Innovative Journal for Opportunities and Development in Science & Technology,
Volume 6, Issue 2, Jan 2026
Paper Id: – IJ2025V6I2 -2 A-F
ISSN 2582-6026

AI - POWERED SMART MICRO GRID WITH RENEWABLE ENERGY INTEGRATION

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ABSTRACT- Energy management improves operational effectiveness, lowers carbon emissions, and increases energy efficiency while lowering energy costs and consumption. Smart grids are a kind of advanced energy infrastructure that use digital communication technology to improve the sustainability, reliability, and efficiency of electricity generation and distribution.. They combine a number of cutting-edge techniques and technology to improve energy resource management. Energy management reduces carbon emissions, boosts energy efficiency, and enhances operational performance while reducing energy expenses and consumption. Smart grids are a type of sophisticated energy infrastructure that enhances the sustainability, dependability, and efficiency of electricity production and distribution through the use of digital communication technologies. Management are an innovative field of study aiming at tackling various difficulties and magnifying the efficiency, dependability, and sustainability of energy systems, including: 1) Renewable sources of power like solar and wind are intermittent and unpredictable 2) Defending smart grid system from various cyber-attacks 3) Incorporating an increasing number of electric vehicles into the system of power grid without overwhelming it. Additionally, it is proposed to use AI and data analytics for better performance on the grid, reliability, and energy management. It also looks into how AI and data analytics can be used to optimize grid performance, enhance reliability, and improve energy management. The authors will explore these significant challenges and ongoing research. Lastly, significant issues in this field are noted, and recommendations for further work are provided.

Keyword - Energy management, Renewable Energy, AI in Power, Smart Grid, Defending Cyber Attack

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I. INTRODUCTION

In emerging nations, electricity is an essential energy source for meeting people's needs and promoting economic development. Reliable and efficient power transmission is essential for a nation's economic health . Since CO2 emissions significantly contribute to global warming, targeting the major sources of these emissions, such as transportation and power generation, is key to addressing climate change. A viable route to a sustainable future is the switch to electric vehicles (known as EVs) and renewable energy sources (in short RESs). Moreover, integrating energy storage systems (ESSs) or battery energy storage systems (known as BESSs) into the current grid and replacing conventional fuel-based Transportation with electric alternative such as plug in hybrid electric vehicles(known as PHEV) as well as known as electric vehicles(in short PEVs) are workable strategies to reduce the Sharpe rise in greenhouse gas GSG emission. Unlike convention energy source, renewable energies are characterized by their variability and intermittency. By combining several RES with energy storage systems (ESS) and backup sources, the fluctuation of RES may be controlled. However, this unpredictability can seriously impair the voltage stability of the system, interfere with conventional on-load tap changer management procedures, and negatively effect the power grid's overall performance. As an An energy management sys- tem (EMS) is essential for optimizing the potential of new resources and types of loads on the electricity network, reducing their negative impacts, ensuring continuous load sup- ply under all conditions, and enhancing network stability . Ac- cording to the International Electrotechnical Commission's IEC 61970 standard,an EMS is defined as "a computer system comprising a software platform that offers essential support services and a set of applications necessary for the efficient operation of generation and transmission systems to ensure energy supply security at minimal cost. In order to provide cost-effective, reliable, and secure electrical system operation, energy management within the framework of a smart grid (SG) ensures supply and demand balance while adhering to all system constraints..

A. ALONG VIEW OF ENERGY MANAGEMENT- FROM FIRE TO SMART GRIDS.

Although the idea of contemporary energy management is relatively new, humankind has been searching for effective power utilization for millennia. Early humans demonstrated a persistent desire to maximize resource usage by conserving fire for warmth and later using wind and water to create simple machines. The development of the steam engine in the 18th century marked a major turning point. James Watt's design pri- oritized efficiency, enabling a significant reduction in fuel consumption for the same power output . However, the oil crisis of the 1970s is credited with giving rise to contemporary energy management. This incident prompted a change from merely consuming less energy to actively controlling it. The 1980s saw the rise of energy audits, monitoring sys- tems, and efficiency upgrades, reflecting a focus on proactive management. This period also witnessed the introduc- tion of micro-combined heat and power (CHP) technology in

1981, offering efficient on-site generation, and the launch of the Energy Efficiency Year campaign in the UK (1986). After that, the emphasis shifted to strategic energy procurement, but in the 2000s, environmental concerns prompted a move toward renewable energy sources and carbon reduction. .

