AIMS Energy, 12(6): 1264–1270.
DOI: 10.3934/energy.2024057
Received: 09 December 2024
Revised: 09 December 2024
Accepted: 09 December 2024
Published: 10 December 2024

http://www.aimspress.com/journal/energy

Editorial

Sustainable energy technologies for emerging renewable energy and electric vehicles

Surender Reddy Salkuti*

Department of Railroad and Electrical Engineering, Woosong University, Daejeon 34606, Republic of Korea

* **Correspondence:** Email: surender@wsu.ac.kr.

Abstract: Renewable energy and electric vehicles are used globally for reducing fuel dependency and carbon footprints. Here, I explore the complex field of "Sustainable Energy Technologies for Emerging Renewable Energy and Electric Vehicles" and examined the most recent advancements, obstacles, and ideas that are promoting the effective use of renewable energy sources (RESs), energy storage systems (ESSs), and electric vehicles (EVs). I focused on the integration of renewable energy (RE), energy storage (ES), and EVs into modern sustainable power grids. With the recent advances in power generation technologies, the fluctuations in generation and electrical demand are common in hybrid power systems. This special issue was aimed at addressing the economic challenge of integrating RESs, ES, and EVs to improve the resilience and flexibility of grid operations. The widespread adoption of intermittent RESs and EVs makes it difficult to maintain a consistent power supply and significantly impacts grid stability. To address this challenge, ESSs are emerging as a potential solution. With the right investments and policies in place, RE, ES, and EVs can play a significant role in creating a more sustainable energy landscape worldwide.

Keywords: smart grid; renewable energy; electric vehicles; energy management system; energy storage; smart cities; emerging technologies

1. Introduction

The electricity demand is rising sharply worldwide. In recent decades, global energy consumption has experienced a significant surge, primarily driven by population and industrial growth. The average growth rate of energy consumption from 2010 to 2019 is 1.5% per year. However, it has grown rapidly in recent years, such as 2.5% in 2023, and it is expected to rise even more sharply around (4–5)% in the years 2024 and 2025. The electricity demand increased by 1270 TWh from 2020 to 2023. Due to the rapid increase in electric power utilization these days, the conventional generation alone will not be enough to meet the ever-growing power demands. Reneweable energy sources (RESs) have proved their availability and credibility as a viable option in generating electrical energy as against conventional fossil fuels. Wind, solar photovoltaic (PV), biomass, geothermal, hydropower, tidal, and wave energies are some of the examples of RESs that have been growing in importance over time. Wind and solar energies are the two most promising RESs that can cater to the rising demand for electrical energy globally. The power output from RESs is also forecasted to rise rapidly from 30% in 2023 to 35% in 2025. Based on the International Energy Agency's (IEA) forecast, the world's capacity of renewable energy (RE) is expected to increase by almost 2400 GW which is equivalent to 75% growth, from 2022 to 2027 [1]. The world must add more than 1000 GW of annual RE capacity by 2050 to limit the global temperature rise to 1.5 °C. Among the power output from these RESs, solar PV power alone is forecasted to meet approximately 50% of electrical demand [2]. Solar PV is one of the most favored energy sources for electricity generation globally due to its abundance, easy installation, minimal maintenance, and modular design.

Furthermore, wind energy has emerged as the fastest-growing energy source on the planet. Solar PV systems can be categorized into standalone, grid-interfaced, and hybrid systems. Standalone solar PV systems rely on energy storage (ES) systems, typically batteries, to match the immediate power demand of the load demand. However, batteries necessitate regular maintenance and eventual replacement, which can be costly and time-consuming. As a result, grid-interfaced solar PV systems without batteries are often favored, particularly in areas where a reliable grid connection is accessible. Partial shading (PS) affects the power output from solar PV arrays and even reduces the lifespan. The presence of PS poses a significant challenge to the optimal utilization of PV systems, leading to performance degradation. Variations in temperature and irradiance cause constant fluctuations in obtaining the maximum power from PV systems. To overcome this issue, various approaches have been introduced in the literature to mitigate the adverse effects of PS including the utilization of maximum power point tracking (MPPT) techniques, PV array topologies, PV array reconfiguration techniques, and bypass diodes [3]. Among these approaches, MPPT and PV array reconfiguration have seemed to be a highly effective solution to enhance the power output of solar PV systems. MPPT techniques guarantee the best possible efficiency and performance for PV systems. Various MPPT approaches are employed to extract the maximum power from solar PV arrays. These MPPT techniques can be applied to partially shaded conditions (PSC) and uniformly shaded conditions (USC). Therefore, there is much research scope in this area. This editorial and special issue on "Sustainable Energy Technologies for Emerging Renewable Energy and Electric Vehicles" will bring new solutions to these research problems.

