Advancements in Renewable Energy Technologies for Sustainable Development: A Review

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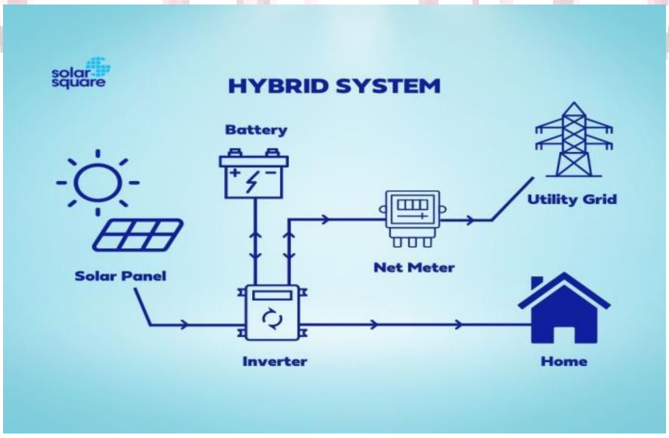
Abstract: *The growing energy demand, coupled with concerns about climate change and environmental degradation, has spurred significant interest in renewable energy technologies as viable alternatives to traditional fossil fuels. This review paper explores the potential of renewable energy sources, focusing on biodiesel, wind turbines (WTs), and photovoltaic (PV) systems, to address energy shortages in isolated rural areas. Additionally, it investigates the utilization of biofuel-diesel blends in diesel engines to reduce dependency on fossil fuels and mitigate exhaust emissions. The study discusses physico-chemical properties, engine performance, and emissions characteristics of biodiesel blends, highlighting their potential for sustainable energy generation. Furthermore, the paper examines the integration of PV plants and wind farms into the energy grid, emphasizing the importance of energy storage technologies and flexible power plants to enhance power generation reliability. Through a comprehensive analysis of renewable energy advancements and case studies, this paper offers insights into the role of renewable energy technologies in achieving sustainable development goals.*

Keywords: *Renewable energy, biodiesel, wind turbines, photovoltaic systems, energy storage, sustainable development.*

I. INTRODUCTION

Energy is necessary for the existence and the development of modern societies. Most of energy used on earth is in the form of fossil fuels, which are likely to become increasingly scarce over the next several decades according to the recent exploration and consumption data, while greenhouse gas emissions are threatening natural and anthropogenic ecosystems. The energy supply for isolated rural areas is usually provided by diesel generators. However, such fuel costs are generally high due to increases in diesel fuel prices and the additional costs of transport. Small villages and remote areas often suffer from energy shortages or blackouts. Consequently, alternative fuels and renewable energy sources have been considered as future alternatives. Among the renewable energy sources, biodiesel, a clean diesel fuel producible from renewable natural resources, and wind turbines (WTs) and photovoltaic (PV) systems are often considered the most promising technologies to meet electrical loads in rural or remote regions.

Given that the energy consumption and CO2 emissions in ASEAN countries increasing day by day, government of ASEAN countries have set target to use biofuel in diesel engines as biofuel-diesel blend has potential to reduce dependency on fossil fuel as well as the exhaust emissions of the engine. Physico-chemical properties of Jatropha biodiesel and its blends with diesel followed by engine performance and emissions characteristics of B10, B20, and B0 were studied. The results showed that viscosities of B20 and B10 were closer to diesel. Compared to B0, the average reduction in brake power is 4.67% for B10 and 8.86% for B20. It was observed that brake specific fuel consumption increases as the percentage of biodiesel increase. Compared to B0, a reduction in hydrocarbon emission of 3.84% and 10.25% and carbon monoxide emission of 16% and 25% was reported using B10 and B20. This is because biodiesel contains higher oxygen than diesel fuel which helps to complete the combustion. Finally, B10 and B20 were used in a diesel engine without any modifications [1].



