THE ROLE OF IOT AND SMART GRID TECHNOLOGIES IN INCREASING THE EFFICIENCY OF RENEWABLE ENERGY USE IN HOMES AND BUSINESS

Lappeenranta–Lahti University of Technology LUT

Bachelor's Programme in Electrical Engineering (Double Degree, in co-operation with Hebut), Bachelor's thesis

2024

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Examiner: Mehar Ullah. PhD in electrical engineering

ABSTRACT

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LUT School of Energy Systems

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Double Degree, in co-operation with Hebei University of Technology

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Nowadays, human beings are no longer satisfied with today's energy structure. More and more people want to use green energy to replace traditional fossil fuels. In this context, the term "renewable energy" began to rise in human society and gradually became mainstream. Its popularity is reflected in all aspects where energy is used. Especially for utilization in homes and businesses. It not only make our lives more convenient, but also preserve the environment. However, the large-scale use of renewable energy in homes and businesses has remained at the theoretical stage. This is because they are very inefficient in actual use which will cause serious economic losses.

However, there are also some solutions to improve the efficiency of renewable energy. Contemporary advanced Internet of Things (IoT) technology and smart grid technology are the best ways to improve the efficiency of renewable energy use. These two technologies optimize the production, transmission and consumption of renewable energy through real-time monitoring, data analysis, intelligent control and other technical means. Thereby improving its usage efficiency. The main idea of this article is to highlight the role of IoT in integration with the smart grid to increase the efficiency of utilizing the green energy. The article concludes that smart grids and the IoT play a key role in improving the efficiency of renewable energy use. At the same time, The article highlights that every country in the future can use renewable energy on a large scale. Countries that master technology can provide some IoT technical support to relatively backward countries, thus helping them to achieve energy transition. This will require the joint efforts of all countries.

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1 Introduction

Energy is an important component for the development and survival of humans, it is also the driving force for human social and economic development, and one of the pillars of modern human civilization [1]. Just as fossil fuels to the first industrial revolution, and electrical energy to the second industrial revolution. Energy plays an essential role in every technological revolution. Nowadays, with the progress of the times and the development of society. The quality of human life is getting better and better. However, such progress is also accompanied by serious environmental pollution. Burning tons of fossil fuels has caused air pollution, water pollution, soil pollution and so on, which harm to human health. People who have their material needs met will pay more attention to their health. On the other hand, the current global energy crisis is serious, and various regions have to start saving energy, reducing carbon emissions. Therefore, most people in today's society realize the importance of renewable energy and strongly support its use [2]. Governments are also paying great attention to the creation and utilization of renewable energy. But they need to be more rigorous than the public. They need to measure many factors, especially energy efficiency. So far, the main reason why renewable energy cannot replace traditional energy is still that it cannot guarantee efficiency [3]. This so-called efficiency can be reflected in every aspect which requires the energy. Such as industry, transportation and so on. Among these, the application of energy in homes and businesses is closely related to ordinary people. Although governments in some regions have begun to comprehensively promote the replacement of traditional energy with renewable energy. But the effect is not very significant [4]. That result are not difficult to understand, because a small business owner or a member of the public obviously don't want to lose money due to the low efficiency of renewable energy. Therefore, how to improve the utilization efficiency of renewable energy has become a big issue. Among them, the most popular solutions are the utilization of the latest technologies like IoT and smart grid. This also leads to the theme of this article: **The role of IoT and smart grid technologies in increasing the efficiency of renewable energy use in homes and businesses.**

The IoT is the product of the revolution in the information technology industry. It refers to connecting devices or objects together through the Internet so that they can interact and

communicate information with each other. In the IoT, some smart devices, sensors and actuators play a very important role. They are connected to the Internet through embedded computing and network connections. Then, they interact and share information through information medium, and ultimately accomplish tasks such as tracking, intelligent identification, positioning, and supervision [5]. Smart grids are generally considered to be next-generation power systems that utilize advanced control and communication technologies to optimize the production, distribution, and consumption of energy. Advanced timers, two-way communications, and smart management devices are some of the technologies that smart grids can use to improve system efficiency. In a smart grid, two-way communication allows suppliers to observe the energy consumed by a house in real time and send the information to consumers through smart meters. Therefore, smart grids can increase consumer participation to optimize energy consumption [6]. It is worth noting that all aspects of the smart grid require technical support from the IoT, and most of its businesses are related to the IoT. Therefore, smart grids are often also called smart grids based on IoT technology.

