Analysis of The Role of Smart Grids in Renewable Energy

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Abstract. The global energy landscape has always been dominated by fossil fuels, but with the intensification of climate change and environmental issues, people realize that the traditional energy system must be transformed. In order to integrate renewable energy and improve the sustainability and resilience of the energy system, smart grids have emerged. Smart grid is a modern grid system based on advanced communication, control and information technology, which can integrate renewable energy more effectively. As one of the renewable energy sources, solar energy plays an important role in the smart grid. It has the advantages of wide distribution, environmental protection, and renewable, and with technological progress and cost reduction, solar power generation is widely used in smart grids. Similarly, wind energy, another important renewable energy source, also plays an important role in the smart grid. The continuous development of wind turbine technology has made wind power generation more efficient and reliable, and the integration with smart grid infrastructure has further improved the efficiency of wind energy utilization. In addition, hydrogen energy has great potential as a clean energy carrier, but the storage and distribution of hydrogen energy in smart grid systems still face challenges.

1 Introduction

According to the Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change, with the extensive use of fossil energy by humans, the global temperature has increased by about 0.85 degrees Celsius from 1880 to 2012 [1]. As shown in Fig. 1, climate warming has had a serious impact on the earth's environment. For example, the melting of glaciers in the North and South Poles has caused sea level rise, causing floods in many places; extreme weather such as heavy rain and snow, drought, and high temperature. occur frequently, leading to crop failure and plant growth cycles. In addition, in addition to releasing carbon dioxide, the combustion of fossil energy will also produce other gases and suspended particles that are harmful to the human respiratory system. The existence of the above problems requires that the traditional energy system must be transformed to better meet the requirements of human society for environmental friendliness [2].

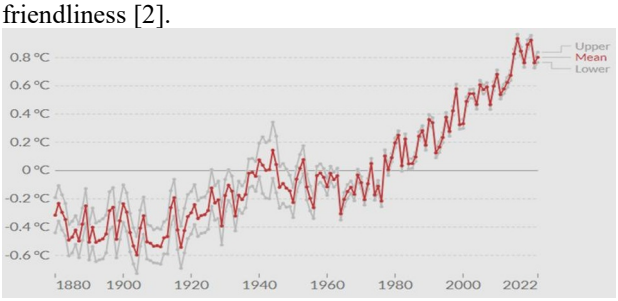

Fig. 1. Average temperature anomaly, Global [2, https://ourworldindata.org/grapher/temperature-anomaly?time=earliest..latest].

Renewable energy refers to energy that is continuously restored through natural processes, such as solar energy and wind energy. Renewable energy demand depends on climate change, energy security and supply stability, price competitiveness, policy support and international cooperation. The global energy landscape is gradually shifting towards renewable energy. Although fossil fuels still dominate the global energy supply, the demand and utilization of renewable energy are showing a rapid growth trend to meet the challenges of climate change, environmental protection and energy sustainable development.

A "smart grid" refers to a modern electricity supply system that monitors, protects and automatically optimizes the operation of its interconnected elements [3]. Smart grids are extremely important for integrating renewable energy. It can more effectively integrate large-scale renewable energy, monitor energy production and consumption in real time through advanced monitoring and consumption systems, and adjust energy distribution according to demand. In addition, smart grids are integrated with energy storage systems, such as batteries and energy storage facilities, to balance the instability of renewable energy supply. By optimizing energy distribution and improving energy utilization efficiency, the smart grid realizes the sustainable use of renewable energy, and promotes opportunities for consumers to participate in and self-manage energy, and promotes energy transformation and the development of a low-carbon economy.

The International Renewable Energy Agency (IRENA) estimates that by 2050, 90% of the world's

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electricity can and should come from renewable sources [4]. The smart grid integrates and optimizes the use of renewable energy, so that the overall flexibility or reliability of the system is improved, and at the same time, it reduces energy dependence and improves energy security. The development of elastic power systems is not only an internal requirement to deal with various fault events, but also an external drive of uncertainty, openness, and complexity brought about by energy transition and smart grid technology [5]. This combination is critical to achieving the sustainable 1clean energy system, creating a sustainable and resilient energy future for us.

