Energy Management System Technology in Smart Grid

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Abstract. The smart grid, envisioned as the future of the power industry, aims to revolutionize energy supply with efficiency and sustainability. This paper extensively examines the critical role of Energy Management System (EMS) technology within the smart grid framework. By harnessing advanced technologies like distributed energy storage, intelligent energy management, electric vehicle charging, intelligent energy dispatching, and fault perception diagnosis, the smart grid promises heightened power system efficiency, reliability, and environmental consciousness. In today's dynamic energy landscape, the integration of renewable sources introduces a unique challenge due to their inherent volatility. EMS emerges as the linchpin, offering real-time monitoring and data-driven optimization to ensure grid stability amid fluctuating supply. The smart grid, with advanced information technology and intelligent control strategies, leans heavily on EMS for seamless energy production, transmission, and consumption. However, challenges persist, encompassing stable energy supply, security, infrastructure upgrades, and cross-border standardization. Yet, with sustained technological innovation and collaborative efforts, a future of intelligent, sustainable, and reliable power systems is attainable. In conclusion, EMS integration into the smart grid not only signifies technological progress but also heralds a monumental shift towards a greener, more sustainable energy landscape. This paper provides a comprehensive exploration of how EMS, as the backbone of the smart grid, empowers us to navigate the complexities of modern energy demands, paving the way for a brighter, more efficient future.

Keywords: Smart grid, energy management system, future aspects, energy storage.

1. Introduction

Nowadays, the world is facing increasing energy demand and environmental problems, which makes it crucial to seek new energy solutions. Although the traditional power grid has provided stable power supply for a long time, there are some limitations in meeting the new energy requirements and sustainability goals. Therefore, the introduction of new energy has become an inevitable trend.

In today's rapidly changing energy field, there are obvious differences between the new energy grid and the traditional grid. Renewable energy such as solar energy and wind energy introduced into the new energy grid has strong volatility, which is a characteristic that the traditional grid does not have. This volatility is due to changes in weather conditions and day and night festivals, leading to unique challenges in power supply for the new energy grid. In order to deal with this instability, energy storage technology and energy management system (EMS) are needed to better suppress fluctuations and ensure reliable power supply.

In this context, smart grid has emerged. As shown in Fig. 1, smart grid is not only a new mode of energy distribution and consumption, but also represents a highly intelligent and sustainable power system [1]. The traditional power grid is often unable to effectively adapt to the rapid power supply changes introduced by the new energy grid, while the smart grid stands out for its ability to coordinate, monitor and optimize energy supply. It introduces intelligence, adaptability and high flexibility to the power system, enabling better manage the volatility of new energy. This has established a close relationship between new energy and smart grid, and laid the foundation for the future energy supply mode.

The basic structure of smart grid includes advanced information and communication technology, data analysis means and intelligent control strategy. Energy management system plays a key role in it. EMS ensures the efficient operation of the power grid by monitoring energy production, transmission and consumption in real time and using data analysis and optimization algorithms. EMS

technology is an indispensable part of smart grid, which helps to realize the reliability, stability and sustainability of power grid.

This paper will deeply introduce the key technologies of energy management system in smart grid, including distributed energy storage, intelligent energy management, electric vehicle charging and changing, intelligent energy dispatching and allocation, intelligent fault perception diagnosis and so on. Through the comprehensive application of these technologies, smart grid will provide solid support for future energy supply and lead the energy industry to a greener and sustainable future.