Demand volatility is determined by the characteristics of the end consumers. The uncertain/intermittent nature of RE is one of the key reasons for generation fluctuations. Frequent fluctuations in demand and generation compromise the grid's stability and complicate system operation. The utilization of RESs is expanding at a rapid pace. However, the intermittent nature of RESs can result in intermittent generation that affects grid stability. To combat this issue, energy storage systems (ESSs) can store energy when it's available from RESs and release it to ensure a continuous supply of electric power. Acting as a buffer between RESs and the grid, the ESSs can minimize the grid's vulnerability to generating intermittency and improve schedulability/dispatchability.

2. Emerging technologies in renewable energy

Accelerated deployment of renewables and emission reductions are needed by 2050 to establish the energy pathway towards meeting the Paris climate targets. With the increasing penetration of RESs, including solar PV arrays and wind turbines, into the energy mix, the modern hybrid power grids provide an ideal platform to harness and integrate these intermittent energy sources. By effectively managing the variability and intermittency of RE, the hybrid power grids can ensure a reliable and stable energy supply while minimizing reliance on conventional power generation. The utilization of RESs such as solar, wind, and others can facilitate the powering of hybrid power grids, thereby diminishing dependence on non-renewable fossil fuels and mitigating carbon emissions [4]. The microgrid (MG) is an autonomous miniature unit of an electrical grid, and represents a highly promising avenue for the utilization of RESs. RE integrated into MGs has the potential to yield economic advantages in addition to its positive environmental impact. Through the process of self-generation, enterprises and localities have the potential to curtail their energy expenditures and potentially generate revenue by selling surplus energy back to the power grid. This phenomenon has the potential to result in substantial reductions in expenses and potentially generate income. It's important to acknowledge that despite the many benefits of RESs, there are some obstacles to integrating them into MGs.

Uncertainty in forecasting is another significant aspect, addressing the challenges of predicting energy demand and generation accurately in the presence of inherent uncertainties. To ensure reliable and efficient MG operation, uncertainty analysis techniques play a vital role in developing robust energy management strategies (EMSs). Therefore, there is a need for uncertainty analysis techniques to better understand and manage the uncertainties in MG EMSs. The integration of RESs into the MGs poses challenges in maintaining system stability, especially during faults and sudden changes in generation. For instance, a fault occurring in a location with significant wind integration can have undue effects on transient stability [5]. The growing adoption of EVs and electrification of various sectors pose additional challenges to grid stability and reliability. MGs offer a compelling solution to address these challenges by bringing power generation, distribution, and consumption closer together. These self-contained systems can operate in grid-connected and islanded modes of operation, ensuring a reliable power supply even during grid outages or emergencies.

3. Emerging technologies in energy storage

Energy storage systems (ESSs) are being deployed globally, with a variety of storage technologies currently being tested. However, relying on diesel and hydropower plants for generation shifting is not a viable long-term solution due to economic and technological constraints. Therefore, the development of ESSs is critical for the efficient use of RESs. Countries such as the United States and Japan have already implemented large-scale ESSs while emerging countries are currently building new ones. The ESSs have the potential to significantly improve grid stability in a variety of ways. The modern hybrid power system relies heavily on battery ESSs (BESSs) to compensate for fluctuations in electricity supply and demand at different times. BESSs offer numerous benefits, including low maintenance costs, and the ability to connect modular units to achieve higher power ratings. This makes it easier to replace and transport modules, which is a significant advantage over other ESSs [6]. However, installation costs can be quite high, making them less accessible to smaller utilities or communities. More research is needed to find an effective solution to mitigate the power quality (PQ) issues arising from the intermittent nature of RESs, effective system topology, and standards for a reliable and stable power supply. The ESSs are integrated with the power grid to reduce the intermittent nature of RESs and achieve power balance in the system. During peak load periods, the ESSs can offer energy with immediate response, which reduces unscheduled exchanges and simplifies scheduling. This also leads to improved market operations by avoiding unplanned interchanges.