2 The role of smart grids in renewable energy

2.1 Solar energy

2.1.1 Explanation of solar energy generation and its advantages as a renewable resource

As one of the most potential renewable energy sources, solar energy mainly has the following two forms of utilization: one is photovoltaic (PV) power generation, which directly converts solar radiation into electrical energy through the photovoltaic effect; the other is solar thermal (concentrated solar power, CSP) generates electricity by concentrating solar energy to convert radiation into heat energy, and then drive a heat engine to generate electricity through a thermodynamic cycle [6]. Solar energy has multiple advantages as a renewable resource.

First of all, solar energy is a permanent and widely distributed resource that emits a large amount of energy every day, and almost anywhere in the world can use solar energy to generate electricity. Secondly, the solar power generation process is non-polluting and environmentally friendly, and does not produce greenhouse gas emissions, air pollution or water pollution, which helps to reduce the negative impact on the environment. In addition, solar energy is a renewable energy source, the sun re-radiates energy every day. The decentralization and energy independence of solar power generation can be carried out in decentralized places, reducing the dependence on the centralized power grid and improving the reliability and independence of energy. In addition, the cost of solar power is gradually falling, and it has the ability to compete with traditional energy sources and become the most economical energy option in some regions. Therefore, solar power as a renewable resource is of great significance in achieving a sustainable energy future and addressing the challenges of climate change.

2.1.2 Discussion on the technological advancements in solar energy generation and its integration into the smart grid

Solar technology has made remarkable progress in terms of efficiency and cost. The efficiency of photovoltaic cells continues to improve, and the photoelectric conversion efficiency is gradually approaching the limit. In addition, the introduction of new materials and manufacturing processes has reduced the cost of solar cells and increased their reliability and durability.

At the same time, other energy storage technologies (e.g., lithium-ion batteries and flow batteries) have also made great progress. These technologies have the advantages of high energy density, long life, and high efficiency, allowing solar energy to provide continuous power, even at night or in cloudy weather conditions. Smart grids require advanced control and management systems to monitor and optimize the integration of solar power generation in real time. Through advanced sensor, communication and data analysis technology, smart grid can realize real-time monitoring and dispatching of solar power generation system. These systems are able to intelligently adjust to energy demand and supply, ensuring grid stability and reliability. Technological advances in solar power and smart grids reinforce each other, making integration of solar power into smart grids more feasible and efficient. This creates a solid foundation for a sustainable, reliable and smart energy future.

2.1.3 Analysis of case studies showcasing successful implementation of solar energy in the smart grid system

Germany is one of the leaders in solar power and smart grid systems. According to the plan, by 2030, renewable energy should account for 65% of Germany's total energy consumption. At the same time, Germany's energy supply should be covered by 100 percent renewable energy by 2050. The Solar Settlement project is a demonstration solar community project in Freiburg, Germany, which aims to demonstrate the integration of sustainable buildings and renewable energy. Designed and built by Architects for Solar Architecture (ASA), the project consists of 50 solar homes, each of which is equipped with solar panels and high-efficiency energy systems. Solar Settlement's homes are designed using solar passive design principles, including large south-facing windows and solar water heaters. In addition, solar panels are installed on the roof of each house to generate electricity. Homes are energy efficient through efficient insulation, energy efficient light fixtures and energy management systems. The residential complex is equipped with a collective energy storage system for storing and dispatching the electricity generated by the solar panels.

Energy information is shared among residents, and energy sharing and mutual assistance are promoted through regular meetings and events. The effectiveness of the Solar Settlement project is evaluated and monitored over time. Results showed that the project achieved lower energy consumption and reduced greenhouse gas emissions, while providing a comfortable and sustainable living environment for

residents. This provides reference and reference for other countries, and promotes the promotion and application of renewable energy on a global scale.

Solar City (now merged by Tesla into Tesla Energy) is a company that has achieved notable success in the solar industry. Solar City has installed a large number of solar systems across the United States. The company provides clean energy solutions to residential, commercial and industrial customers by leasing, purchasing and installing solar panels and related equipment. As of 2016, Solar City installed solar systems with a total capacity of more than 5 GW. Solar City focuses on the development of intelligent energy management systems. They provide an energy monitoring and management platform that helps customers track energy generation and consumption in real time and optimize energy usage.

2.2 Wind power

2.2.1 Overview of wind power generation and its benefits as a renewable energy source

Wind power is a renewable energy technology that uses wind energy to convert it into electricity. The process of wind power generation is to use wind generators to convert wind energy into mechanical energy, and then use mechanical energy to generate electricity. Wind power has many benefits. First, wind power is an infinite renewable resource that cannot be exhausted. Secondly, wind power will not produce greenhouse gases such as carbon dioxide or other pollutants because it is a clean energy, which helps reduce greenhouse gas emissions. Wind energy is also used in other aspects, such as wind pumping. Traditional electric water pumping requires a large amount of infrastructure construction and high electricity costs, which is extremely unfavourable to rural areas, but the use of wind pumps can save a lot of resources and promote the development of related areas economic development.

