Enhanced Grid Power Quality through Hybrid Solar-Wind Power Integration with UPQC

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Abstract: *Renewable Energy Sources (RES) such as solar and wind play a critical role in meeting future energy demands. India, with plans to enhance its solar and wind capacities to 20,000 MW and 38,500 MW by 2022, aims to integrate these variable RES outputs into its national grid. Currently, RES contributes 12.1% to the country's total grid capacity. While RES integration offers environmental advantages, it also introduces challenges in maintaining grid power quality. The Unified Power Quality Conditioner (UPQC) is an effective solution to address these issues, utilizing techniques like DC-links, distributed Dynamic Voltage Restorers (DVR), and static synchronous compensators (STATCOM). This paper provides a review of UPQC applications, focusing on control strategies for grid-connected systems. It also explores the benefits of hybrid solar-wind power generation and the challenges of integration, proposing the use of fuzzy logic-based UPQC for enhanced power quality. The study highlights a multi-feeder interline UPQC design utilizing fuzzy logic to minimize harmonic distortion. Additionally, it discusses Malaysia's initiatives for renewable energy integration, emphasizing sustainable energy development. The integration of hybrid solar-wind generation with UPQC offers promising solutions to improve power quality in grid-connected systems.*

Keywords: *Renewable Energy, Solar, Wind, Grid Integration, Power Quality, Unified Power Quality Conditioner (UPQC), Hybrid Systems, Fuzzy Logic, Sustainable Energy*.

I. INTRODUCTION

Renewable energy resources (RES) such as solar and wind are emerging as key alternatives for meeting future energy demands. India, with its vast geographical expanse, can leverage its continental size to balance the variable outputs of renewable energy sources, which are primarily concentrated in a few states, by integrating them into the national grid. Currently, grid-interactive power generation from RES stands at 24,914 MW, accounting for approximately 12.1% of the total installed energy capacity. The Ministry of New and Renewable Energy (MNRE), Government of India, has set ambitious targets to achieve 20,000 MW of grid-connected solar power and 38,500 MW from wind energy by 2022. Over the past two to three decades, solar and wind energy have emerged as the primary contributors to renewable electricity generation, experiencing rapid growth [1]. The contribution of renewable energy from wind and solar has substantially increased in recent years, forming a significant portion of the total grid generation. These renewable systems are proving to be promising and environmentally friendly energy sources, particularly in countries with limited fossil fuel resources. In recent years, solar and wind-based systems have garnered significant attention as reliable solutions to provide power to remote and electricity-deficient regions [2].

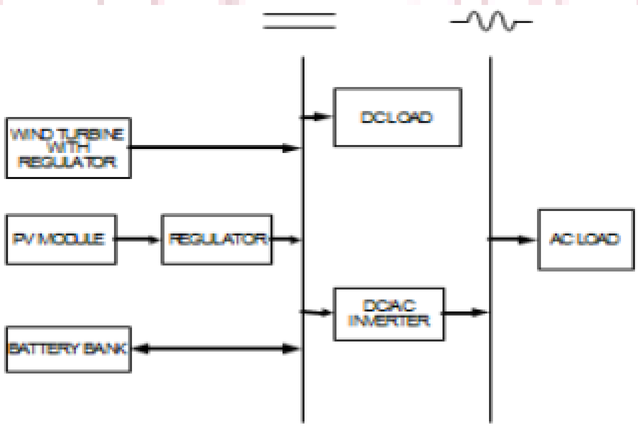

Figure 1 Wind & Solar Hybrid Energy System

These resources are connected to the national network or the public network. It works in two modes. They are island mode and network connected mode. Renewable energy sources (RES) are very important in terms of the spread of a sustainable world. Nowadays, the integration of RESs into the network is becoming widespread. However, RESs are not completely without problems. The main disadvantages are that they have irregular characteristics and cause undesirable problems such as power quality issues. Of course, the advantages of RES to our lives are more than their disadvantages [3]. The application of unified power quality control (UPQC) to power quality problems brought on by power electronics devices is examined in this study. It suggests control strategies that make use of a DC-link and a distributed dynamic voltage restorer (DVR) or static synchronous compensator (STATCOM). Reactive power, harmonics, negative-sequence current, and voltage imbalance are all targets of the UPQC. Additionally included are a number of control tactics, including hysteresis control approaches, BPT, UVTGT, and PI [4].

