Smart Home Powered by New Energy: Energy Management Systems (EMS) Technologies and Future Prospects

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Abstract. The world needs to switch to sustainable energy sources, and smart homes are emerging as a key frontier in this shift. Energy Management Systems (EMS) are essential in this situation for maximizing energy use and guaranteeing effective use of renewable resources in residential settings. Integrating new energy sources with the changing needs of contemporary households is a challenge. This analysis explores cutting-edge EMS systems designed for smart homes, highlighting its potential for utilizing renewable energy sources like solar and wind. Our thorough research shows that combining artificial intelligence with optimization techniques like particle swarm optimization opens up interesting new directions for demand-side management and dynamic energy scheduling. These developments redefine our notion of sustainable household energy management while also improving the efficiency of smart houses. In essence, the combination of EMS with smart home technologies ushers in a new era in domestic energy, paving the way for a more environmentally friendly and economically sensible future.

Keywords: Smart home, energy management systems, renewable energy resources, artificial intelligence.

1. Introduction

The use of new energy sources in the field of smart homes has emerged as a research hotspot as the world's focus on renewable energy has recently increased [1]. Traditional household energy systems rely largely on fossil fuels like coal, oil, and natural gas, but these energy sources are also scarce and emit a lot of greenhouse gases when consumed, which unquestionably exacerbates the global greenhouse effect. In contrast, clean, sustainable, and ecologically friendly options are provided by emerging energy sources including solar, wind, and hydropower. The primary distinction between traditional and new energy families is the type of energy they use and how it is managed. In order to achieve self-sufficiency and lessen reliance on external power networks, new energy households place a high priority on the efficient use of energy and make use of cutting-edge technologies. Traditional homes lack many benefits that come with new energy homes, thus the latter are rapidly being substituted.

The general public is no longer unfamiliar with the idea of a smart house. The home is enabled to become more automated and intelligent by the integration of many household equipment into a centralized management system [2]. An Energy Management System (EMS) is the name for this centralized system. Monitoring, controlling, and optimizing household energy use to ensure that it is used efficiently are the main duties of an EMS. To meet the unique requirements of the user, the EMS must be tightly integrated with a variety of sensors and communication technologies. In order to give the user recommendations for the best energy use, the EMS continuously gathers real-time data and information from the home environment, such as temperature, humidity, lighting, and human activities [3]. Then, it does computations and generates predictions using sophisticated algorithms and models to examine this data. For instance, if the EMS detects a rise in internal temperature, it can select to charge household appliances with less expensive electricity during off-peak hours. It can also automatically modify the air conditioning settings. The EMS may also interact with the external power grid to facilitate energy scheduling and trade, further increasing energy efficiency.

A vital part of the smart home sector is the Home Energy Management System (HEMS). HEMS, the final component of an integrated future energy system, enables homeowners to manage the use of their household appliances, renewable energy generation, energy storage systems, and even electric vehicles in an efficient and practical manner. A holistic approach is widely used to arrange the associated physical equipment of various types, centering on the preferences of users. Integrating energy storage and electric vehicles into the HEMS can lead to more flexibility, financial gains, and even longer battery life [4].

This paper will delve into advanced EMS technologies related to renewable energy, examine the underlying technologies that support the smart home, and evaluate prospective optimization tactics and future technology trends for HEMS from a forward-looking standpoint.

2. Home Energy Management Systems

An integrated intelligent system called a smart home energy management system is created to optimize energy use within the home, resulting in energy savings and efficiency. HEMS uses a range of technologies to do this, with sensor and communication technology playing a crucial role [5]. Figure 1 provides a preliminary understanding of the HEMS system.

