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

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Abstract: *Renewable energy resources (RES) like solar and wind are crucial for future energy needs. India can balance variable RES outputs across states by integrating them into national grids. Currently, grid-interactive RES power generation in India is 12.1% of total capacity, with plans to increase solar and wind capacities to 20000 MW and 38500 MW by 2022. While RES integration offers environmental benefits, it poses power quality challenges. Unified Power Quality Conditioner (UPQC) addresses these, using strategies like DC-links and distributed dynamic voltage restorers (DVR) or static synchronous compensators (STATCOM). This paper reviews UPQC applications, highlighting control tactics for grid-connected systems. It also discusses hybrid solar-wind power advantages and integration challenges, proposing fuzzy logic-based UPQC integration for improved power quality. The study showcases a multi-feeder interline UPQC design using fuzzy logic to reduce harmonic distortion. Additionally, it outlines Malaysia's RE integration initiatives, emphasizing sustainable energy development. Integrating hybrid solar-wind generation with UPQC shows promise for enhancing 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) like solar and wind are going to become alternative for future energy needs. India is a country of continental size and this is helpful in balancing the variable output of renewable energy sources located in few states by integrating them into all India grids. As on the grid interactive power generation from RES is 24914 MW i.e. around 12.1 % of the total installed energy capacity. Further Ministry of New and Renewable Energy (MNRE), Government of India is targeting to achieve 20000 MW grid interactive powers through solar and 38500 MW from wind by 2022. Wind energy and Solar energy, are considered to be the main attributes of renewable energy for electricity generation, and are growing at faster rate, the last two-three decades. Renewable generation from wind and solar has increased substantially during past few years and forms a significance proportion of the total generation in the grid [1]. Renewable energy systems are proving to be promising and environmentally friendly sources of the energy age, especially in countries with insufficient fossil fuels. In the present years, solar and wind-based systems have attracted additional interest to provide power to remote or electricity-poor regions [2].

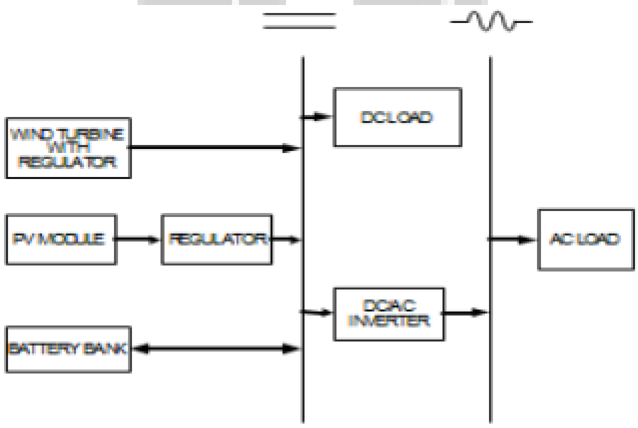

Figure 1 Wind & Solar Hybrid Energy System

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 refers to the combined use of solar and wind energy sources to generate electricity. This approach offers several advantages over standalone solar or wind systems, including increased reliability, improved energy capture efficiency, and better utilization of resources. The integration of renewable energy sources has garnered significant interest due to their cost-effectiveness, environmental benefits, and ease of deployment. Among these sources, photovoltaic (PV) and wind turbines (WT) have emerged as highly attractive options, thanks to their abundance, technological advancements, and economic advantages. Combining these distributed energy resources into a hybrid system addresses their inherent intermittency issues, thereby enhancing overall system reliability. The primary objective of this project is to leverage renewable energy sources to generate electricity with minimal environmental impact. The hybrid solar-wind energy generation system presented in this project aims to overcome the limitations of standalone renewable energy systems. Through successful operation and consideration of cost-effectiveness, this system is recommended for adoption in rural communities to meet their electricity needs sustainably.

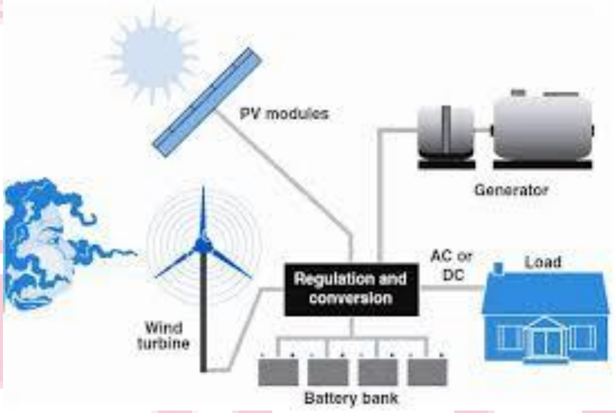

Fig. 3 The hybrid solar–wind power generation

A. Advantages of Hybrid Solar-Wind Systems

Enhanced Reliability: By combining two renewable energy sources, hybrid systems can provide a more reliable power supply compared to standalone systems. This is particularly beneficial in areas with variable weather conditions.

Increased Energy Capture: Solar and wind energy are complementary in nature, as solar energy production is typically higher during the day, while wind energy production can be more consistent throughout the day and night. By combining these sources, hybrid systems can capture more energy over time.

Resource Utilization: Hybrid systems can make more efficient use of available land and infrastructure by combining both solar panels and wind turbines in the same location. This can be especially useful in areas where space is limited.

Cost Savings: In some cases, hybrid systems can be more cost-effective than standalone systems, as they can share certain components such as inverters, transmission lines, and monitoring systems.