II. HYBRID SOLAR-WIND POWER GENERATION

Hybrid solar-wind power generation involves the integration of solar and wind energy sources to produce electricity. This approach offers several benefits over using solar or wind systems independently, such as enhanced reliability, improved energy capture efficiency, and optimal resource utilization. The integration of renewable energy sources has gained significant attention due to its cost-effectiveness, environmental benefits, and ease of implementation. Photovoltaic (PV) and wind turbines (WT) are among the most attractive renewable energy options, thanks to their abundance, technological advancements, and economic viability. By combining these distributed energy resources into a hybrid system, the intermittent nature of each source is mitigated, improving overall system reliability. The main goal of this project is to harness renewable energy for electricity generation with minimal environmental impact. The hybrid solar-wind system developed in this project seeks to address the limitations of standalone renewable energy systems. With its successful operation and cost-effectiveness, this system is highly recommended for adoption in rural areas to provide a sustainable solution for meeting their electricity needs.

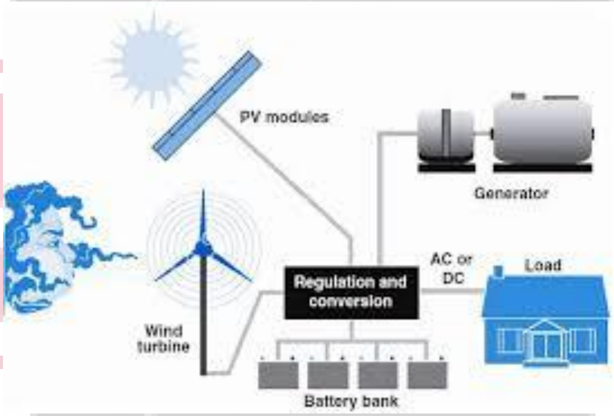

Fig. 3 The hybrid solar–wind power generation

A. Advantages of Hybrid Solar-Wind Systems

Enhanced Reliability: By integrating two renewable energy sources, hybrid systems offer a more dependable power supply than standalone systems. This is especially advantageous in regions with fluctuating weather patterns, ensuring a consistent energy flow.

Increased Energy Capture: Solar and wind energy are naturally complementary. Solar energy tends to be higher during the day, while wind energy can provide a steadier output both day and night. Combining these sources allows hybrid systems to maximize energy capture over a longer period.

Resource Utilization: Hybrid systems make more efficient use of available land and infrastructure by deploying both solar panels and wind turbines in the same location. This is particularly valuable in areas where land or space is limited, allowing for a dual use of resources.

Cost Savings:Hybrid systems can offer cost advantages over standalone systems, as they allow for shared components such as inverters, transmission lines, and monitoring systems, thus reducing overall costs. This shared infrastructure leads to a more affordable setup and maintenance.

B. Challenges and Considerations

Hybrid solar-wind power generation combines the advantages of both solar and wind energy to create a more reliable and efficient renewable energy source. By harnessing the complementary nature of these two sources, hybrid systems can mitigate the challenges of intermittency and variability typically faced by standalone solar or wind systems. This integration not only enhances the overall reliability of the power supply but also improves energy capture efficiency and reduces operational costs. However, there are several challenges that must be addressed for the successful deployment of hybrid solar-wind systems:

Intermittency: Despite the combined use of solar and wind, hybrid systems still face intermittency due to changing weather conditions. Variations in sunlight and wind speed can impact energy production, requiring the integration of energy storage solutions to maintain a steady power supply during low-generation periods.

Grid Integration: Integrating hybrid systems into the power grid presents challenges, as the output of renewable energy sources can fluctuate significantly. To ensure grid stability, advanced grid management and control technologies are necessary to accommodate the variability and ensure continuous, reliable power delivery.

Siting and Design: Proper siting and system design are essential for optimizing the performance of hybrid systems. Key factors such as local wind speed, solar radiation levels, and terrain characteristics must be carefully evaluated to determine the best locations and configuration for maximizing energy generation.