Hybrid Solar System: Types,

According to the report of the Intergovernmental Panel on Climate Change (IPCC), the net zero CO2 emission needs to be achieved by 2050 to limit the increase in the global average temperature to 1.5 °C. The structure of energy demand is undergoing tremendous changes. Renewable energy will gradually replace traditional fossil energy and assume the primary responsibility of meeting the ever-increasing energy demand. The report of BP Energy Outlook 2020 pointed out that renewable energy, led by wind and solar energy, is expected to grow the fastest over the next 30 years. However, the power outputs of photovoltaic (PV) plants and wind farms are intermittent and fluctuating. The matching between these power outputs and the load demand is usually poor. Therefore, simply expanding the construction of PV plants and wind farms will cause huge hidden dangers. To improve the power generation reliability of the system based on PV plant/wind farm, some energy storage technologies and power plants with flexible output capability have to be introduced [2]. The economy and the advancement of a nation are inconceivably reliant on the vitality era of that country. The fossil gives a vast segment of energies in both developed and developing countries which cause a terrible effect on the environment. Furthermore, the shortage of fossil powers is making cerebral pain to discover options [3].

Advantages of Solar-Wind Hybrid Systems

- Complementary Nature: Solar and wind energy sources complement each other's intermittency and variability. Solar panels generate electricity during the day when sunlight is abundant, while wind turbines produce power primarily at night and during periods of higher wind speeds. By combining both sources, solar-wind hybrid systems can provide a more consistent and reliable power output throughout the day and year.
- Enhanced Reliability: Integrating multiple renewable energy sources increases the reliability and resilience of the power generation system. Solar-wind hybrid systems are less susceptible to fluctuations in weather conditions compared to standalone solar or wind systems, reducing the risk of power outages and ensuring a more stable energy supply.
- Optimized Energy Production: Hybrid systems can maximize energy production by leveraging the strengths of each energy source. During periods of low solar irradiance, wind turbines can continue to generate electricity, and vice versa. This optimized energy production helps to meet varying energy demand patterns and improve overall system efficiency.
- Reduced Environmental Impact: Solar-wind hybrid systems contribute to reducing greenhouse gas emissions and mitigating climate change by displacing fossil fuel-based electricity generation. By harnessing renewable energy from sunlight and wind, these systems promote sustainable development and environmental conservation, leading to cleaner air and a healthier planet.
- Cost Savings: Hybrid systems can offer cost savings compared to standalone solar or wind installations. By sharing infrastructure such as inverters, transmission lines, and energy storage systems, the overall capital and operational costs can be reduced. Additionally, hybrid systems may be eligible for financial incentives, tax credits, and subsidies that further lower the cost of deployment.

Disadvantages of Solar-Wind Hybrid Systems

- Complex Design and Integration: Designing and integrating a solar-wind hybrid system requires careful planning and technical expertise. Balancing the electrical output of solar panels and wind turbines, managing energy storage, and coordinating control systems can be challenging and may require specialized knowledge and resources.
- Intermittency and Variability: Despite the complementary nature of solar and wind energy, both sources are inherently intermittent and variable. Cloud cover, atmospheric conditions, and fluctuations in wind speed can lead to unpredictable energy generation patterns, affecting system performance and reliability. Energy storage systems are required to mitigate these fluctuations, adding complexity and cost to the system.
- Space and Land Requirements: Solar-wind hybrid systems may require significant land or roof space for the installation of solar panels and wind turbines. In densely populated areas or regions with limited available land, finding suitable sites for deployment can be challenging. Additionally, land use conflicts and environmental concerns may arise, particularly in sensitive ecosystems or agricultural areas.
- Maintenance and Operating Costs: Like any renewable energy system, solar-wind hybrid systems require regular maintenance and upkeep to ensure optimal performance and longevity. Components such as solar panels, wind turbines, inverters, and batteries may require periodic inspections, repairs, and replacements, adding to the overall operating costs of the system.
- Grid Integration Challenges: Connecting solar-wind hybrid systems to the electrical grid can pose technical challenges, particularly in regions with limited grid infrastructure or high levels of renewable energy penetration. Grid stability, voltage regulation, and power quality issues may arise due to the variable nature of renewable energy generation, requiring advanced grid management and control strategies. Additionally, regulatory barriers and utility interconnection requirements may hinder the deployment of hybrid systems in some areas.

II. LITERATURE REVIEW

Mohd Radzi et al. (2020) conducted a study on harmonic distortion in power distribution systems in laboratory and office buildings. They found that harmonic distortion levels exceeded regulatory thresholds, indicating inadequate power quality and associated energy losses.