The storage of electrical energy can be achieved through various approaches including mechanical, electrochemical, electromagnetic, electrostatic, and thermal storage. Among these methods, some are more suitable for large-scale storage due to their ease of use and budgetary benefits. Selecting an appropriate ESSs require careful consideration of several criteria, including capital cost, maintenance cost, cycle life, cycle efficiency, specific energy, energy density, reaction time, self-discharge, system management, and environmental impact. These factors play a critical role in evaluating the effectiveness and feasibility of an ESSs, and their evaluation is necessary to ensure that the chosen system meets the desired requirements and objectives. The selection of ESSs plays a crucial role in peak load shaving and transient mitigation of power grids by providing a fast response as well as a prolonged operation. However, a single ESS cannot meet these goals; consequently, hybridization of ESSs with high specific energy and specific power is the solution for proper compensation for power fluctuations in power grids. Therefore, combining the two ESSs will achieve better results leading to hybrid ESSs (HESSs). For example, combining a lead-acid battery and a supercapacitor (SC) compensates for the gap between high energy density and high power density, proving to be the optimum solution for HESS applications.

The ESSs mitigate the effect of sudden variations in solar PV power, wind power, and EVs. The use of HESSs supplies both steady-state and transient power demand in wind power generation and enhances the performance compared to the use of a single ESS. The common HESS combinations can be obtained as battery and SC; battery and flywheel; battery and superconducting magnetic energy storage (SMES); fuel cell (FC) and battery; battery and compressed-air-energy storage (CAES); FC and SC; and FC and flywheel. The increased penetration of RESs into the grid has a negative impact on PQ because of fluctuations in frequency, current, and voltage. Equipment failure or malfunctioning could result from these discrepancies [7]. PQ in a power system with RESs injection can be improved by ESSs using power regulation, energy shifting, and smoothening. EESs can improve voltage and frequency management by supplying the mismatch power between RESs power generation and load demand.

4. Emerging technologies in electric vehicles

The advancement in EV technology is one of the potential solutions to significantly reduce the greenhouse gas (GHG) emission share of the transportation sector. The weather patterns are changing throughout the globe and becoming hard to predict due to environmental deterioration and temperature rise due to GHG emissions. The transport sector contributes more than 30% towards the emission release into the environment. EVs have advantages over conventional internal combustion engine (ICE) vehicles due to reduced emissions, less fuel cost, and improved control. EVs have several benefits but there are certain limitations due to higher costs than ICE vehicles, long charging times, short battery life, and limited ranges. The primary issues with EV batteries are safety, cost, power density, dependability, and long span of life. A standard battery pack is typically expected to have a certain capacity for 10 to 15 years. At present batteries such as Li-ion, lead-acid, and nickel metal hydride are employed for EVs. Inadequate charging infrastructure and fast charging are the major problems for the EV market. The increase in EV demand created an urge for reliable and fast charging methods. Different fast battery charging techniques are being developed for Li-ion batteries as it is proven to be more reliable. Multi-level charging is a rapid and safe way to charge a battery. Hybrid RESs and SCs can be used with multi-level charging to charge the EV battery on a 24-hour basis. With fast charging technologies, an EV can be charged to (75–80)% of its state of charge in 15 to 20 minutes. The fast charging lowers the cost of operation and boosts the output as the fast charging boosts the vehicle speed and it is more efficient than regular chargers.

EVs have dynamic charging requirements, and their connection to the utility grid can introduce additional fluctuations in energy demand. These fluctuations need to be carefully managed to maintain the stability of the grid. Managing the flow of energy in the utility grid is inherently complex due to the integration of multiple energy sources and loads [8]. Balancing the generation and consumption of energy is essential to ensure the grid operates efficiently and effectively. Efficient EMSs play a crucial role in achieving this balance. By intelligently optimizing the energy flow, the utility grids can minimize energy costs and maximize the utilization of available resources. EVs are also a superior option for grid energy storage with the ability to reduce peak power demand by sending power to the grid, regulating frequency, and promoting the use of RE. By replacing the EV battery with a conditioned battery, lengthy wait times for battery charging facilities are reduced. That can provide instant service between EV owners and charging stations. The integration of EVs into MGs is a noteworthy criterion, as it explores the impact and opportunities associated with incorporating EV charging infrastructure and optimizing their operations within the MG context.