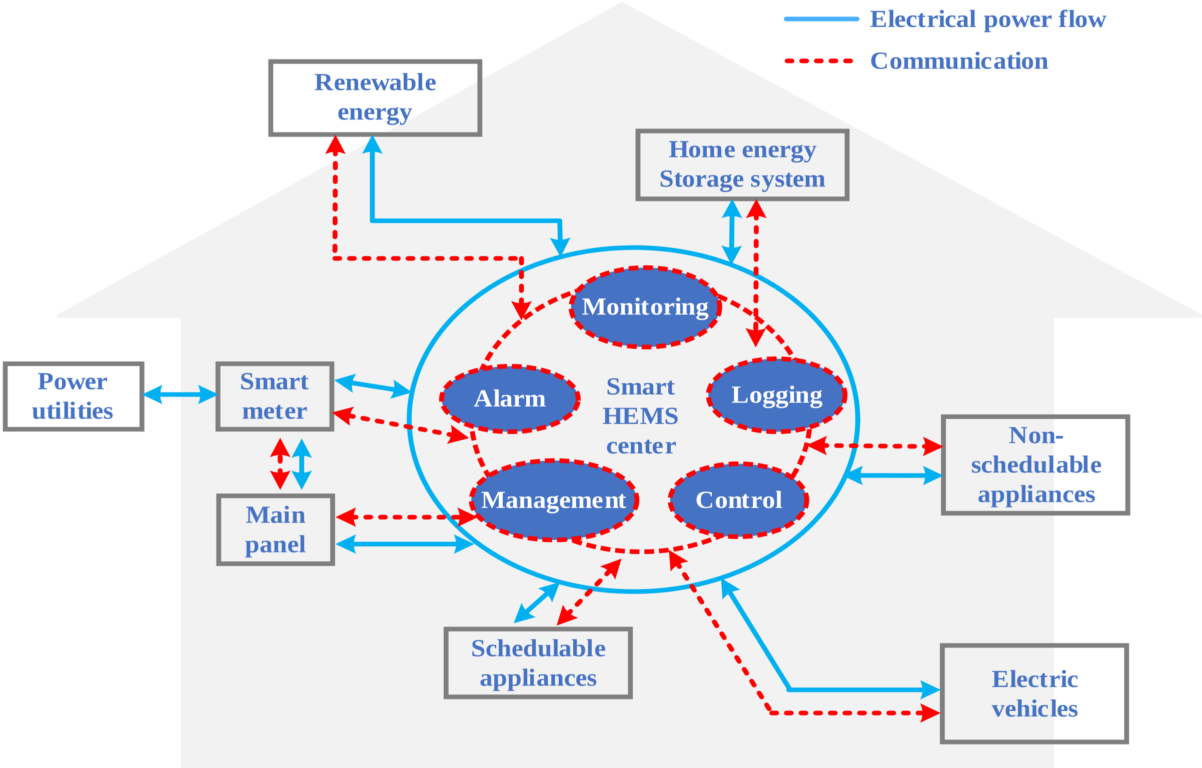

Fig. 1 The general design of a sample HEMS [4]

The main goal of a smart home energy management system is to control and monitor household energy use in real-time in order to optimize it. With HEMS, households can increase the effectiveness of energy use and reduce their energy costs. In more detail, HEMS technology can guarantee optimal use of appliances. Home users are more worried than ever about using energy efficiently and preventing the financial losses linked to energy waste as global energy demand rises and energy prices vary. In addition, home users want to use renewable energy sources like solar and wind technologies more efficiently, and different EMS technology principles offer ways to do so [6]. As a result, there is an increasing need to convert EMS technologies that are integrated with new energy sources into HEMS technologies that are integrated with new energy sources.

Integration is yet another important HEMS principle. As a result, HEMS is a complicated system that incorporates a number of different technologies and apparatuses rather than being a simple system. Together, these tools and technology make it possible for homes to use energy as efficiently as possible. To accomplish this, HEMS must gather and analyze data in real-time in order to forecast energy consumption and base choices on these forecasts [6].

Last but not least, EMS also stresses user involvement. As a result, EMS is a system that homeowners may interact with, rather than just a "back-office" technology. Users can choose their home electricity consumption plan remotely using their computers or cell phones, which enables them to live more sustainably and with less energy use. The temperature and illumination brightness can be customized by the user, and HEMS will adapt to their preferences. This guarantees that the HEMS not only satisfies the user's energy requirements but also creates a cozy and enjoyable living space [6].