Al Hanaineh et al. (2023) emphasized the importance of integrating Distributed Generators (DGs) into distribution systems (DSs) for improved power delivery reliability. Their research proposed novel fault protection techniques, including Multiple Second Order Generalized Integrator (MSOGI) and SOGI-THD, for rapid fault detection and isolation, demonstrating robustness against harmonic distortion.

Yahya M. Al-Sharif et al. (2022) highlighted technical hurdles from the integration of grid-connected PV rooftops at the distribution level. They proposed deploying single-tuned filters to mitigate harmonic distortion, achieving a marked reduction in both individual and total harmonic distortion within a substantial grid-connected PV microgrid.

Kuwałek, P., & Wiczy´nski, G. (2022) addressed challenges in Total Harmonic Distortion (THD) measurement with Advanced Metering Infrastructure (AMI) meters amidst voltage fluctuations, providing insights into discrepancies between THD measurements obtained from AMI meters and class A power quality analyzers.

Ruiz-Cortés, et al. (2015) explored simulation-based approaches to analyze and mitigate harmonic distortion, leveraging cloud-based platforms to address evolving power quality requirements in Smart Grids.

Kumar, Anup et al. (2017) conducted a survey on Space Vector Pulse Width Modulation (SVPWM) strategies for two-level voltage source inverters, introducing an innovative enhanced 600 discontinuous PWM technique to mitigate current Total Harmonic Distortion (THD).

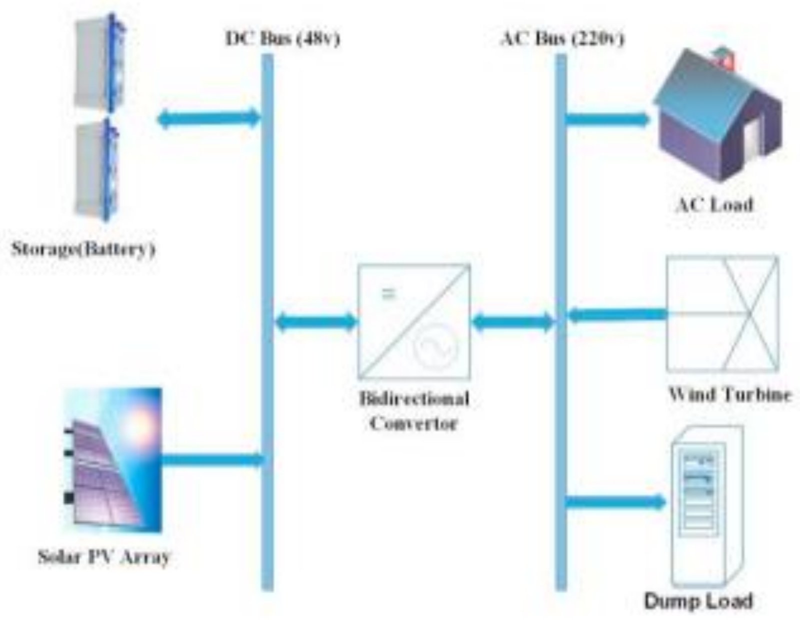
Shengyang Lu, et al. (2023) proposed an SVPWM strategy for Modular Multilevel Converters (MMCs) to suppress circulating currents and maintain submodule voltage balance, demonstrating effectiveness through simulation and experimental validation.

Madhavan, M., et al. (2023) introduced a segment reduction-based SVPWM strategy for F-type three-level inverters (FT2LI) to minimize switching state transitions and improve THD performance, validated through simulation and experimental evaluations.

Hu, H., et al. (2022) developed a simpler SVPWM method for permanent magnet synchronous machine (PMSM) drives to improve performance and efficiency. Their method, focusing on optimal vector dwell time, showed promising results in reducing distorted currents and improving system monitoring frequency.