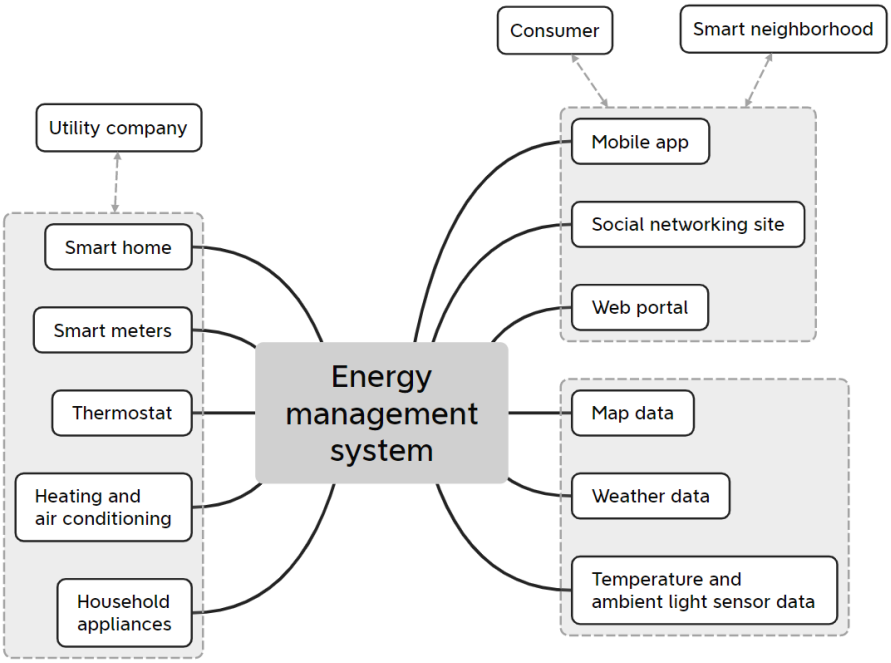


Fig. 1 Energy management system in a smart grid [1].

2. Key technologies of energy management system in Smart Grid

As an innovative evolution of the energy system, smart grid provides new possibilities for the efficient management, optimal distribution and sustainable supply of energy. Under the framework of smart grid, the key technologies of energy management system become the key driving factor to achieve this goal. They are committed to achieving more intelligent, efficient and coordinated energy management in all aspects of power production, transmission and consumption. Fig. 2 illustrated key technologies of great significance in smart grid [2].

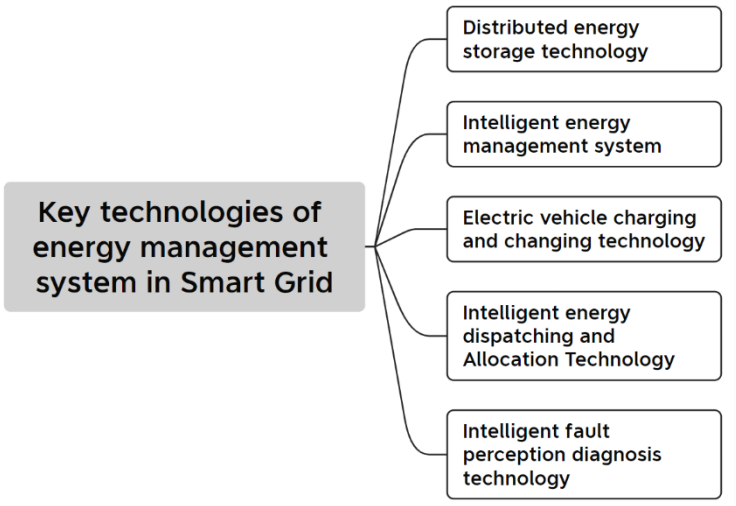


Fig. 2. Key technologies of energy management system in Smart grid [2].

2.1. Distributed Energy Storage Technolog

One of the key technologies of energy management system in smart grid is distributed energy storage technology. Distributed energy storage system is usually composed of small energy storage units, which are distributed throughout the power grid to form a decentralized energy storage network. It can provide the flexibility of energy storage and release, balance the difference between power supply and demand, and improve the stability of the power grid. It can also cope with sudden demand and peak load. Distributed energy storage technology plays an important role in dealing with the volatility of new energy, improving power supply reliability and optimizing power quality.

1) Response to the volatility of new energy: smart grid needs to solve the problem of high volatility of new energy power generation. Distributed energy storage technology can effectively balance the load fluctuation of power grid by storing energy when energy is sufficient and releasing energy when energy supply is insufficient. This technology can reduce the imbalance between energy supply and demand, and stabilize the operation of the power system [3].

2) Improvement of power supply reliability: distributed energy storage technology plays the role of standby power in smart grid, especially when power system encounters fault or disaster. It can start quickly, maintain the power supply of important loads, ensure the continuous operation of power system, and improve the reliability of power supply.

3) Improvement of power quality: the distributed energy storage system has the characteristics of rapid response, and can adjust the parameters of power, such as voltage, frequency, etc., to optimize power quality. It can reduce power quality problems, such as harmonics and voltage fluctuations, and provide a more stable and high-quality power supply.