3. Key Technology for Home Energy Management Systems

3.1. Sensor Technology

Smart home systems heavily rely on sensor technologies. These sensors serve as the smart home system's eyes and ears, continuously gathering information about the outside world to support house intelligence. Numerous inputs from the physical environment can be detected by sensors, including window and door contact, human presence (for lighting, heating, and security), motion, humidity, temperature, etc.. General-purpose, light, motion, sound, humidity, and temperature sensors are employed in some instances [6].

Additionally, wireless voice sensor-based smart home control systems open up new avenues for home automation [7]. These devices can be operated via voice commands, giving consumers a more user-friendly and practical method of operation.

HEMS and sensors are inextricably linked, for instance, HEMS can detect human touch with doors, windows, and floors, which gives smart home energy control systems the fundamental data they need to decide whether to turn on or off appliances. Figure 2 demonstrates how sensors enable the system to communicate with the outside world.

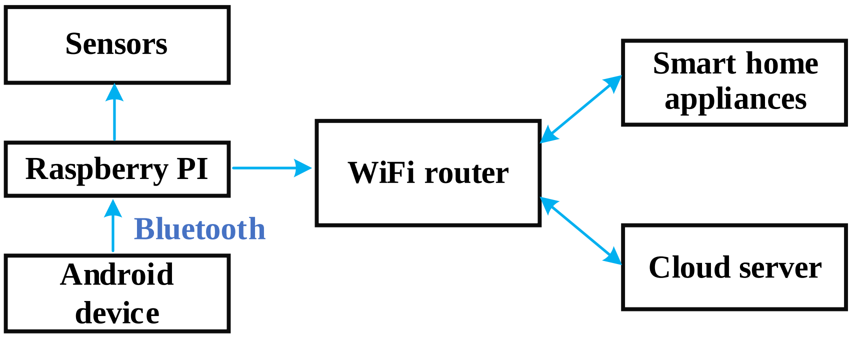

Fig. 2 Smart home system model based on Raspberry PI and Andro [4]

3.2. Communication Technology

Compared to the other communication technologies used in the smart home system, Bluetooth technology is regarded to be more useful. Communication technology plays a crucial role in the smart home by ensuring that the data collected by the sensors is efficiently sent to the central control system or other devices. His biggest advantage is the lower cost because it has been used extensively for a long time, meaning it has been fully developed and utilized. Additionally, Bluetooth outperforms competing technologies in real-world applications since it doesn't require a hub and can respond to commands immediately. Additionally, Bluetooth has a larger data capacity than ZigBee and Z-Wave (although it is still lower than Wi-Fi), which enables Bluetooth-enabled gadgets to perform tasks other than simply reporting motion or toggling switches.

In conclusion, communication technology, a key element of HEMS, provides effective data transfer and seamless collaboration between devices.