III. LITREATURE REVIEW

Twaisan K et al. (2022) explore the enhancement of microgrid responsiveness by using multimodal indicators that cover financial, technological, ecological, and social dimensions. Their study focuses on a microgrid structure that integrates Combined Heat and Power (CHP) devices, boilers, and various Distributed Energy Resources (DERs). They discover that, in isolated mode, the operational cost of the microgrid exceeds that of its grid-connected counterpart, stressing the need for a holistic evaluation approach to assess microgrid effectiveness.

Shravani et al. (2023) analyze a distributed generation system that combines a grid-connected solar photovoltaic (PV) array with a Unified Power Quality Conditioner (UPQC) and a battery. Their study highlights the effective mitigation of power quality issues in renewable energy systems, such as harmonics, voltage fluctuations, and ripples. By examining the system's performance under different scenarios, including unbalanced loads, they demonstrate how renewable energy integration can enhance power quality.

S. Poongothai et al. (2020) introduce a single-phase Unified Power Quality Conditioner (UPQC) designed for grid-connected photovoltaic systems, addressing challenges such as voltage sags/swells, power factor improvement, and harmonics elimination. Their controller, which uses a unit vector template control algorithm, proves effective in mitigating voltage and current disturbances, ensuring compliance with IEEE standards for Total Harmonic Distortion (THD).

Karelia, N. D., & Pandya, V. J. (2015) investigate the adoption of Distributed Generation (DG) with Renewable Energy Sources and Custom Power Devices to enhance power quality. They emphasize the role of UPQC-DG in providing ancillary services, boosting energy efficiency, and offering operational flexibility, underlining the importance of custom power solutions for integrating DG into existing power systems.

Wang (2019) introduces a quasi-single-stage UPQC-DG that simplifies the integration of distributed generation sources with the AC grid or AC loads. This innovative architecture reduces the number of power conversion stages, improving conversion efficiency. The study provides valuable insights into power flow dynamics and presents a promising model for efficient power conversion in modern energy systems.

Han, Byung & Bae et al. (2023) examine a UPQC collaborating with distributed generation to tackle voltage issues, interruptions, harmonics, and reactive power. Through simulations and hardware prototype experiments, they demonstrate the system's effectiveness in enhancing power quality across various power distribution and industrial systems.

Ratnakaran, R., et al. (2023) present an advanced control strategy for a photovoltaic system and battery-powered UPQC tailored for microgrid applications. Their controller dynamically adjusts parameters to minimize errors, swiftly responding to real-time grid voltage fluctuations and ensuring stability during grid fault transitions, thereby enhancing power quality in microgrid applications.

Kumar, K. P., et al. (2019) explore a UPQC integrated with Distributed Generation (DG) to mitigate voltage-related issues and improve power quality in power distribution systems. Their simulation studies provide insights into the operational dynamics of the system and highlight the potential of UPQC-DG integration to enhance power distribution.

Goud BS et al. (2018) propose a Distributed Power Flow Controller (DPFC) for grid-connected Hybrid Renewable Energy Systems (HRESs) to resolve power quality (PQ) issues. Their novel control strategy, which utilizes Black Widow Optimization (BWO) and a Fractional-Order PID (FOPID) controller, shows superior performance in mitigating PQ issues within grid-connected HRESs.

Khosravi, N. et al. (2020) focus on enhancing the operational parameters of stand-alone Hybrid Microgrids (HMGs) by incorporating a Modulated-Unified Power Quality Conditioner (M-UPQC) for AC microgrids and a Switched-Inductor Boost Converter Module (S-IBCM) for DC microgrids. Their research improves power quality and overall system performance in both AC and DC microgrid setups, marking significant advancements in system performance.

Renduchintala UK et al. (2021) aim to improve power quality in interconnected power distribution systems through the integration of microgrids and a Unified Power Quality Conditioner (UPQC). Their approach not only addresses power quality challenges but also optimizes power utilization, thereby enhancing overall system efficiency, as demonstrated through case studies and simulations.