4) Implementation of peak shaving and valley filling strategy: in the smart grid, the distributed energy storage technology can adopt the peak shaving and valley filling strategy by storing energy at the peak of energy supply and releasing energy at the trough to balance grid load fluctuations. This helps to reduce the load peak valley difference of power system, reduce energy waste and improve energy utilization [3].

5) Multi energy coordinated management: the coordinated management of distributed energy storage technology and multi energy resources is the key to smart grid. It can intelligently allocate and adjust the use of various energies, optimize the configuration according to the generation and consumption of different energies, and improve the overall energy utilization efficiency.

6) Frequency modulation and frequency control: distributed energy storage technology has high-speed response ability, and can be used for frequency modulation and frequency control of power system. When the power system frequency fluctuates or the load changes, the distributed energy storage system can quickly adjust the energy charge and discharge power, stabilize the grid frequency, and ensure the stable operation of the power system [4].

7) To sum up, distributed energy storage technology plays a vital role in the energy management system of smart grid. Distributed energy storage technology provides key support for the sustainable development and stable operation of smart grid by coping with the fluctuation of new energy, improving power supply reliability and power quality.

2.2. Distributed Energy Storage Technolog

The intelligent energy management system in smart grid is one of the key technologies to realize energy efficient utilization and intelligent power consumption. This system comprehensively uses advanced information and communication technology, data analysis means and intelligent control strategy to meet the intelligent power demand of industrial users in power quality monitoring, equipment energy consumption analysis, load monitoring management and photovoltaic energy generation, storage and distribution.

1) Power quality monitoring and optimization: This is one of the core of the system. By monitoring power quality parameters such as voltage fluctuations, harmonics, imbalance, etc., the system can analyze the power grid operation status in real time, and quickly find and locate potential power

quality problems. Through continuous optimization and adjustment, industrial users can enjoy stable power supply, improve production efficiency, and reduce interference to the power system [5].

2) Analysis and optimization of equipment energy consumption: it occupies an important position in the system. By monitoring and analyzing the energy consumption of various equipment in real time, the system can identify abnormal energy consumption and inefficient equipment. This provides industrial users with the opportunity to optimize energy consumption. Through targeted adjustment, it can not only reduce energy waste, but also reduce operating costs [6].

3) Strong communication and data transmission capability: the system needs to establish a stable communication network to realize real-time data transmission between the equipment terminal and the monitoring master station. This provides a basis for ensuring the timeliness and accuracy of data [7].

4) Load monitoring and management: energy management system plays a key role in this field. The system can track the load changes of industrial users in real time, and carry out load distribution and scheduling intelligently according to the load characteristics. Through the measures of on load voltage regulation, on-off harmonic control and so on, the system ensures the stability of the load and improves the energy utilization efficiency [5].

5) Data analysis and decision support capability: the system needs to have strong data analysis and decision support capability, which can integrate and analyze a large number of real-time data and provide users with scientific decision basis. This helps the system to make intelligent adjustment and optimization according to the situation.

6) Photovoltaic energy generation, storage and distribution management: as an emerging field, photovoltaic energy has attracted the attention of intelligent energy management system. By monitoring the information of photovoltaic power generation and energy storage system status, the system can provide industrial users with efficient photovoltaic energy utilization strategies. The rational allocation of photovoltaic energy and energy storage system can not only independently use renewable energy, but also reduce peak load at the peak of energy demand and reduce dependence on traditional energy [5].

In general, the energy management system in smart grid is not only the smart power assistant of industrial users, but also an important part of smart grid construction. Through intelligent monitoring, optimization and management, the system will effectively improve energy efficiency, reduce energy waste, create considerable economic benefits for industrial users, and contribute to the stable operation and sustainable development of the power system.

2.3. Electric Vehicle Charging Technology

With the rapid popularization of electric vehicles, electric vehicle charging and changing technology has become an important part of the smart grid. This technology combines the electric vehicle and power system, and realizes the monitoring and control of the charging and power exchange process of the electric vehicle through the intelligent charging pile and communication technology. Through intelligent dispatching and optimization, the charging demand of electric vehicles can be reasonably met, so as to avoid the occurrence of peak load in the power system and improve the stability of the power grid. At the same time, the electric vehicle charging and changing technology also provides users with a more flexible, convenient and intelligent electric vehicle use experience, which promotes the further popularization of electric vehicles.