There are small turbines for power generation, wind-solar electric vehicle charging stations, and wind-driven street lighting systems. These application facilities make reasonable use of the characteristics of wind energy and achieve the purpose of saving energy. In addition, if the technological conditions are sufficient, wind energy can also be integrated with other renewable energy sources. This multi-energy hybrid mode can not only increase power generation, but also alleviate peak time electricity demand. Although wind power also faces some challenges, with the advancement of technology and better planning, wind power is still considered as one of the important solutions with great potential in the field of renewable energy.

2.2.2 Examination of the evolving wind turbine technology and its integration into the smart grid infrastructure

In wind turbine technology, the latest research and engineering practices focus on improving conversion efficiency, increasing reliability and enhancing adaptability. On the one hand, through the use of advanced aerodynamic profiles and materials, wind turbine designs can improve wind energy conversion efficiency and maximize the use of available wind energy resources. On the other hand, improved bearings, control systems and monitoring technologies increase the reliability and life of equipment and reduce maintenance costs. The flexibility has also become an important goal in the design of new generation wind turbines to adapt to different wind speeds and climatic conditions. With the help of the reactive power compensation device (APF), the wind power generation system can realize the goal of dynamic compensation and achieve the goal of controlling reactive power voltage. When this technology is used, it can reduce the system oscillation problem and achieve the goal of optimizing and improving the power transmission environment. Therefore, the wind energy power system has significant advantages in the currently available new energy power systems, and can be applied to a variety of environmental operations. It not only promotes the sustainable development of the power industry, but also greatly reduces energy consumption [7].

At the same time, the smart grid integration of wind power generation systems has become a research and practice hot spot. Smart grid infrastructure provides a platform for real-time data and information exchange, enabling wind turbines to more accurately forecast wind energy resources, optimize power production schedules, and intelligently match power output to demand. The integration with the smart grid provides a more intelligent, flexible and sustainable energy management solution for the wind power system, promoting energy transformation and sustainable development.

2.2.3 Evaluation of real-world examples demonstrating the effective utilization of wind power within the smart grid framework

Denmark's V2G (Vehicle-to-Grid) project is a pioneering project aimed at integrating wind power with electric vehicle charging facilities. The project enables bi-directional energy flow by considering electric vehicles as part of an energy storage system. In V2G projects, excess electricity generated by wind power can be used to charge electric vehicles. When wind power is plentiful, electric vehicle batteries can absorb the extra power for recharging. At the same time, these EVs are considered part of an energy storage system, as their batteries can store excess energy from wind power. On the other hand, electric vehicle batteries can return stored energy to the grid when grid load demand peaks. This bi-directional energy flow allows EVs to act as an adjustable resource to the grid to balance load demands, provide backup energy, and participate in electricity market transactions.

The goal of this project is to increase energy efficiency, reduce dependence on conventional grids, and promote sustainable transport and energy transition. Denmark's V2G project provides evidence and guidance for the coordinated development of wind energy and

electric vehicle industries, and at the same time promotes the application and development of smart grid technology.

2.3 Hydrogen energy

2.3.1 Introduction to hydrogen energy production and its potential as a clean and sustainable energy carrier

From a global perspective, major developed countries in the world place great emphasis on the development of hydrogen energy from the perspectives of resources and environmental protection. At present, hydrogen energy and fuel cells have initially achieved commercialization in some subdivided fields. In 2017, the global installed capacity of fuel cells reached 670 MW, with mobile installed capacity of 455.7 MW and fixed installed capacity of 213.5 MW [8]. Hydrogen energy production is a process that uses hydrogen as a clean and sustainable energy carrier, and the main method is electrolysis of water. The chemical composition of biomass is similar to that of fossil fuels such as coal and petroleum, and it can be better connected with fossil energy in terms of utilization methods and technical routes, which is conducive to achieving the goal of replacing traditional energy to a certain extent, and is helpful for solving energy shortages, environmental pollution and other issues. have an important role. Compared with other technical routes, the biomass gasification hydrogen production route has the lowest energy consumption and the lowest greenhouse gas emission in the whole life cycle. It is a better choice for energy saving and emission reduction, but there are still problems such as high tar content and difficult catalyst recovery [9]. These methods provide a variety of ways to generate hydrogen, and the appropriate method can be selected according to different resources and needs.