The IoT and smart grid technology can indeed improve the efficiency of renewable energy utilization. This point of view is not the first time to be raised by this article. There have been a lot of articles expounding this view before. Some scholars have added their own ideas to this theory. They believe that IoT technology can help improve energy efficiency and reduce energy waste. and real-time monitoring and control can be achieved to ensure efficient use of energy by connecting equipment and systems in homes, factories and commercial buildings [7]. There are also some scholars whose articles are more persuasive. They demonstrate their views by citing cases that have been implemented. For example, in manufacturing, the IoT connects production equipment and robots to achieve intelligent manufacturing and energy optimization. The equipment can automatically switch on and off according to production needs, reducing unnecessary energy consumption. In addition, some very innovative articles can also be found on the Internet. For example, some scholars want to design an agricultural data collection system based on NB-IoT [8]. To address the present issues with GPRS, ZigBee, LoRa, and other techniques for gathering data automatically about crop growth environments, such as high power consumption, development costs and difficulty. There are also some scholars who want to study the application of key technologies in smart construction site systems based on BIM+GIS+IoT technology [9]. These researchers also concentrated on examining BIM, GIS, and IoT

technologies in order to guarantee that the construction management model of the construction site meets strict requirements in terms of safety, quality, efficiency.

The researches by Wang Yingqiang, Zhang Weigang and Wang Honggang mentioned above are undoubtedly valuable and can be considered as good references [8] [9]. However, there is a scarcity of literature on the web on how to enhance the efficiency of renewable energy use in the home and business through IoT and smart grid technologies. This paper will focus on three keywords: "IoT technology", "smart grid" and "renewable energy". Moreover, the article will analyse and explain each of these three keywords and identify the links between them. The main problem addressed in the article is to find out how IoT and smart grids can improve the efficiency of renewable energy use in homes and business, in other words, what role they play in improving the efficiency of renewable energy use. In order to enhance the credibility and authenticity of the results. The article will cite a large amount of literature. The new insights will be given based on the citations and summaries. In addition to that, the article will give a maximum of practical examples to support the correctness of the results, and finally give a discussion and summary at the end of the article. As mentioned in the first paragraph of the article introduction, homes and business are the two areas that the public is most likely to be involved with. With the gradual popularization of renewable energy technologies, if the IoT and smart grid can enhance the utilization efficiency of renewable energy in these two aspects. That will undoubtedly be a huge contribution to human energy source and environmental protection. This is also the purpose and significance of researching and writing this paper.

2 Internet of things (IoT)

The term Internet of Things is abbreviated as IoT, and this term has been defined by a wide range of groups, including academics, researchers, practitioners, innovators, developers, and business people. These individuals or groups all have their own opinions. But all of these definitions agree that data created by people was the focus of the first iteration of the Internet, while data created by things was the focus of the subsequent iteration. Thus, the following could be the best way to define the IoT: “A comprehensive and transparent

network of intelligent objects with the ability to self-organize, exchange data, and resources, and respond and act in response to external events and changes" [10].

2.1 What is IoT

The term "IoT" originated in the last century. Kevin Ashton, who is the co-founder of the Massachusetts Institute of Technology (MIT) Automatic Identification Center, proposed the term "Internet of Things" in 1999 while working at the MIT Auto-ID Laboratory. At the same time, he first used this term in a speech at Procter & Gamble (P&G) in 1999. As he once said: "I may be incorrect, but I believe the term "Internet of Things" originated from the title of a 1999 presentation that I gave at P&G. Connecting P&G's RFID supply chain concept to the then-trendy Internet was more than just a clever tactic to grab executives' attention. It encapsulated a crucial realization that is still frequently misinterpreted. Ashton (2008) [11]. Figure 1 is a photo of Kevin Ashton.