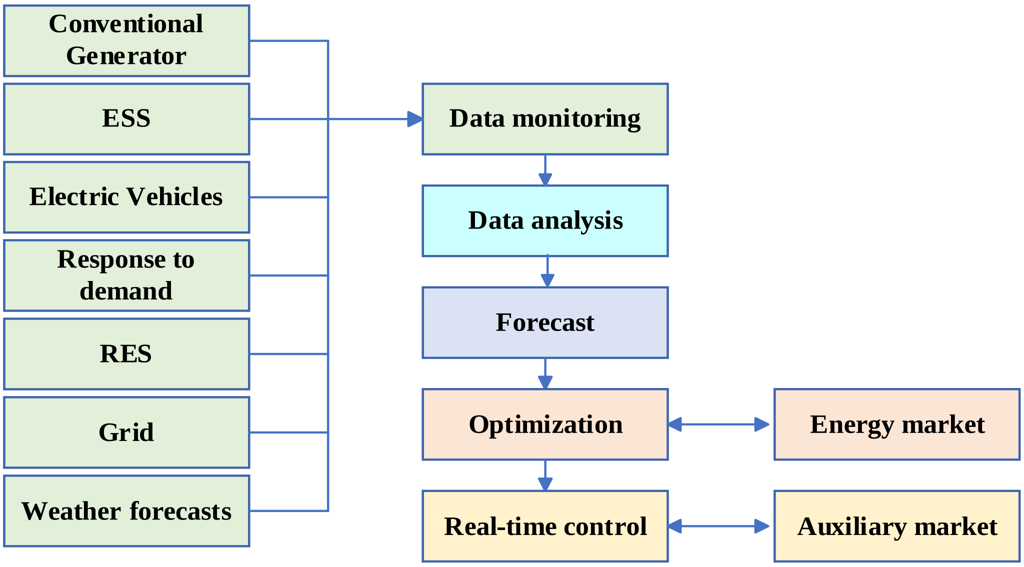

Fig. 3 MG power management functions [8]

4. New EMS Technologies Connected to Energy and Their Applications

4.1. Artificial Intelligence in Microgrid Energy Management Strategies

Modern energy solutions now heavily rely on microgrids (MGs), as shown in Figure 3, particularly when coupled with resources like photovoltaic (PV) panels, wind turbines, diesel engines, energy storage systems (ESS), and controllable loads [8]. People who live in rural places notably benefit from microgrids since they offer a more decentralized, efficient, and dependable power supply than conventional centralized power producing systems.

Energy management systems (EMS) play a particularly important function in this situation. As shown in Figure 4, the article goes into great length about an artificial intelligence-based emergency management system (EMS) that uses fuzzy logic (FL) programming for decision-making, nonlinear autoregressive models of prediction, and artificial neural network (ANN) algorithms for prediction [8]. This EMS can dynamically decide whether to buy or sell electricity based on numerous criteria such as energy costs, load demand, and battery state of charge. It combines advanced prediction algorithms with decision-making abilities. This not only aids in energy efficiency but also considerably lowers user costs.

The article also underlines the significance of integrating RES into microgrids, which, when combined with ESS and controllable loads, such as PV panels and wind turbines, offer local consumers dependable and sustainable power. This variety of microgrids, however, also presents difficulties, particularly with regard to non-dispatchable renewable energy sources (NDRS), bi-directional energy flows, and more engaged users [8].

Microgrids and associated EMS technologies present fresh chances and possibilities for contemporary energy management. How to combine these technologies with home energy management systems becomes a crucial issue, though, when we think about smart home environments. Powerful tools for HEMS to better adapt to the energy demand and consumption patterns of the home are provided by artificial intelligence, particularly ANN and FL. For instance, HEMS may dynamically change the energy supply to ensure that energy usage within the home optimum efficiency by continuously monitoring device usage and energy consumption. Additionally, as IoT technology advances, household appliances can connect with the EMS system in real-time to provide data on current energy usage, improving the accuracy and efficiency of ANN and FL-based energy scheduling techniques. To maintain these systems' stability, reliability, and effectiveness in the home setting, we must further study and improve them as technology develops. Future study should focus on how to better integrate different renewable energy sources into HEMS and how to overcome difficulties associated with NDRS, bi-directional energy flow, etc.