B. WHAT EXACTLY DOES ENERGY MANAGEMENT ENTAIL-

A methodical approach to managing the full energy lifecycle, including production, distribution, and consumption, is known as energy management. This is accomplished by combining methods and tools aimed at increased productivity, including renewable energy sources, and employing demand control techniques. Utilizing sophisticated tools and systems, energy monitoring and data analysis follow historical trends and real-time consumption to uncover more improvement options. In addition, the incorporation of energy from renewable sources such as wind and solar power is essential for decreas- ing dependency on fossil fuels and lowering greenhouse gas emissions Finally, sustainability planning establishes a long-term vision to ensure responsible energy use, meeting regulatory require- ments and aligning with corporate goals for environmental stewardship.

C. THE SMART GRID CONCEPT IN MANAGEMENT OF ENERGY

Although the idea of a sharper electrical grid has been around for decades, widespread adoption has not happened yet. There are limits to the effectiveness, reliability, and ability to incorporate renewable energy sources into the traditional electrical grid, which is a complex network of generating plants, transmission lines, and distribution networks.

II. LITERATURE REVIEW

a. Challenges in modern power grids

With its extensive network of plants of power, lines for transmission, and distribution systems, the present power grid is finding it difficult to meet our expanding energy needs. According to a research by the International Energy Agency, there will be a 30% increase in global energy consumption by 2040 [46]. This challenge is driving the development of smarter grids. In Pakistan, for instance, monthly electricity demand is expected to jump from 120,000 GWh in 2019- 2020 to 200,000 GWh by 2024-2025, highlighting the need for a more efficient system [2]. To address these challenges, researchers are actively exploring ways to improve energy management systems and integrate them with smart grid technologies for a more sustainable and reliable future.

b. Energy management systems (ems), demand response programs (drp) and the role of iot and cloud computing in smart grids

The study [47] report offers the most recent information on various energy administration

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platforms at the network, aggregator, and household levels. Each system's benefits and drawbacks are examined and contrasted, taking into account its primary components—objective functions, limitations, algorithms for optimization, communication protocols, and the effect of EVs. Home EMS (HEMS) refers to energy management done at the house level, and Grid EMS (GEMS) refers to energy management done on the grid side. By utilizing the adaptability of the controlled loads at home, the HEMS lowers the cost of power. The GEMS is primarily focused on minimizing power losses, operating costs, and voltage control. Program for Demand Response (DRP) In order to balance a customer's power consumption and the utility's power supply, DRP modifies the consumer's demand for electricity on the energy grid. DRP is a crucial part of EMS that reduces peak demand, enhances load profiles, and permits greater utilization of system resources. DRP im- proves power system performance, minimizes voltage vari- ation, optimizes income, and lowers operating expenses in addition to ensuring a dependable power system.

The time cost (TOU) [48], immediate pricing (RTP) [49], crucial peak costing [50], and tending block rate [51] are examples of price-based techniques, as seen in Fig. 1. The market-based or traditional incentive-based approaches are further subdivided into capacity markets, demands bidding, interruptible loads, direct load control [52], and urgent de- mand reduction.

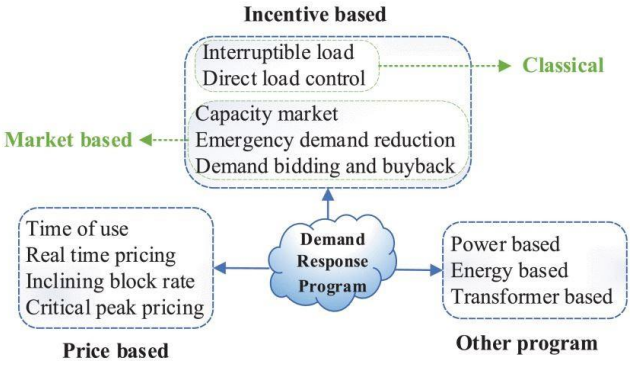
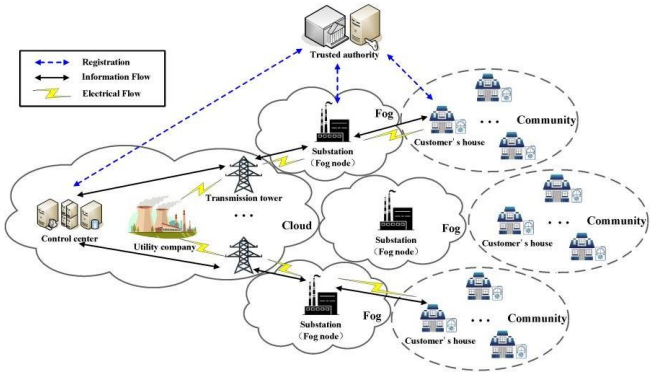