IV. INTEGRATION OF HYBRID SOLAR-WIND WITH UPQC

The goal of this project is to create an interline unifying power quality conditioner (IUPQC) using fuzzy logic to enhance grid-connected systems' power quality and minimize power quality disturbances. Integration of renewable energy sources into grid-connected systems increases the difficulty of PQ disturbances such as harmonics, voltage sag, swell, and current. In order to handle these disturbances, a multi-feeder interline unified power quality conditioner (MF-IUPQC) is designed using fuzzy logic in the described approach. Each of the three legs and levels of the MFIUPQC has four diode-clamped inverters. Switching is achieved by space vector pulse width/duration modulation (SVPWM). In comparison to the industry standard proportional-integral (PI) controller, the fuzzy-based controller generates a voltage profile with significantly lower total harmonic distortion [5].
Presently, the Malaysian government has looked into the promising growth of RE to sustain the demand of electricity in the future. On this matter, this leads to the concept of integrating renewable energy (RE) sources within the distribution network. In this approach, the power losses between generation and load can be reduced, decreasing fossil fuel consumption economically in addition to promoting green energy. In consideration of implementing the concept of distributed generation (DG), policies have been introduced to encourage industries and public in adopting RE generation. Numerous initiatives and incentives on installation and operational costs, pricing tariffs, tender program, and research grants have been proposed to empower the RE strategies towards sustainable development goals (SDG) in the energy sector. This substantially subsidizes the larger needs of fossil fuel generation, which can be lowered or compensated by RE technology within the distribution network, which is shown in Figure 1. As for now, there are many mini hydro power generators, roof-top, and smaller-scaled solar farms, and biomass generators are interconnected within the distributed network to support the load demand by utilizing a greener energy to preserve the environment [6].

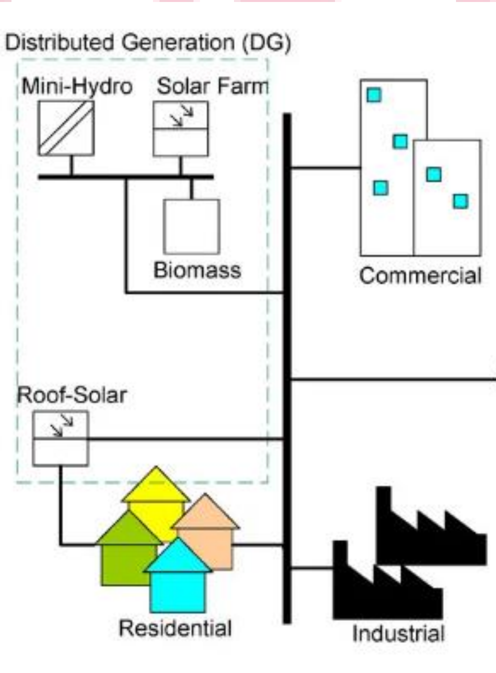

Fig. 2 A representation of distribution grid- interconnected with renewable sources and distribution loads

However, there are limitations that contribute to the ineffectiveness of DG in providing support to the grid system. Through integration of RES into the grid system, power quality issues are presumably higher as compared to the traditional grid system. To maintain the stability of the integrated grid system with RES, power quality standards are constantly revised to maintain the quality of power delivered to the consumer. Both solar and wind renewables are an example of RES that are heavily affected by the changes within its surroundings and environment, which compromise the effectiveness of the RE generation.

V. CONCLUSION

The integration of renewable energy sources (RES) into grid-connected systems brings both challenges and opportunities. While solar and wind energy provide significant environmental benefits, their inherent variability can lead to power quality issues. The Unified Power Quality Conditioner (UPQC) offers an effective solution to these challenges by mitigating reactive power, harmonics, and voltage imbalances. By combining the strengths of both solar and wind energy, hybrid solar-wind systems enhance reliability and energy capture efficiency. When integrated with UPQC and optimized with fuzzy logic control, these hybrid systems show great promise in improving power quality and minimizing disturbances in grid-connected setups. Malaysia's initiatives to integrate renewable energy sources into its distribution network further demonstrate its commitment to sustainable energy development. In conclusion, the combination of hybrid solar-wind power generation with UPQC provides a promising pathway to enhance power quality and advance sustainable energy practices in grid-connected systems.

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