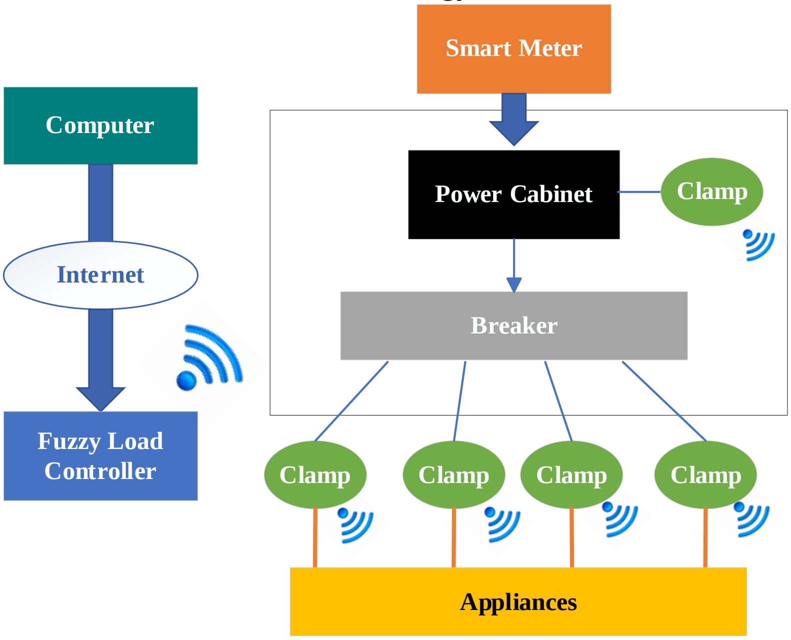

Fig. 4 The planned HEMS architecture [8]

4.2. Smart Home Energy Management Systems and Advanced Demand Side Management

With the advancement of microgrid technology and rising demand response (DR) involvement, demand side management (DSM) has emerged as a crucial element of the electricity system. Zunnurain and his team propose an advanced DSM framework that incorporates an intelligent Home Energy Management System with an appropriate communication mechanism [9]. The framework's primary elements and characteristics are shown in the part after this:

Microgrid modeling: A microgrid model that combines solar PV, wind turbines, and diesel generators was constructed to supply electricity to several typical DR residences that are outfitted with intelligent load control devices.

Selection of communication medium: The most suitable communication infrastructure for the implementation of DR and HEMS was chosen based on the literature assessment and the community's geographic location.

Smart HEMS modeling: Using data on actual load profiles and appliance consumption collected by smart load monitoring devices, a smart HEMS is created. The HEMS makes judgments about consumption using pre-established fuzzy logic rules. Based on user consumption preferences, available microgrid renewable energy generation, DR signals (dynamic pricing and DLC), and weather conditions, these fuzzy rules are developed.

One of the main contributions of this DSM framework is to test a DSM framework with state-of-the-art communication tools and HEMS in a real microgrid environment with solar PV, wind turbines, and backup diesel generators. Fuzzy logic was used to create a load controller for a smart HEMS that optimizes home appliances based on the microgrid's renewable energy generation capacity, local voltage measurements from smart meters, weather patterns, consumer spending preferences, TOU prices, and DLC signals from the utility. Smart HEMS can maintain user comfort while significantly lowering energy consumption, standby power losses, and user energy costs. The suggested HEMS's general architecture is shown in Figure 4.

This study offers a thorough framework for sophisticated demand-side management in a microgrid setting, where smart home energy management technologies are equally significant. This framework was developed by the researchers by combining cutting-edge communication technologies, fuzzy logic control, and demand response techniques. It provides a strong tool for achieving more efficient and sustainable home energy management.