III. THE INVOLVED HYBRID PV/WIND SYSTEM CASE STUDY

The involved hybrid PV/wind system case study Hybrid PV-wind-battery systems are more economically effective and reliable, especially for remote areas, as these sources have complementary nature between them as compared to single source systems. The components of the HRES and energy flow between production and demand units is shown in the Fig. . The electricity produced by PV/wind is managed by storage system while the dump load is added to shunt the extra energy when needed. Dump load can be air or water heaters and used when the system cannot take the electricity produced by solar/wind. As shown in the Fig. load, WT and dump load are connected to the AC bus while PV and storage bank is connected to AC bus via bi-directional converter. The island selected for study is named as "Jiuduansha" and located near Shanghai. This Island did not yet electrify due to the remote location from the main grid nad no particular people lived there. The load is designed to supply electricity ten houses and anticipated at 255 kWh/day. The metrological data used in the study was taken from small metrological station in the campus of Shanghai Jiao Tong University (green energy laboratory). From data, it is found that yearly average solar radiation is 4.13 kWh/m^2/day, while average wind speed of the proposed site is 5.65 m/s. The monthly average solar and wind resources rate [4].



The Energy flow diagram of proposed Hybrid (PV-Wind) System with battery storage

IV. DESIGN PRINCIPLES AND COMPONENTS

Designing a solar-wind hybrid system requires careful consideration of various components and principles to ensure optimal performance and reliability. This section explores the fundamental design principles and key components of solar-wind hybrid systems, shedding light on the integration strategies and technological aspects involved in harnessing renewable energy from solar and wind sources.

System Sizing and Configuration

Proper sizing of solar PV panels and wind turbines is essential to meet the energy demand of the intended application.

Factors such as available solar irradiance, wind speed, load profile, and system efficiency must be considered during the sizing process.

The configuration of the hybrid system, including the arrangement of solar panels, wind turbines, and energy storage components, influences overall system performance and energy yield.

Hybridization Techniques

Hybridization techniques aim to optimize the utilization of solar and wind resources to maximize energy generation.

Strategies such as parallel configuration, series-parallel configuration, and complementary operation are employed to achieve synergy between solar and wind components.

Hybridization also involves integrating energy storage systems, such as batteries or pumped hydro storage, to store excess energy for later use and enhance system reliability.

Solar PV Panels

Solar PV panels convert sunlight into electricity through the photovoltaic effect, utilizing semiconductor materials to generate a direct current (DC) output.

Factors influencing the performance of solar panels include solar irradiance, temperature, shading, orientation, and tilt angle.

Advancements in solar panel technology, such as thin-film, monocrystalline, and polycrystalline silicon cells, contribute to higher efficiency and lower costs.

Wind Turbines

Wind turbines harness kinetic energy from the wind to generate electricity, with horizontal-axis and vertical-axis designs being the most common.

Blade design, rotor diameter, hub height, and turbine capacity influence the power output and efficiency of wind turbines.

Variable-speed and pitch-controlled turbines optimize energy capture by adjusting rotor speed and blade pitch to changing wind conditions.

Energy Storage Systems

Energy storage systems, such as batteries, flywheels, and pumped hydro storage, play a crucial role in balancing supply and demand in hybrid systems.

Batteries, including lithium-ion, lead-acid, and flow batteries, store excess energy for use during periods of low generation or high demand.

Energy storage sizing and management strategies ensure optimal utilization of stored energy and enhance system stability.

Power Electronics and Control Systems

Power electronics components, including inverters, converters, and charge controllers, interface renewable energy sources with the electrical grid or loads.

Control systems regulate the operation of solar PV panels, wind turbines, and energy storage devices to optimize energy production and system efficiency.

Advanced control algorithms, such as maximum power point tracking (MPPT) and predictive control, enhance the dynamic response and stability of hybrid systems.

V. CONCLUSION

Solar-wind hybrid systems emerge as promising solutions to address the energy challenges faced by modern societies. By leveraging complementary nature, these systems offer enhanced reliability, optimized energy production, and reduced environmental impact compared to standalone installations. However, challenges such as complex design, intermittency, space requirements, maintenance costs, and grid integration persist. Nonetheless, through meticulous system sizing, hybridization techniques, utilization of advanced components, and integration of energy storage systems, solar-wind hybrid systems can pave the way for sustainable energy generation. Continued research, technological advancements, and policy support are crucial to accelerate the transition towards renewable energy and achieve a more sustainable future.

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