Figure 1. Kevin Ashton who proposed the concept of IoT adopted from [12].

In that speech, he not only proposed the concept of IoT but also proposed the use of radio frequency identification (RFID, which speeds up the acquisition and processing of target object information through radio frequency [13].) and other sensor technologies. His academic works provided a strong basis for the Internet of Things' development, and in the decades that followed, his ideas were expanded upon and applied widely, sparking an array of scholarly debates and scientific investigations. As a result, he became one of the well-known figures in the field of IoT and was respected as the "Father of IoT". It is worth

noting that although he proposed the concept of the IoT, the development of the IoT was jointly promoted by many scientists, engineers and entrepreneurs, involving technological innovation in multiple fields.

Economist Xie Donggen believes that everything in the world will go through five stages: origin, development, prosperity, decline, and destruction [14]. Well, IoT technology is in its development state and is about to reach its peak. As we all know, The important foundation and core of IoT technology is the Internet. According to statistics, as of August 12, 2016, there were an estimated 3,432,809,100 Internet users worldwide. Internet users account for nearly 40% of the world population [15]. Therefore, it is not an exaggeration to say that the IoT has become the mainstream in the technological era.

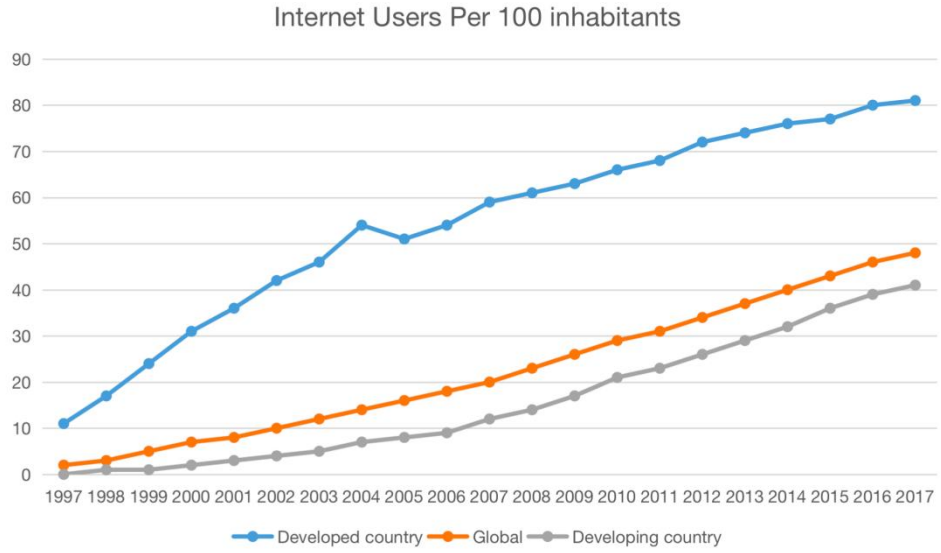

Figure 2. Internet users per 100 population from year 1997 to year 2007 line chart.

As shown in figure 2, the number of Internet users around the world is increasing year by year. Moreover, based on this development trend, it is not difficult to imagine that in the next five to ten years, the term "IoT" will never stop becoming the newest and most popular idea in the IT field [15].

The IoT brings a new experience to human beings. In the world of the Internet of Things, everything can be connected and communicate with each other in a “unique” way. Figure 3 shows the network structure of the IoT. People can deeply feel this convenient in their daily lives. For an ordinary person, the most common devices that can play a "connective" role are electronic devices, such as computers, tablets, phones, and smartphones. And "connection" is also the first part to be considered in the field of IoT. In the so-called

Internet of Things, various objects are embedded with sensors and actuators, connected through wired or wireless networks, and communicate using Internet Protocol (IP) [16]. These connected objects are able to sense their surroundings and transmit large amounts of information to computers for analysis through data generation [17].