As a clean and sustainable energy carrier, hydrogen has the following potentials and advantages. First of all, the combustion process of hydrogen only produces water vapor, and does not emit greenhouse gases such as carbon dioxide and air pollutants, achieving zero carbon emissions. This helps reduce climate change and improve air quality. Secondly, hydrogen, as an energy storage medium, can solve the intermittency and volatility problems of renewable energy. By using electricity from renewable energy for water electrolysis to produce hydrogen, it can be converted into electricity when needed, achieving a smooth supply of energy and matching supply and demand. In addition, hydrogen also has high energy density, which can store more energy in a smaller volume and weight, and is suitable for scenarios that require high power requirements and long-term operation.

2.3.2 Analysis of the role of hydrogen energy in the smart grid system, including its storage and distribution challenges

Hydrogen energy has the potential of energy interconnection in smart grid systems. Through the establishment of hydrogen infrastructure, such as hydrogen stations and hydrogen pipelines, energy interconnection between different energy carriers can be achieved to achieve energy diversification and complementarity.

The storage of hydrogen is relatively complex, requiring high pressure or low temperature conditions to maintain the stability and storage density of hydrogen. This requires consideration of safety and cost issues in the design of hydrogen storage systems. The cost of the hydrogen storage system is relatively high, including investment in storage tanks, pressure vessels and safety facilities. There are leakage and safety risks in the process of hydrogen storage and transportation, and strict safety measures need to be taken to prevent and respond to potential accidents.

In terms of energy distribution, hydrogen energy, as a clean energy carrier, has flexible distribution and dispatch capabilities in the smart grid. Hydrogen can be transported by pipeline or stored in hydrogen stations and distributed when needed to end users or energy demand points such as homes, businesses and transportation. However, the distribution of hydrogen energy faces some challenges. First of all, establishing a sound hydrogen infrastructure is a key issue in the distribution process, which requires investment in infrastructure such as large-scale hydrogen transmission pipelines, hydrogen refuelling stations, and distribution networks. Overcoming these challenges requires technological innovation, policy support, and investment cooperation to promote the application and development of hydrogen energy and realize a sustainable energy transition for smart grids.

2.3.3 Review of case studies highlighting the successful incorporation of hydrogen energy in the smart grid network

The German company "Hydrogenious Technologies" has successfully integrated hydrogen energy into the smart grid. The company has developed a technology called "LOHC (Liquid Organic Hydrogen Carrier)", which realizes the storage and distribution of hydrogen by absorbing hydrogen into a liquid organic carrier, as shown in Fig. 2. LOHC technology is used for energy storage and dispatch in smart grid systems. Specifically, the system converts renewable energy into hydrogen by electrolyzing water, and absorbs it into LOHC carriers for storage. When the hydrogen needs to be released, the LOHC carriers are sent to the release device, under appropriate temperature and pressure conditions, releasing stored hydrogen to supply fuel cells or other energy needs. LOHC technology has received extensive attention and research at home and abroad. Internationally, the United States, Germany, Japan and other developed countries are actively investing in related research.

The American Air Chemical Company has made in-depth research on nitrogen heterocyclic hydrogen storage

and has obtained a series of patents; German Hydrogenious Technologies (HT) is also committed to the research and development and promotion of LOHC technology. At present, the LOHC technology storage system developed by HT Company (Storage BOX) and release system (Release BOX) have been demonstrated in Germany, and project debugging has been carried out in the United States [10]. This distribution and delivery of hydrogen provides greater flexibility and scalability for smart grid systems. It provides enlightenment for the further application and development of hydrogen energy in smart grid systems in the future.

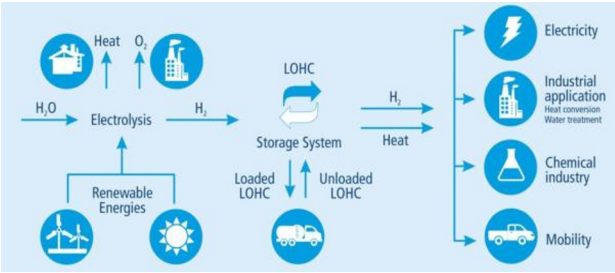

Fig. 2. LOHC process [12, http://www.bce.ac.cn/EN/10.3969/j.issn.1673-5854.2022.03.007].