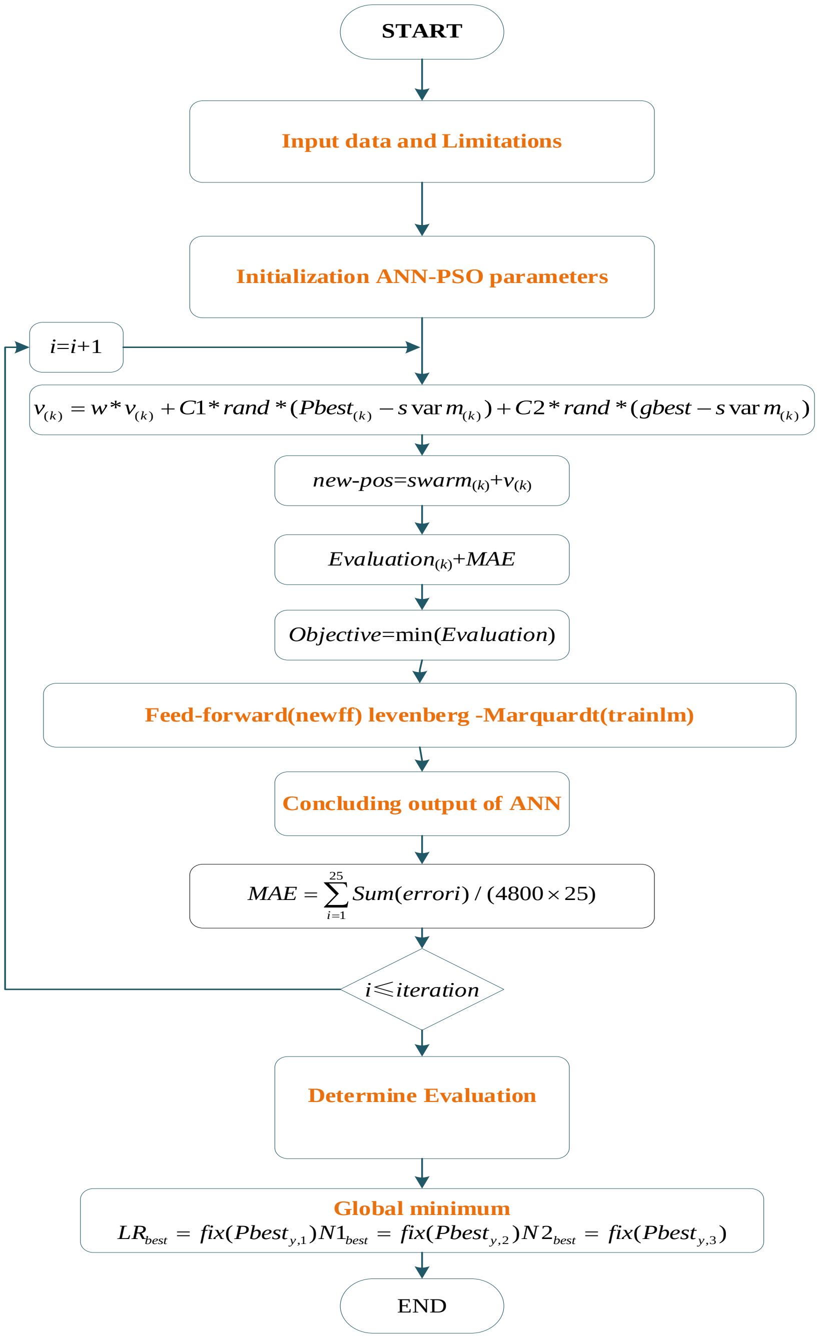

Fig. 5 Flowchart of ANN-BPSO [10]

4.3. Microgrid Energy Scheduling

4.3.1 ANN-BPSO method

Researchers have begun to explore the use of advanced computational methods to optimize the energy displacement of micro-grids to improve the energy utilization efficiency and cost-effectiveness of the micro grids. In this article, researchers have proposed an optimized energy dispatch method based on artificial neural networks (ANN) and particle swarm optimization (PSO). ANN is used to predict the generation and consumption of various energy sources in the microgrids, such as solar radiation, wind speed, battery status, fuel level, etc. The binary particle swarm optimization (BPSO) algorithm is a group-based optimization algority that simulates the behavior of natural groups such as birds or fish populations to find the best solutions, and is used in studies to optimise the variation of energy variations in micro grid. An outstanding feature of ANN-BPSO's method is that it combines ANN and BPSO to increase the accuracy of the electrical grid, which can also be used to determine the energy efficiency of the network [10]. The flowchart in Fig.5 shows the full implementation of the ANN-based PSO method.

4.3.2 Smart Home's Connection

HEMS's function has a greater significance in the setting of smart homes. Energy demand and consumption patterns in the home become more complex as smart home equipment, smart lighting, and smart thermostats become more common. For the best use of energy, this calls for an effective, adaptable, and intelligent energy management system. An efficient method for smart homes is the ANN and PSO-based energy scheduling technique for microgrids, which enables households to plan their energy use based on current energy prices, weather, and the operational status of home appliances. This maximizes energy efficiency while lowering expenses.