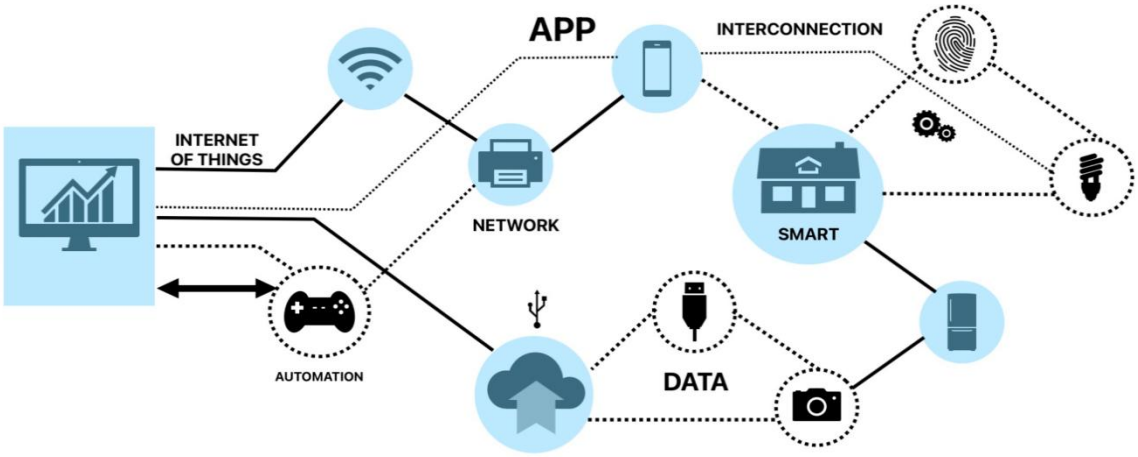

Figure 3. Internet of Things network architecture diagram.

Most importantly, these objects can both sense their environment and communicate with each other, making them tools for understanding and responding quickly to complex situations. Additionally, the objects are independently connected, and some content is generated by means of IP addresses linked to the Electronic Product Code (EPC) network and encoded Radio Frequency Identification (RFID) tags, which gives the objects a distinct online identity that can be tracked and controlled [18]. This property makes IoT technology epoch-making because these object information systems can work largely independently without human intervention.

IoT technology makes the physical world and the digital world more closely integrated with each other. This concept is rapidly emerging and is changing every aspect of our lives and work. This includes household equipment, cars, industrial machines, and more. First, it creates an intelligent and efficient living environment for humans [19]. Secondly, it realizes intelligent monitoring and management of the environment through data collection and analysis, improves energy utilization efficiency and reduces unnecessary waste of resources [20]. In the medical field, remote medical monitoring technology based on the IoT enables medical equipment to remotely monitor patients' physiological parameters, such as heart rate, blood pressure, blood sugar levels. This real-time monitoring allows doctors to have a more comprehensive understanding of the patient's condition, and to

intervene and adjust treatment plans in a timely manner [21]. Figure 4 shows the operation process of an intelligent medical detection system.

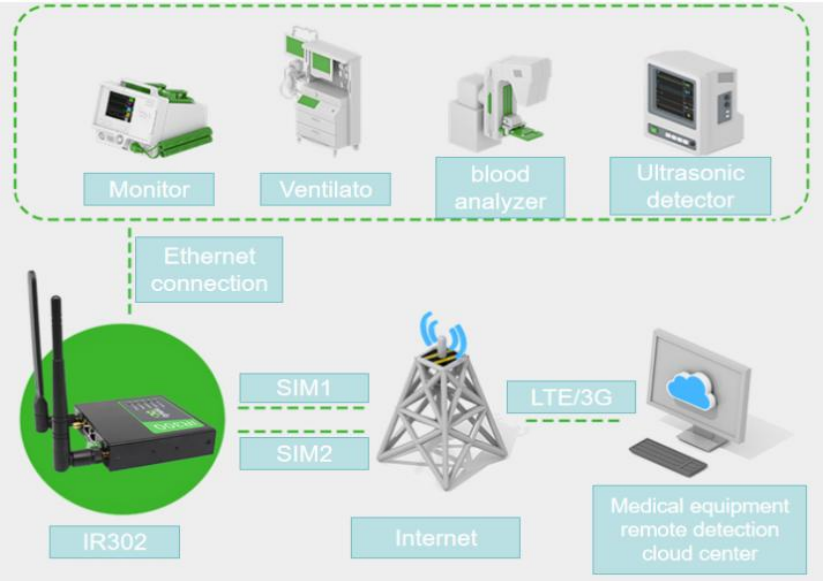

Figure 4. Intelligent medical detection system based on Internet of Things.

