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REVIEW ARTICLE

A survey on Renewable Energy in Power Management Systems: Trends, Technologies, and Future Perspectives

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***Abstract*—A switch to renewable energy sources (RES) is essential due to the growing demand for energy worldwide and the negative environmental impacts of fossil fuel-based power generation. Sustainable strategies to halt climate change, reduce greenhouse gas emissions, and provide long-term energy security include renewable energy technologies including solar, wind, hydro, geothermal, and biomass. However, because RES are intermittent, integrating them into power management systems (PMS) is difficult and calls for sophisticated control mechanisms for efficiency and stability. This study examines power management systems (PMS) in the context of renewable energy integration in detail, focussing on important technologies such as hybrid energy systems, microgrids, smart grids, and superconducting magnetic energy storage (SMES). The application of machine learning (ML), artificial intelligence, and predictive analytics to energy forecasting and optimization is also covered. The paper also explores challenges in global energy sector development, including infrastructure limitations, economic constraints, and policy considerations. To speed up the worldwide shift to renewable energy-driven power management systems, future research directions are finally highlighted, highlighting the necessity of creative energy storage options, improved grid resilience, and sustainable energy regulations.**

Keywords*—Renewable Energy, Power Management Systems, Smart Grids, Microgrids, Energy Storage, Artificial Intelligence, Machine Learning, Predictive Analytics, Grid Stability, Energy Forecasting, Hybrid Energy Systems, Sustainable Energy.

I. INTRODUCTION

The global demands, especially in developed and developing countries, demand that energy technology be used in place of conventional electrical-producing resources like fossil fuels. Global warming and climate change are two detrimental environmental issues caused by energy sources based on fossil fuels. Over the last several decades, the quantity of greenhouse gases that electricity generation has discharged into the environment has increased exponentially. Therefore, in order to mitigate the current environmental catastrophe, RE such as solar, wind, hydro, biomass, geothermal, and hydrogen have been proposed to create power.[1].

An essential component of manufacturing in the contemporary economy is energy. Additionally, rising energy consumption coincides with the world economy's faster growth [2]. To fulfill the expanding demands of humanity, energy output must inevitably rise. The basis of energy sources is the utilization of non-renewable natural resources. Unquestionably the most important are fossil fuels, which encompass coal, oil, and natural gas and were produced over millions of years. Since they are non-renewable natural resources, their amount is quantitatively restricted, and the possible depletion of these and other non-renewable natural resource reserves is a serious concern for mankind [3].

Systems for capturing energy from renewable natural resources, such as sunshine, wind, water, and geothermal heat, are known as renewable energy systems. Fossil fuels, which are scarce and significantly worsen climate change and environmental damage, are not the same as these systems [4]. In order to mitigate the consequences of climate change, cut greenhouse gas emissions, and attain sustainable development, the world must move towards renewable energy. Definitions of essential concepts are necessary to comprehend the idea of renewable energy systems. Renewable energy is defined as energy generated by continuously replenishing natural processes, including energy from biomass, geothermal, hydropower, wind, and solar sources [5].

Integration of renewables and other distributed energy resources (DER) is partly hindered by intermittent nature of renewables, whose adverse effects have led to establishment of corrective measures just in case operational and power quality issues are prevalent; demand side management and protection planning are among the security measures power system operators have to take into consideration [6]. The control goals and compensation length of the power management systems (PMS) varied significantly. When developing an energy management plan, researchers must take into account important factors including system life, fuel costs, maintenance expenses, and capital costs [7].

A. *Structure of the paper*

The structure of this document is as follows: The foundations of power management systems (PMS) are described in Section II. The use of renewable energy sources in power management is covered in Section III. Section IV discusses obstacles to the growth of the global energy sector. Section V reviews literature and case studies. Section VI concludes with findings and future research directions.

II. Fundamentals Of Power Management Systems(PMS)

A Power Management System (PMS) is a critical component in modern electrical networks, designed to optimize energy generation, distribution, and consumption while ensuring efficiency, reliability, and sustainability. In MG and NG applications, power management systems are used to balance the supply and demand units in utility grids (in the case of grid-connected systems) by continually adjusting the DC bus voltage using the ESS. The PMS helps manage the flow of both reactive and real power to improve MG operations [8]. The primary objective of the PMS is to balance the output power from dispersed generators with the demand for load electricity. The PMS may be used to accomplish a number of objectives, such as voltage support, transient power support, and power factor adjustment. The MG system's operating conditions are directly impacted by the three main electrical components employed in the PMS: current, voltage, and power [7].