An integration of RESs into the utility grid can decrease harmful emissions. Environmental based economic dispatch is a complex optimization problem, and it is becoming more complex due to the integration of stochastic RESs. A novel chaotic Jaya optimization algorithm was proposed in [9] using the basic Jaya algorithm. These researchers investigated the impact of the integration of RESs into conventional systems by considering the generation cost and emission objectives. The researchers in [10] developed the electromagnetic processes of the stand-alone hybrid electrical system that provides power to autonomous energy consumers with varying load demands. This work developed and simulated of hybrid considering the hydrogen fuel cell and variable-speed diesel generator systems. The obtained results on MATLAB present the voltage and current changes in the critical components of a hybrid energy system considering the stepwise load changes.

5. Conclusions

The transition to renewable energy sources (RESs), energy storage (ES), and electric vehicles (EVs) has gained significant momentum, offering a promising pathway to reduce greenhouse gas (GHG) emissions and achieve energy sustainability. In this editorial on a special issue "Sustainable Energy Technologies for Emerging Renewable Energy and Electric Vehicles", I aim to present the most recent sustainable energy technologies of energy storage systems (ESSs) and EVs integrated with RESs. EVs and other bidirectional power components are part of the modern hybrid power system, including an increasing amount of distributed and fluctuating RESs. The goal of hybrid power grids is to generate energy with lower emissions, which promotes the adoption of sustainable and environmentally friendly energy generation methods. This will lead to enhanced energy efficiency, reliability, and sustainability within energy management practices. The selection of ESSs plays a crucial role in peak load shaving and transient mitigation of power grids by providing a fast response as well as a prolonged operation. The integration of EVs presents new challenges and opportunities in hybrid power systems. Decision-making processes need to consider the constraints associated with EV charging, such as charging time and capacity, to effectively schedule energy resources and accommodate the charging needs of the vehicles.

Use of AI tools declaration

The author declares he has not used Artificial Intelligence (AI) tools in the creation of this article.

Acknowledgments

This work was supported by “WOOSONG UNIVERSITY’s Academic Research Funding-2024”.

Conflict of interest

The author declares no conflict of interest.

References

1. Renewables 2022—Analysis and forecast to 2027. Available from: https://www.iea.org/reports/renewables-2022.
2. Solar PV technology and generation. Available from: https://www.iea.org/energy-system/renewables/solar-pv.
3. Gjukaj A, Shaqiri R, Kabashi Q, et al. (2024) Renewable energy integration and distributed generation in Kosovo: Challenges and solutions for enhanced energy quality. *AIMS Energy* 12: 686–705. https://doi.org/10.3934/energy.2024032
4. Liu Y, Xu Z, Yu Y, et al. (2024) A novel binary genetic differential evolution optimization algorithm for wind layout problems. *AIMS Energy* 12: 321–349. https://doi.org/10.3934/energy.2024016
5. Salkuti SR (2022) Emerging and advanced green energy technologies for sustainable and resilient future grid. *Energies* 15: 6667. https://doi.org/10.3390/en15186667
6. Kaur S, Brar YS, Dhillon JS, et al. (2022) Multi-objective real-time integrated solar-wind-thermal power dispatch by using meta-heuristic technique. *AIMS Energy* 10: 943–971. https://doi.org/10.3934/energy.2022043
7. Salkuti SR (2023) Advanced technologies for energy storage and electric vehicles. *Energies* 16: 2312. https://doi.org/10.3390/en16052312
8. Okafor C, Madu C, Ajaero C, et al. (2021) Moving beyond fossil fuel in an oil-exporting and emerging economy: Paradigm shift. *AIMS Energy* 9: 379–413. https://doi.org/10.3934/energy.2021020

9. Chaudhary V, Dubey HM, Pandit M, et al. (2024) A chaotic Jaya algorithm for environmental economic dispatch incorporating wind and solar power. *AIMS Energy* 12: 1–30. https://doi.org/10.3934/energy.2024001
10. Dar'enkov A, Kralin A, Kryukov E, et al. (2024) Research into the operating modes of a stand-alone dual-channel hybrid power system. *AIMS Energy* 12: 706–726. https://doi.org/10.3934/energy.2024033