It can be seen that IoT has promoted the emergence of various innovative applications in various fields, enriched our lives and promoted scientific and technological progress. However, with its development, the Internet of Things also faces some problems, such as data privacy, network security and so on. These issues need to be taken seriously and dealt with. Overall, the future of IoT technology is bright, as it has become a key technology to promote social progress and improve the quality of life.

2.2 The component of IoT

The IoT functions as a huge system, and when it comes into play, it is often not accomplished by just one part. It will be a complex and orderly process. In order to have a deeper understanding of the functions and significance of the IoT, scholars usually use the method of building models to simulate an IoT system. The first step of the research is to clearly construct the various modules of the entire system. These modules can be regarded as the components of the IoT. Each component completes its own tasks and cooperates to provide functions. Generally speaking, the entire IoT system consists of six IoT building blocks [22]. As shown in the figure 5, these building blocks interact with each other while maintaining their own unique functionality.

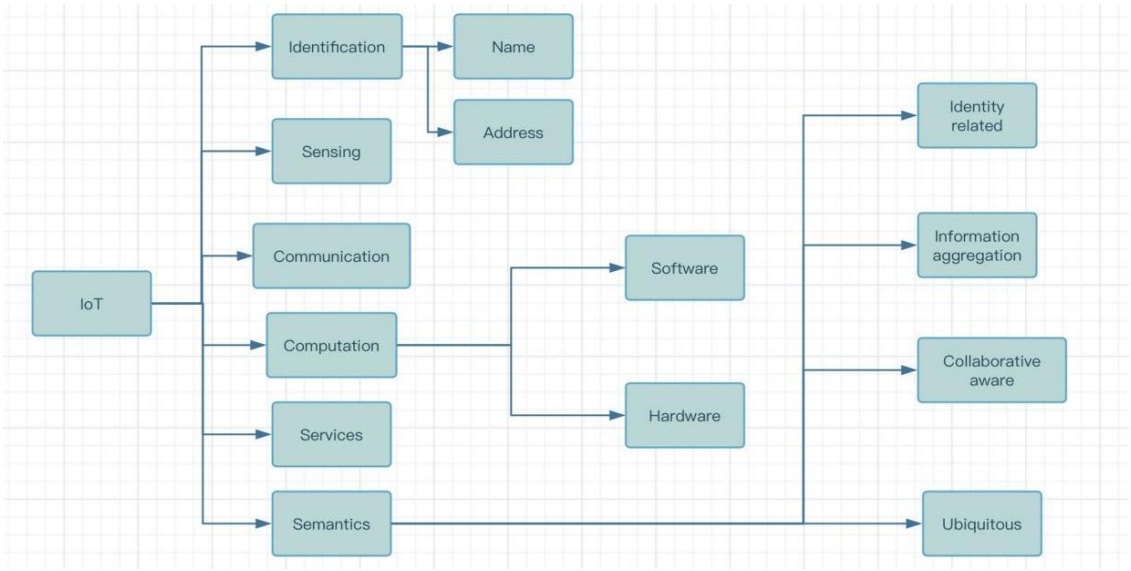

Figure 5. IoT building blocks figure.

The first block is **the identification block** and can be used to identify the objects in the network, normally an object can be identify with its name or address. The device is usually identified by using Object ID and Object Address. The main addressing methods for IoT objects are IPv6 and IPv4 [23].

Next, "**The sensing block**". It is mainly composed of sensors and actuators, and it aims to sense and collect data about objects or the environment. Figure 6 shows the working process of the sensing block, its essence is the conversion of signals [22].