Fig 1: Classification of demand response programs



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Fig 2: Proposed fog-based smart grid's system model of research

The goal of the authors' review [57] is to examine how machine learning (ML) tech- niques are used in Smart Grids (SGs) to identify and mitigate cyberattacks. They address various instructional paradigms (supervised, unsupervised, and reinforcement learning) and modeling architectures (ordinary, hybrid, and ensemble), and they offer guidelines on ML model selection. They also categorize ML tools based on model complexity and security attributes (Confidentiality, Integrity, and Availability – CIA). The review also outlines the difficulties, limitations, and pos- sible solutions for using ML in SG cybersecurity. The main goals are to provide a thorough review of the most recent machine learning methods used in security governance (SG) contexts for cyberattack analysis and to provide best practices for developing models of prediction for attack detection.

III. COMPONENTS OF SMART GRID

i. **Custome:** Building automation and control systems serve as the central management hub of a building. These systems integrate instrumentation, control, and management technologies for all structures, plants, outdoor facilities, and equipment within the building.

ii. **Bulk Generation:** Smart generation involves in- creased use of power electronics to manage harmonics, address fluctuating generation failures from renewable energy, and enhance the flexibility of fossil power plants due to the higher integration of renewable en- ergy sources.

iii. **Transmission and Distribution:** The energy manage- ment system (EMS) operates as the control center for the transmission network [62], requiring open archi- tecture for easy IT integration and better backups to prevent blackouts. Power electronics, including HVDC and FACTS systems [62], enable control of power flow and help increase transport capacity without causing short-circuit increases.

iv. **Communication:** Current data communication within the network is primarily one-way, leading to longer recovery periods during faults. Many devices, such as transformers, remain isolated and cannot be moni- tored online. Installed protection equipment is largely electromechanical and lacks integration with digital sensors, limiting the information available to operators in control rooms.

IV. AI AND DATA ANALYTICS IN SMART GRID

The success of the smart grid power paradigm will depend on how well the big data analytics component performs. Large data collection, transport, processing, interpretation, visualization,

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and application are all included in this. The study [104] provides detailed insights on several big data technologies and discusses big data analysis in connection to the smart grid. The [104] study also discusses the challenges and opportunities presented by the development of big data from electrical grids and machine learning. An executive summary of the data stream entering the utility is displayed in Figure 7.

Pre-established methodologies are necessary for Big Data analytics due to the large amount of data [104]. The speed and diversity of data can present difficulties for data analytics procedure. Real-time processing of the smart grid's data is essential because it allows for the identification of important trends that can be used to inform decision-making [104]. The

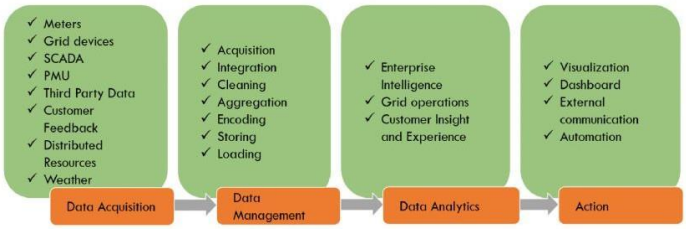


Fig 3: High-level view of the flow of data into the utility

V. CONCLUSION

This article provides an overview of the smart grid's history, features, technology, applications, advantages, opportunities, challenges, and future potential. The significance of integrating smart grids with renewable energy sources is also thoroughly examined in this study. The study's main goal is to identify the main challenges that smart grids must overcome, including the inconsistent supply of renewable energy, worries about cybersecurity, and the incorporation of electric vehicles under the grid. The authors also look into how data analytics and AI might be used to solve these problems and improve smart grid performance. The report offers helpful suggestions for future areas of study in this quickly expanding discipline by evaluating the state of the field and emphasizing important concerns. Rejuvenating the power infrastructure makes it possible to implement demand side management plans for global energy management.

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