A. Key Functions of PMS in Renewable Energy Integration

A steady power supply, stable grid, and effective energy distribution are all made possible by PMS, which are essential in the growing use of RES including solar, wind, and hydroelectric power. Unlike traditional power sources, renewables are inherently variable due to factors like time of day and weather. PMS helps address these challenges by optimizing the balance between energy generation and consumption through intelligent control mechanisms.

1) Grid Synchronization

Grid Synchronization ensures that renewable energy sources match the grid's voltage, frequency, and phase for stable operation [9]. Since solar and wind energy fluctuate, PMS helps balance power supply, maintain frequency stability, and integrate Distributed Energy Resources (DERs). Technologies like FACTS, HVDC, PLL, and smart inverters aid in stabilizing and optimizing grid performance [10].

2) Forecasting and Predictive Analytics

Predictive analytics and forecasting employ AI and ML to identify trends in the generation and consumption of renewable energy [11]. This enhances grid stability by preparing for fluctuations, improves energy planning by optimizing dispatch strategies, and ensures cost efficiency by reducing reliance on expensive backup power. Key technologies include ML models (LSTM, CNN-ESN, GRU) for energy prediction, Big Data Analytics for optimization, Real-time data collecting using IoT sensors and smart meters, and energy scenario simulation using digital twins[12].

3) Hybrid Energy Management

In order to maintain load balance and an efficient power condition, hybrid energy management combines power sources such as solar, wind, and hydropower with battery management. In conjunction with that, the PMS's primary goal is to keep battery storage and backup generation operational in order to achieve load leveling and, therefore, continuous power supply while minimizing the consumption of fossil fuels. Essential technologies include microgrid control systems to manage these regions, batteries for renewable energy storage, energy management systems for load forecasting, and hybrid power converters for DC/AC interface [13].

B. Technologies for Renewable Energy Integration in Power Management Systems

In order to achieve effective and sustainable energy use, power management systems must incorporate renewable energy sources (RES). Various technologies enable this integration, ensuring grid stability, energy efficiency, and optimal utilization of renewable resources. The key technologies include:

1) Microgrid To Smart Grid

The smart grid states represent the progress of electrical networks. A smart grid is a type of electrical network that can economically integrate the actions and behaviors of all users, including consumers, generators, and those who do both. This, according to the ERGEG, which was created using the ETPS definition, ensures a cost-effective, sustainable power system with low losses and high standards of quality, supply security, and safety. The few domains in Figure 1 provide a brief overview of the smart grid model concept..

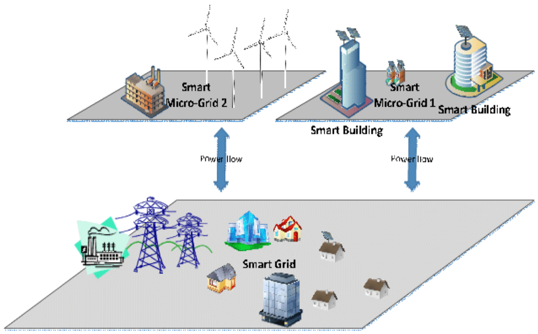

Fig. 1. Microgrid to smart grid

2) Superconducting Magnetic Energy Storage (SMES)

A superconducting coil, which is a component of SMES, can store electric energy as a magnetic field produced by DC current flowing through it. Electrical resistance does not exist in this coil. The coil also doesn't lose energy [14]. The second part of SMES is a cryogenically cooled refrigerator, which uses liquid nitrogen or helium to maintain the coil at a cryogenic temperature. As a result, around 2–3% of the energy is wasted as a result of the cooling mechanism. A power conditioning system is the third component of SMEs, which transforms the stored energy into AC power [15]. The temperature of the coil ought to be lower than its critical temperature. Figure 2 displays an SMES's schematic representation.

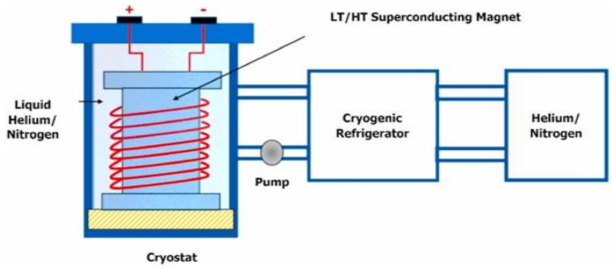

Fig. 2. Superconducting magnetic energy storage (SMES)

3) Geothermal energy

The heat that is stored under the Earth's surface is used to generate geothermal energy. It may be utilized straight for heating and cooling or harnessed to generate power. Geothermal energy accounted for approximately 0.3% of global electricity consumption [16]. The following Figure 3 shows the geothermal energy.