Currently, countries that have achieved 100% Renewable Energy Electricity System (REPS) include Paraguay, Iceland, Albania and Congo. Among them, Paraguay realized 100% renewable energy in the power system as early as 2000. Almost all the power generation of the system comes from hydropower generation. Nearly 82% of the power generation is used for power export every year, which is a very high system [13].

3 Conclusion

Currently, countries that have achieved 100% REPS (100% Renewable Energy Electricity System) include Paraguay, Iceland, Albania and Congo. Among them, Paraguay has realized 100% renewable energy in the power system as early as 2000. Almost all the power generation of the system comes from hydropower, and nearly 82% of its annual power generation is used for the export of electricity. very high system. The development of renewable energy and smart grids is a key step in the energy transition, which can save energy and reduce emissions while promoting economic growth. At the same time, they can increase the diversity and stability of energy supply and enhance energy security. However, the development of renewable energy and smart grids needs to overcome technical challenges and cost issues, including reducing the cost of energy conversion and storage technologies, building large-scale infrastructure, and ensuring network stability and security. In addition, rational planning and management of power grids, formulation of supporting regulations and policies, and improvement of social acceptance are also challenging in the development process.

Nowadays, while the total global energy demand continues to grow, the problem of climate change is also becoming more and more serious. Renewable energy, as a clean, sustainable and widely available energy option, provides a feasible solution to reduce greenhouse gas emissions, protect the environment, and improve energy security. The introduction and development of smart grid enables renewable energy to be more effectively integrated into the existing energy system, to achieve flexible scheduling of energy, optimize energy distribution and improve energy utilization efficiency. The smart grid also promotes the decentralization and participation of energy, giving consumers more energy management rights and choices. Through global cooperation and efforts to integrate renewable energy and smart grids, we can achieve a sustainable and resilient energy future, leaving a better world for future generations.

References

1. United Nations. (2018, August 18). Climate change.
2. Our world in data. https://ourworldindata.org/grapher/temperature-anomaly?time=earliest..latest
3. WANG Ning, GUO Shuiwen. Areview of the academic progress and application of smart energy system research. Journal of Chongqing University (Social Science Edition), 2019, 25(5): 123-133.
4. December 2009Zhongguo Dianji Gongcheng Xuebao/Proceedings of the Chinese Society of Electrical Engineering 29(34):1-8
5. Bie, Z., Lin, C., Li, G., & Qiu, A. (2020). Development and Prospect of Resilient Power System in the Context of Energy Transition. Journal of Chinese Society for Electrical Engineering, 40(9), 2735.
6. ZHANG Zheyang, JU Xing, PAN Xinyu, YANG Yu, XU Chao, DU Xiaoze. Photovoltaic/Concentrated Solar Power Hybrid Technology and Its Commercial Application. Power Generation Technology, 2020, 41(3): 220-230
7. Gao, L. (2023). Application and Effectiveness of New Energy Generation Technologies in Power Systems: A Discussion. Journal of Mechanical and Electronic Control Engineering, 5(2), 205.
8. Sovacool, B. K., Noel, L., Axsen, J., & Kempton, W. (2018). The neglected social dimensions to a vehicle-to-grid (V2G) transition: a critical and systematic review. Environmental Research Letters, 13(1), 013001.
9. Cao, J., Qin, X., Geng, G., et al. (2021). Development Status and Prospects of Hydrogen Storage and Transportation Technology. Journal of Petrochemical Industry and Process Engineering, 37(6), 1461-1478.
10. Wen, Y., Yang, W., Wang, R., Xu, W., Ye, X., & Li, T. (2020). Review and Prospect of Constructing a 100% Renewable Energy Power System. Proceedings of the Chinese Society for Electrical Engineering, 1843.

11. https://www.greencarcongress.com/2016/05/20160504-hydrogenious.html
12. Ren, J., Su, Y., Ying, H., Sun, Y., Xu, W., & Yin, H. (2022). Research Progress of Biomass Gasification for Hydrogen-rich Syngas. Biomass Chemical Engineering, 56(3), 39-46.
13. Zhang, X., & Li, T. (2022, July). Development of Renewable Energy Technologies — Analysis Based on Solar Energy and Wind Energy. Engineering and Technology Research, 2022(7).