1) Energy storage and balance management: facing the growing supply of renewable energy, such as solar energy and wind energy, the battery system of electric vehicles has become a huge power storage. These vehicles store electric energy during low load periods, release electric energy during peak hours, effectively balance the grid load, and make the energy supply more stable.

2) Application of time of use price and charging and discharging strategy: the electric vehicle charging system encourages users to charge during periods of light grid load through time of use price, so as to avoid energy waste at peak hours to the greatest extent. The intelligent charging and

discharging strategy ensures that the battery is sufficient, and injects energy into the power grid when necessary, providing strong support for the reliable operation of the power grid [8].

3) Charging and discharging scheduling and Optimization: with the help of advanced scheduling algorithm, the charging and discharging plan of electric vehicle is closely combined with the grid state and user requirements to achieve the optimal resource allocation. This kind of intelligent dispatching can not only maximize the utilization of electric energy, but also balance the load of the power grid, which provides an indispensable guarantee for the stable operation of the smart grid [9].

4) Intelligent control and communication technology: the charging and changing system of electric vehicles realizes seamless connection with the energy management system through intelligent communication protocol. This real-time communication enables the energy management system to monitor the battery status, charging demand and other key information, so as to flexibly adjust the charging and discharging strategy and maximize the energy utilization efficiency.

In the future, the development of smart grid will continue to promote the innovation and application of electric vehicle charging and replacing technology. The deep integration of these technologies will provide a powerful engine for the green transformation of energy and the intelligent upgrading of power grids. Whether it is to realize the efficient use of energy or to provide a more stable and reliable power supply for the city, the electric vehicle charging and replacing technology will play a leading role in the smart grid and trigger a new chapter in the energy industry.

2.4. Intelligent Energy Dispatching and Allocation Technology

Intelligent energy dispatching and allocation technology is one of the important technologies to realize the efficient operation of smart grid. This technology is based on real-time data acquisition and intelligent optimization algorithm to achieve efficient distribution and balance of energy, ensure stable supply in peak and trough periods, and improve energy utilization.

1) Comprehensive data integration: energy management system in smart grid depends on data collection, integration and analysis. Data from different departments and systems need to be integrated to establish a comprehensive energy information database, so as to better understand energy use, demand changes and efficiency [10].

2) Intelligent prediction and Optimization: Based on historical data and real-time information, intelligent energy dispatching and allocation technology can predict energy demand and generation. These forecasts can be used to optimize energy distribution, ensure stable supply during peak and trough periods, and improve energy utilization.

3) Multi domain collaboration: the energy management system of smart grid needs to consider the collaborative scheduling of power, gas, heat and other energy. The interaction between different energy sources needs to be simulated and optimized to achieve the optimal scheduling strategy [10].

4) Intelligent optimization algorithm: complex energy scheduling problems can be solved by using optimization algorithms such as linear programming, integer programming, mixed integer linear programming, etc. These algorithms can find the best energy allocation scheme for different scenarios and constraints.

5) Real time monitoring and control: intelligent energy dispatching technology needs to monitor the operation status of each energy node in real time and adjust the energy distribution strategy in time. This requires the establishment of a powerful monitoring system and automatic control mechanism to ensure the efficient and stable operation of the system.

6) Data analysis and decision support: data analysis technology can mine patterns and trends in historical data to provide support for decision-making. The energy management system in smart grid can formulate a more reasonable energy scheduling strategy according to the results of data analysis.

7) The application of advanced technologies: such as artificial intelligence, big data analysis, simulation and so on, can more accurately predict the energy demand and supply, so as to achieve more refined energy scheduling.

8) Emergency response and emergency response capability: in case of emergency, the energy management system of smart grid needs to have emergency response and emergency response

capability. Through the preset scheme and intelligent algorithm, the energy distribution can be adjusted in time to ensure the safe operation of the system.