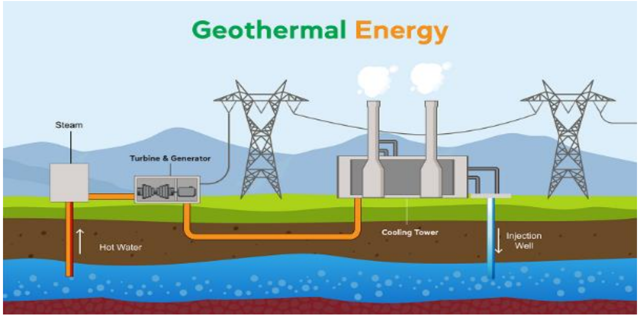

Fig. 3. Geothermal Energy

III. Renewable Energy Sources In Power Management

In the context of power management, Reduce reliance on fossil fuels and the associated environmental repercussions by using renewable energy sources, which include natural, replenishable energy sources like sun, wind, and hydropower, to generate electricity and maintain a sustainable power system [17]. Because they provide sustainable and eco-friendly substitutes for fossil fuels, renewable energy sources are essential to contemporary power management. These sources harness naturally replenishing resources, ensuring long-term energy availability while reducing greenhouse gas emissions and dependence on finite resources. Effective power management using renewable energy involves optimizing energy generation, distribution, storage, and consumption for maximum efficiency and reliability.

A. Key Renewable Energy Sources in Power Management

Quality Renewable energy sources commonly used in power management and this are include:

1) Wind Energy

The WECS is made up of converters and wind turbines. Wind turbines supply generators with mechanical energy, which they then transform into electrical energy. After that, the energy is transferred via the converter system to either the power grid or a battery bank [18]. The two most often used generators for converting wind energy at varying speeds are synchronous and DFIG generators [19].

2) Solar Energy

The amount of solar energy emitted in the form of heat and radiation. Figure 4 shows this. Various ever-evolving technologies have the potential to capture the sun's rays and heat for various uses, artificial photosynthesis, solar thermal energy, solar heating, solar architecture, and power plants that use molten salt. Solar energy is a highly attractive power source because of its availability. Oceans, clouds, and landmasses absorb the remaining 30% of solar radiation, with the other 30% being reflected back into space [20].

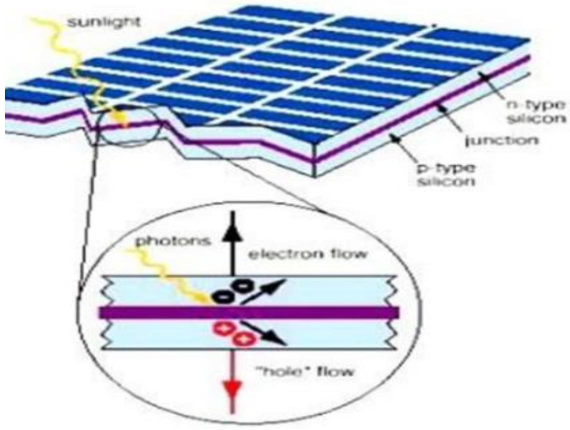

Fig. 4. Internal of Reaction of Solar Energy

3) Hydropower Energy

One of the biggest and oldest renewable energy sources, it creates power by harnessing the natural flow of flowing water. [21]. The water's density, head, and flow discharge all affect the amount of hydropower produced. The hydroelectric plants are categorized according to the amount of power they produce that illustrate in Figure 5. The power plants are classified as either "small hydro" (up to 10 MW) or "large hydro" (above 10 MW).

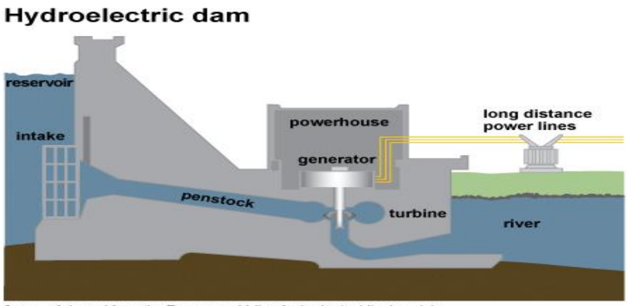

Fig. 5. Hydropower Energy

B. Role of Renewable Energy in Power Management

Power management benefits greatly from renewable energy as it offers sustainable substitutes for conventional energy sources. Renewable energy sources can be efficiently integrated into smart grids because of their ability to respond to variations in supply and demand [22]. Systems that store extra energy for later use, such as pumped hydro and batteries, aid in grid stabilization.