B. Challenges and Considerations

Hybrid solar-wind power generation combines the benefits of solar and wind energy to create a more reliable and efficient renewable energy source. By leveraging the complementary nature of these two sources, hybrid systems can overcome the challenges of intermittency and variability that are inherent in standalone solar or wind systems. This approach not only improves the overall reliability of the power supply but also enhances energy capture efficiency and reduces costs. However, challenges such as grid integration, energy storage, and optimal system design must be carefully addressed to ensure the successful implementation of hybrid solar-wind systems.

- Intermittency: Like standalone solar and wind systems, hybrid systems are subject to intermittency due to changes in weather conditions. This can affect the reliability of the power supply and may require the integration of energy storage systems.
- Grid Integration: Integrating hybrid systems with the grid can be challenging, as the output of renewable energy sources can vary significantly. Advanced grid management and control systems are needed to ensure stability and reliability.

- Siting and Design: Proper siting and design are critical for the success of hybrid systems. Factors such as wind speed, solar radiation, and local terrain need to be carefully considered to optimize energy production.

III. LITREATURE REVIEW

Twaisan K, et al. (2022) focus on enhancing microgrid responsiveness by utilizing multimodal indicators encompassing financial, technological, ecological, and social dimensions. Their study examines a microgrid structure incorporating Combined Heat and Power (CHP) devices, boilers, and various Distributed Energy Resources (DERs). They find that in isolated mode, the total operational cost of the microgrid surpasses that of its grid-connected counterpart, highlighting the need for a comprehensive approach in evaluating microgrid effectiveness.

Shravani et al. (2023) investigate a distributed generation system integrating a grid-connected solar photovoltaic (PV) array with a Unified Power Quality Conditioner (UPQC) and a battery. Their study demonstrates the effective mitigation of power quality challenges in renewable energy systems, such as harmonics, voltage fluctuations, and ripples. By analyzing the system's performance under diverse scenarios, including unbalanced loads, they showcase the potential of renewable energy integration to enhance power quality.

S. Poongothai et al. (2020) introduce a single-phase Unified Power Quality Conditioner (UPQC) for grid-connected photovoltaic systems, addressing issues like voltage sags/swells, power factor improvement, and harmonics elimination. Their controller, employing a unit vector template control algorithm, demonstrates efficient performance in mitigating voltage and current disturbances, meeting IEEE standards for Total Harmonic Distortion (THD).

Karelia, N. D., & Pandya, V. J. (2015) examine 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, improving energy efficiency, and offering operational flexibility, highlighting the importance of custom power solutions in integrating DG into existing power systems.

Wang (2019) presents a quasi-single-stage UPQC-DG that streamlines the integration of distributed generation sources with the AC grid or AC loads. This novel architecture reduces the number of power conversion stages, enhancing overall conversion efficiency. Their research provides valuable insights into power flow dynamics and offers a promising paradigm for efficient power conversion in contemporary energy systems.

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

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

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

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

Khosravi, N. et al. (2020) aim to improve the operational parameters of stand-alone Hybrid Microgrids (HMGs) by implementing 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 enhances power quality and overall system performance in both ACMG and DCMG setups, showcasing significant advancements in performance conditions.

Renduchintala UK et al. (2021) focus on elevating power quality within interconnected power distribution systems through the integration of microgrids and a Unified Power Quality Conditioner (UPQC). Their approach not only resolves power quality issues but also optimizes power utilization, thereby enhancing overall system efficiency, as validated 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].

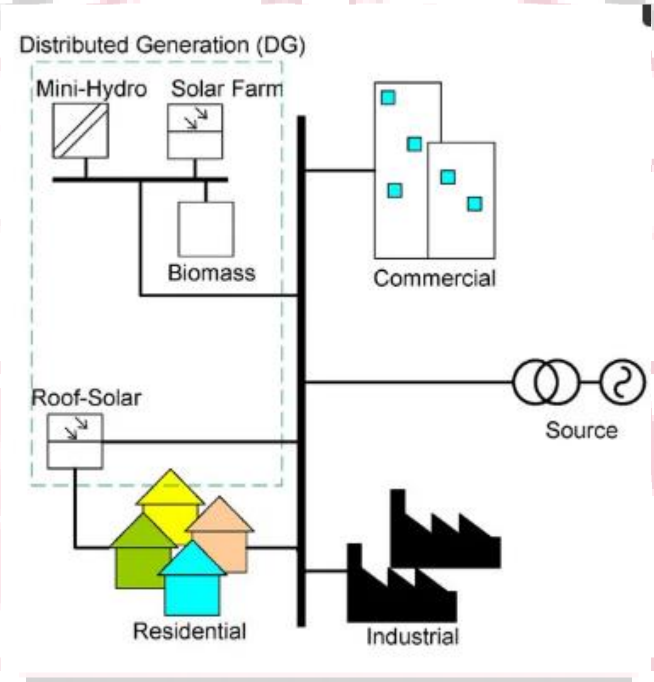

Fig. 2 A representation of distribution grid- interconnected with renewable sources and distribution loads

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 presents both challenges and opportunities. While RES such as solar and wind offer environmental benefits, they also introduce power quality issues due to their variable nature. Unified Power Quality Conditioner (UPQC) emerges as a viable solution to address these challenges, offering strategies to mitigate reactive power, harmonics, and voltage imbalances. Hybrid solar-wind power generation, combining the benefits of both sources, offers increased reliability and energy capture efficiency. The integration of hybrid systems with UPQC, utilizing fuzzy logic, shows promise in enhancing power quality and minimizing disturbances in grid-connected systems. Malaysia's initiatives in integrating RE sources into its distribution network demonstrate a commitment to sustainable energy development. Overall, the integration of hybrid solar-wind power generation with UPQC presents a promising approach to improve power quality and promote sustainable energy practices in grid-connected systems.

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