In general, smart energy dispatching and allocation technology is one of the core technologies of energy management system in smart grid. By comprehensively considering data, prediction, optimization, monitoring and response and other factors, this technology is expected to achieve efficient energy utilization and promote the sustainable development of smart grid.

2.5. Intelligent Fault Perception Diagnosis Technolog

Through real-time monitoring and data analysis, intelligent fault sensing diagnosis technology can quickly detect abnormal conditions and faults in power system, and provide accurate diagnosis results. Once a problem is found, the system can respond quickly and take appropriate measures to avoid further expansion of the fault and improve the safety and reliability of the power system [11]. The application of this technology helps to prevent power grid accidents, reduce the outage time of power system, and improve the robustness of the whole power system.

By integrating high-precision sensors, efficient data communication and intelligent analysis methods, intelligent fault sensing diagnosis technology can realize real-time monitoring, anomaly detection and fault diagnosis of power grid operation status, thus greatly improving the reliability, security and operation efficiency of power grid.

1) Sensor technology: current, voltage, temperature and other sensors can collect the data of different nodes of the power grid in real time, providing a real-time reference for fault diagnosis. These data not only help to capture the small changes of power grid operation status, but also provide a data basis for subsequent data analysis and modeling.

2) Data communication technology: the high-speed and stable data transmission network can quickly transmit sensor data to the central monitoring system to realize real-time monitoring and remote diagnosis of the power grid. This means that no matter where the operation and maintenance personnel are, they can obtain the power grid status information in time [12].

3) Data analysis and mining technology: through the analysis of historical data, some potential abnormal patterns and trends can be identified, so as to provide early warning before the fault occurs. With the introduction of advanced technologies such as machine learning and artificial intelligence, the system can gradually improve the accuracy and automation level of fault diagnosis [12].

4) Design and optimization of fault diagnosis algorithms: these algorithms need to be able to analyze sensor data, identify abnormal conditions in the power grid, and further determine the type, location and impact of faults. This intelligent fault diagnosis can help the operation and maintenance personnel make decisions quickly and reduce the fault processing time.

5) Real time alarm and decision support: once the system detects abnormal conditions, it can notify the operation and maintenance personnel through real-time alarm to help them respond quickly. At the same time, the system can also provide decision support according to the analysis results, and provide fault handling suggestions for operation and maintenance personnel, so as to improve the efficiency and accuracy of fault handling.

The intelligent fault sensing diagnosis technology of energy management system in smart grid plays a key role in real-time monitoring, anomaly detection, fault prediction and decision support, and provides strong support for the safe and stable operation of power grid.

To sum up, the key technologies of energy management system in smart grid cover many aspects, such as distributed energy storage, intelligent energy management, electric vehicle charging and changing, intelligent energy dispatching and allocation, and intelligent fault perception diagnosis. The application of these technologies will provide solid support for the efficient operation of smart grid, promote the innovation and development of energy industry, and realize the sustainability, robustness and reliability of power system.

3. Challenges faced by smart grid and future solutions

Smart grid is a revolutionary change in the power industry, which integrates information technology and power system to achieve efficient and sustainable power supply and accurate response to customer demand. However, this great vision is accompanied by a series of challenges that need innovation and collaboration to overcome. In this part, the author will deeply discuss the key challenges faced by smart grid and provide feasible solutions in the future to promote a more intelligent, sustainable and stable power future.

3.1. Instability of Energy Supply

The instability of new energy is a major challenge for smart grid. The generation of renewable energy such as solar energy and wind energy is limited by weather conditions, resulting in increased volatility of power supply. This may lead to grid instability and power shortage.

In order to solve this problem, the smart grid needs a more powerful energy storage system to store energy when the new energy supply is sufficient and release energy at the peak of demand. In addition, the further development and optimization of intelligent energy dispatching technology can better coordinate the distribution of energy and ensure the stability of power supply.

3.2. Security and Privacy Protectionstability

With the increase of data exchange and communication in smart grid, security and privacy protection issues become more and more important. The failure or attack of power system may have a serious impact on power supply, and the leakage of user data may cause privacy problems.

In order to ensure the security of smart grid, it is necessary to strengthen network security measures and data encryption technology. The application of intelligent fault sensing diagnosis technology can also help detect and respond to potential security threats in time. At the same time, it is also crucial to formulate strict privacy policies and regulations to protect users' privacy.