- **Grid Integration & Stability:** Real-time power use monitoring and management are made possible by smart grids, which make it easier to integrate renewable energy sources like solar and wind [23]. These grids adapt dynamically to changes in the supply and demand for electricity, enhancing the power system's overall stability.
- **Demand-Side Management (DSM):** Demand-side management encourages customers to utilize electricity when renewable energy is plentiful, which helps to optimize energy use, thus reducing strain on the grid. Through demand-response programs, utilities can shift electricity loads to match peak renewable generation, enhancing the efficiency of energy distribution [24].

- **Hybrid Energy Systems:** A continuous, dependable power supply is provided by hybrid energy systems, which combine traditional power-generating techniques with renewable energy sources like the sun and wind. Grid resilience is increased by this integration, particularly in isolated or disaster-prone regions, by establishing microgrids that can operate independently of the main grid as needed [25].
- **Energy Storage Solutions:** Energy storage technologies like batteries, compressed air, and thermal storage are essential for increasing the efficiency of renewable energy sources. These systems store excess energy when output is high and release it when demand is high or renewable generation is low [26].
- **Policy & Incentives:** To promote the use of renewable energy technology, governments and utilities offer feed-in tariffs, tax credits, and subsidies. These regulations speed up the switch to sustainable energy and lower the upfront investment expenses [27].

IV. Challenges For Global Energy Sector Development

The primary obstacles to renewable energy's ability to compete in the global energy market are:

- The necessity of making large expenditures in order to carry out initiatives in the field of renewable energy. Many low-income nations lack the capacity to spread renewable energy technology and foster the growth of their own. The growth of renewable energy is directly impacted by increased economic development since it often results in greater public and private investment [28].
- Energy use is subsidized by fossil fuels. Energy subsidies are still used by governments in many nations today to assist low-income energy users. As a result, worldwide subsidies for the use of fossil fuels were $400 billion in 2018, which is far more than the amount invested in renewable energy [29].
- The electrical grid's infrastructure is outdated and cannot support significant RE penetration. Issues with bus stability, such as flickers, grid fault-ride through, harmonic distortion in currents, voltage fluctuations, and voltage drop or rise, will arise from the integration of VRE into the electrical grid [30].
- Technology that can absorb, store, and utilize CO_2 from industrial power plants, store it underground, or utilize it for other applications like carbon mineralization or increased oil recovery is crucial [31].
- Educating and raising public awareness may sometimes be quite difficult. The environmental effects of conventional energy sources and the advantages of renewable energy are not widely known. In addition to promoting public involvement in renewable energy projects, governments and organizations should endeavor to educate the public about renewable energy and its advantages [32].
- The absence of proper informational and educational policies on clarification of the benefits and the necessity of financial support for renewable energy is the reason for the population's low knowledge of the advantages of renewable energy. Thus, there are several economic, political, technological, and social obstacles to the development of renewable energy that need to be reduced in order to hasten this industry's growth [33].

V. Literature Review

The following section provides the literature review for A survey on Renewable Energy in Power Management Systems: Trends, Technologies, and Future Perspectives.

In this study, Eyimaya, Altin and Bal (2021) the use of backup energy storage and the elimination of power fluctuations brought on by abrupt changes in environmental variables like wind speed and solar radiation, the proposed BESS control system improves load and grid power quality. Wind speed and solar radiation are examples of natural variables in renewable energy sources. Since it is hard to continuously maintain the balance between energy output and demand, BESSs and energy management units are used in these systems. The hybrid system, which comprises wind turbines and solar photovoltaic (PV) modules, is modeled and assessed using MATLAB/Simulink, along with the recommended control method[34].

In this study, Saranya and Samuel (2023) Reviewing earlier research that employed interpretable machine learning techniques for energy management allows you to see how model interpretability is improved. There is a clear discussion of the methods and algorithms that support energy management. Additionally, a comparison of the various approaches is conducted to determine which is the most effective energy management strategy. This study reviews previous works that employed interpretable machine learning algorithms for energy management in order to investigate how model interpretability is enhanced[35].

