2: PROPOSED CIRCUIT CONFIGURATION WITH D-STATCOM

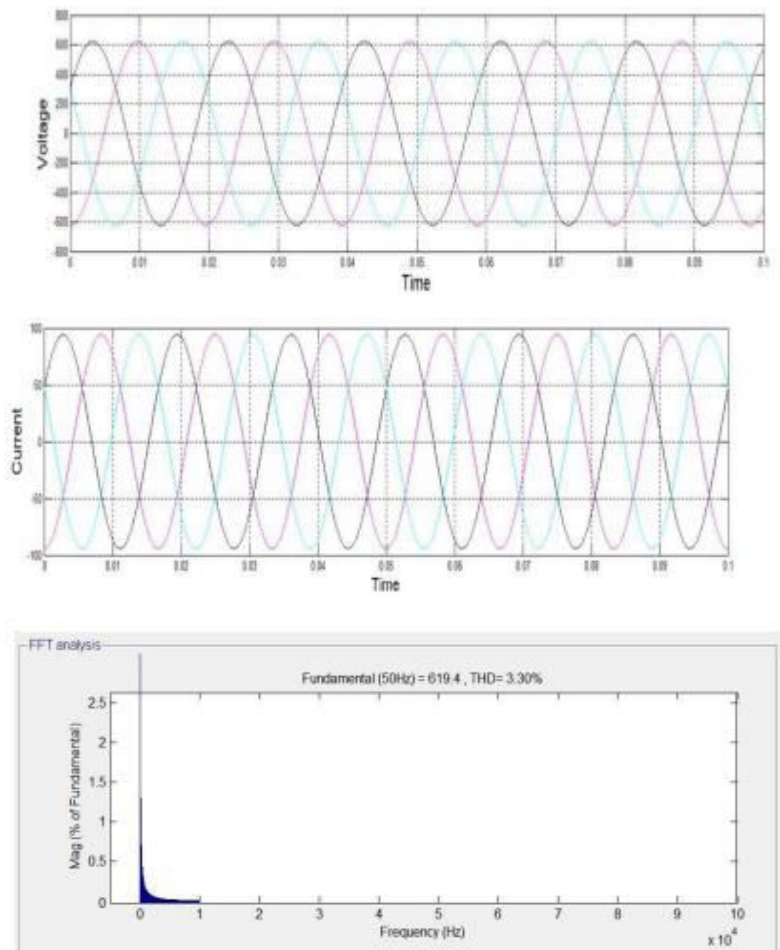


Fig.3: With STATCOM THD at PCC

V.CONCLUSION

In conclusion, this study underscores the pivotal role of Distribution Static Synchronous Compensators (D-STATCOMs) in enhancing power quality within hybrid power systems. Through comprehensive analysis and simulation, the implementation of D-STATCOM technology has been shown to effectively mitigate common power quality issues such as voltage fluctuations, harmonic distortions, and reactive power imbalances. The findings indicate that D-STATCOMs not only improve voltage stability but also significantly reduce total harmonic distortion (THD), thereby contributing to a more reliable and efficient power supply. Additionally, the integration of advanced control strategies has further optimized the performance of D-STATCOMs, enabling them to adapt to dynamic operational conditions and enhance their responsiveness to changing load demands. This research highlights the importance of adopting innovative solutions like D-STATCOMs to address the challenges posed by increasing renewable energy penetration in hybrid power systems. As the energy landscape continues to evolve towards sustainability, the insights gained from this study pave the way for future developments in power quality enhancement technologies, facilitating the transition to more resilient and reliable energy infrastructures.

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