3.3. Infrastructure Upgrading

To support the development of smart grid, it is necessary to upgrade and transform the power infrastructure. This includes the renewal of power transmission and distribution grid, the deployment of intelligent metering equipment and the strengthening of communication network.

The government and power companies need to increase investment in power infrastructure to meet the needs of smart grid. At the same time, using advanced communication technology to improve the monitoring and control ability of power grid is also an important step.

3.4. Cross Border Collaboration and Standardization

Smart grid involves collaborative operation in many fields, including power, information and communication. The inconsistency of standards and specifications in different fields may lead to problems in integration and collaboration.

Develop unified cross-border standards and specifications to ensure that various systems and technologies can be seamlessly integrated and work together. International cooperation and the participation of industry organizations will also contribute to the development of global standards.

In order to realize the great potential of power system in the future, it’s necessary to face the challenges of instability of energy supply, security and privacy protection, infrastructure upgrading, and cross-border coordination and standardization. Through stronger energy storage systems, network security measures, infrastructure investment and cross-border cooperation, these problems can be gradually solved . In a word, smart grid will not only improve the efficiency of power system, but also create opportunities for large-scale integration of renewable energy and promote environmental sustainability. Let's work together to meet the challenges of power system in the future and realize more intelligent and sustainable power supply.

4. Outlook

Although smart grid and its energy management system have made remarkable progress, there are still some problems. In the future, the power grid must be more adaptable to the needs of multiple energy generation modes and highly market-oriented power trading.

Energy market and economic model: The traditional electricity market model needs to adapt to the change of smart grid. The solution may involve formulating new energy market policies and regulations to encourage the development of renewable energy and intelligent energy management. In addition, the establishment of a flexible electricity price system to reflect the actual situation of energy supply and demand will help to encourage users to reduce power demand during energy peak hours.

Infrastructure upgrading: In order to support the development of smart grid, power infrastructure needs to be upgraded and transformed on a large scale. This includes the renewal of power transmission and distribution grid, the deployment of intelligent metering equipment and the strengthening of communication network. The solution includes the government and power companies to increase investment in power infrastructure to meet the demand of smart grid. The use of advanced communication technologies, such as 5g and the Internet of things, will improve the monitoring and control capabilities of the power grid, making it more intelligent and efficient.

Social participation and sharing economy: Smart grid needs wider social participation and sharing economy mode. The solution includes the establishment of shared energy projects to encourage individuals and communities to participate in energy production and distribution. By establishing more energy cooperatives and sharing platforms, energy production can be more decentralized, reduce dependence on traditional energy supply, and promote sustainable development.

To sum up, smart grid still faces a series of challenges in the future, which need attention and efforts. By consistently innovating technologically, investing wisely, and fostering international collaboration, the goal of addressing these challenges and advancing smart grid development toward a more environmentally friendly, intelligent, and enduring future becomes attainable. In the future, concerted efforts are essential to confront these challenges and attain a smarter and more sustainable power supply.

5. Conclusions

This paper underscores the pivotal role of energy management system (EMS) technology within the realm of the smart grid. The smart grid represents a transformative shift in the power industry towards an intelligent, sustainable, and efficient energy distribution system. As the linchpin of this transition, EMS enables real-time monitoring, intelligent control, and optimization algorithms for efficient energy utilization. The discussed key technologies, including distributed energy storage, intelligent energy management, electric vehicle charging, intelligent energy dispatching, and fault perception diagnosis, collectively form the bedrock of the smart grid. Distributed energy storage mitigates supply-demand disparities and enhances grid stability. Intelligent energy management empowers users with efficient energy consumption practices, reducing waste. Electric vehicle charging technology aids load management and fosters sustainable electric vehicle integration. Intelligent energy dispatching optimizes energy allocation, enhancing overall efficiency. Fault perception diagnosis ensures stable operations and enhances reliability. To sum up, the technology and application of energy management system in smart grid not only provide a new direction for the innovation and development of the power industry, but also establish a bright prospect for the sustainable development of the energy field. Through continuous technological innovation and practical application, smart grid will further improve the efficiency, reliability and environmental protection of power system, lay a solid foundation for future energy supply, and lead the energy field to a greener and sustainable future.

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