In this study, Ravikumar et al. (2023) examine how the Internet of Things can transform the electrical system, renewable energy, and electric cars. Energy distribution and consumption may be altered via intelligent energy management systems, V2I communication, and smart charging stations. EVs must have V2G capabilities, batteries, and charging infrastructure in order to become fully used as distributed energy resources and integrated into the power grid. The article also discusses the rise of electric vehicles and renewable energy in the electrical industry. Clean and sustainable energy sources include hydroelectric, solar, wind, and biomass[36].

In this study, Le, Chuduc and Tran (2024) provide useful insights to the field of sustainable urban development and energy-efficient building design by evaluating current trends, difficulties, and research needs. In order to meet global sustainability targets and move towards a future with reduced carbon emissions, the findings emphasize how important it is to enhance the intelligent buildings' integration of renewable energy[37].

In this study, Bizhani, Rezayof Tatari and Iwanski (2024) All of the possible HES operating modes are specified, taking into account the local load and battery condition. The ARPM scheme is then developed to adjust the battery's reference current and the reactive component of the grid's current, thus ensuring comprehensive reactive power support for stabilizing the grid voltage while allowing the seamless transfer of generated active power to the grid. Additionally, an active power reduction mechanism is introduced to limit the power output from the solar system, thereby freeing up the shared inverter's unused capacity for reactive power provision[38].

In this study, Udayakumar et al. (2023) Assess the system's cost-effectiveness and the utilization of renewable energy sources (RES) to supply heat and electricity to a typical Indian home is the aim of this study. An analysis is conducted on how the feed-in tariff adjustment affects the investment's value. In order to satisfy the energy requirements of a typical family, they examine a small, grid-connected hybrid system. In order to generate electricity, they have proposed a hybrid system that harnesses the power of the sun, wind, and hydro. Since high-rise building rooftops are typically empty, putting solar panels allows us to harness the building's solar energy[39].

TABLE I. LITERATURE ON ROBUST CONTROL FOR RENEWABLE ENERGY IN POWER AND ENERGY MANAGEMENT SYSTEMS

References	Focus Area	Performance	Limitations & Future Work
[34]	BESS control for mitigating power fluctuations in hybrid wind-PV systems	Improves grid power quality and stability by balancing energy production and demand	Further optimization of control strategies for real-time adaptability and integration with smart grids
[35]	Interpretable Machine Learning (IML) techniques for energy management	Enhances model transparency and effectiveness in energy optimization	Needs validation on larger datasets and real-world deployment for scalability
[36]	IoT-enabled energy management for EVs and renewable integration	Supports smart charging, V2G connectivity, and intelligent distribution for energy efficiency	Requires improvements in battery technology and advanced communication protocols for seamless integration
[37]	Renewable energy integration in smart buildings for sustainable urban development	Highlights the importance of intelligent energy management for reducing carbon footprint	Calls for advanced AI-driven solutions and smart grid enhancements for efficient deployment
[38]	Adaptive Reactive Power Management (ARPM) for hybrid energy systems (HES)	Stabilizes grid voltage and ensures smooth power transfer while optimizing inverter capacity	Further research needed on dynamic load conditions and multi-energy source optimization
[39]	Hybrid renewable energy system for household energy supply in India	Cost-effective hybrid system utilizing solar, wind, and hydro	Needs policy support and incentives for large-scale adoption and feed-in tariff modifications

VI. CONCLUSION AND FUTURE WORK

A sustainable and eco-friendly energy future depends on the incorporation of renewable energy into power management systems. This study has investigated the function of various renewable energy sources, such as solar, wind, hydropower, biomass, and geothermal energy, in contemporary power management systems. The potential of key technologies including blockchain, energy storage systems, smart grids, and artificial intelligence to promote grid stability and effective energy use has been investigated. Nonetheless, there are still several major problems to overcome, including energy intermittency, high upfront investment costs, regulatory restrictions, and complicated grid connectivity. Addressing these issues requires continued advancements in technology, favorable laws and better infrastructure to enable the smooth integration of renewable energy.

Future research should focus on enhancing energy storage technologies, optimizing power distribution through AI-driven predictive analytics, and developing decentralized energy trading models using blockchain. Additionally, hybrid renewable energy systems, smart grids with IoT-enabled automation, and secure energy management frameworks must be explored to improve system efficiency and resilience. A more reliable and adaptable energy network will also be facilitated by the incorporation of electric cars into energy grids and the creation of strong cybersecurity safeguards for smart power systems. By pursuing these lines of inquiry, the shift to a sustainable and clean energy landscape.

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