Additionally, as IoT technology advances, home appliances can connect with the HEMS system in real-time to provide data on current energy usage, improving the accuracy and efficiency of ANN and PSO-based energy scheduling techniques. Households will save money as a result of this in addition to having better energy efficiency.

The authors go into great detail in section 3 about EMS technologies related to new energy sources and their uses in smart homes. The use of artificial intelligence in microgrid energy management strategies is first covered, emphasizing the connection between modern energy solutions and microgrid technology while going into great depth about how EMS built on AI algorithms may maximize energy use. The relationship between sophisticated demand-side management and intelligent home energy management systems is then discussed, and it is investigated how the employment of sophisticated communication medium in conjunction with HEMS can be used to reduce the energy consumption of home appliances. Finally, the potential for smart houses is investigated when Artificial Neural Networks and Particle Swarm Optimization are integrated into microgrid energy scheduling. These methods offer a practical approach for smart homes that may be used by households to maximize energy efficiency and cut expenditures.

5. Discussion and Future Perspectives

5.1. Constraints of existing EMS technology

The EMS innovations covered in section 3 have a lot of potential for smart homes, but they still have significant drawbacks.

First off, training AI-based EMS requires a lot of data, and in reality, sometimes there may not be enough data. This may result in incorrect projections, which could have an impact on the overall effectiveness of energy management. Second, even though the PSO algorithm finds optimal solutions effectively, it can be hampered by local optimal solutions, which would result in the loss of the overall optimal solution. This means that occasionally the algorithm might not give the user the best energy management plan.The complexity of many energy sources and varied consumption patterns is not taken into account by current EMS solutions, which instead place a heavy emphasis on a single energy management method. This could prevent EMS from offering the best energy management solutions in challenging energy circumstances. Additionally, EMS must communicate with more gadgets and systems because to the growing complexity of smart home gadgets and systems. The complexity of this situation may be beyond the capabilities of current EMS systems, particularly when it comes to real-time data streams and interactions between a large number of devices. Finally, even if EMS technologies have advanced significantly, more processing power and storage space are still needed to manage massive volumes of data and intricate algorithms. This can make the system more expensive and difficult, which might impair users' acceptability.

Future research paths, according to the authors, may concentrate on creating more effective algorithms, leveraging a wider variety of data sources, enhancing the integration strategies of current methodologies, and enhancing the scalability and interoperability of systems in order to get over these restrictions.

5.2. Trends and Improvements in Future Technology

EMS technology is also ready for a number of advancements and modifications. Based on existing technology and industry demands, the authors have predicted the following future EMS technology trends:

Augmented learning and deep learning are converging. Current EMS technology largely relies on conventional AI algorithms like ANN and PSO. To give more precise and immediate decision assistance for energy management, deep and augmented learning technologies may become widely used in EMS as they develop.

Integration of the Internet of Things (IoT): As the number of smart home devices rises, IoT technology will become more integrated into EMSs. In order to make precise energy management decisions, EMS can collect and analyze data from multiple devices utilizing IoT technologies in real time [11].

Blockchain technology application: Blockchain technology can offer EMS a safe, open, and decentralized platform for data administration and trading. This will support data security and integrity while automating and optimizing energy transactions [12].

A more individualized approach to energy management will likely be provided through the development of adaptive algorithms, which future EMS are anticipated to use more of. These algorithms can automatically react to changes in the user's needs and the environment in real-time.

6. Conclusion

In-depth information on EMS technology and its potential applications in new energy-driven smart homes is provided in this article. The authors begin by outlining the intimate relationship between the emergence of new energy sources and HEMS technology for smart homes. The introduction of HEMS for smart homes, as well as EMS technologies related to new energy sources and their applications in smart homes, are then covered in detail by the authors. They also analyze the limitations of current EMS technologies and talk about future technology trends and developments. The future trend will generally be the fusion of new energy, smart homes, and EMS. It will take years of research and development to create a genuinely green and sustainable smart home, therefore researchers must never stop looking for new solutions. We anticipate that this paper will inform readers on EMS technology and its use in smart homes and pique their interest in further study.

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