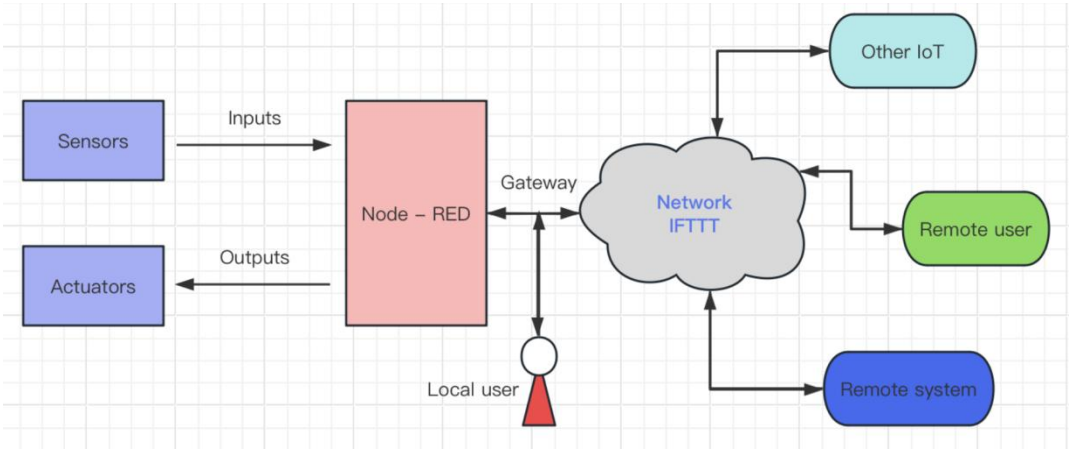

Figure 6. The sensing block of IoT system.

For example, sensors can detect physical quantities such as temperature, humidity, and light. In this process, environmental signals are converted into electrical signals, and then these collected electrical signals are transmitted to the target database or the cloud through

the equipment in the sensing block, and then analyzed by the cloud to obtain useful information.

The communication block of the IoT is a crucial component which is composed of various heterogeneous objects. It aims to enable efficient and reliable data exchange between devices and platforms. This block contains IoT communication protocols such as MQTT and CoAP. This block also implements the connection of different IoT objects and connects devices to the Internet through various communication technologies such as ZigBee, NFC, UWB, Wi-Fi, SigFox and BLE [24]. In this module, the network is built, and sensors and other devices can transmit data in real time to achieve collaborative work and intelligent services.

The computation block is also a key component in the IoT, which is composed of two main aspects: hardware and software, designed to support the computing needs and data processing of IoT devices. Hardware platforms include a variety of platforms, such as Intel Galileo, Raspberry PI, Gadgeteer, UDOO, and Arduino. They are used to run IoT applications [25]. The software platform covers the operating system and is responsible for the operation of the device throughout its activation time.

The service block of IoT provides support to application developers, simplifying the application building process by providing various services. Service blocks provide developers with powerful support, allowing them to focus more on application innovation and feature implementation without having to pay deep attention to the underlying service and architectural design. Through such support, IoT applications can be developed and deployed more quickly, improving development efficiency and innovation capabilities.

Finally, "**The semantic block**" of IoT, which is often considered the brain of IoT. It is in charge of obtaining knowledge from the IoT through resource discovery, information modeling, data identification, and analysis in order to facilitate decision-making and give users the right services. This block also make sure that various devices and services can share and comprehend each other's information by comprehending and interpreting data. Semantic blocks make the system more flexible and provide intelligent functions, and realize the intelligent features of the IoT [26].

2.3 How IoT works

As mentioned above, the IoT is composed of physical devices that are connected to each other. On the other hand, these devices can also communicate with each other and share data through the Internet. In general, the operation of the IoT can be summarized into four steps, which are 1. Data collection, 2. Data transmission, 3. Cloud processing, and 4. Decision execution. Firstly, IoT devices are equipped with sensors which can collect data form the surrounding environment or the device itself, such as temperature, humidity, location. These collected data are then transmitted to the cloud platform through the IoT gateway, ensuring safe and reliable data transmission. The cloud platform can receive the data from devices, then analyze, store, and execute corresponding decisions. Ultimately, decisions are made and sent back to the IoT device, causing corresponding actions or adjustments, based on the analysis results in the cloud [27]. Figure 7 shows how IoT works.

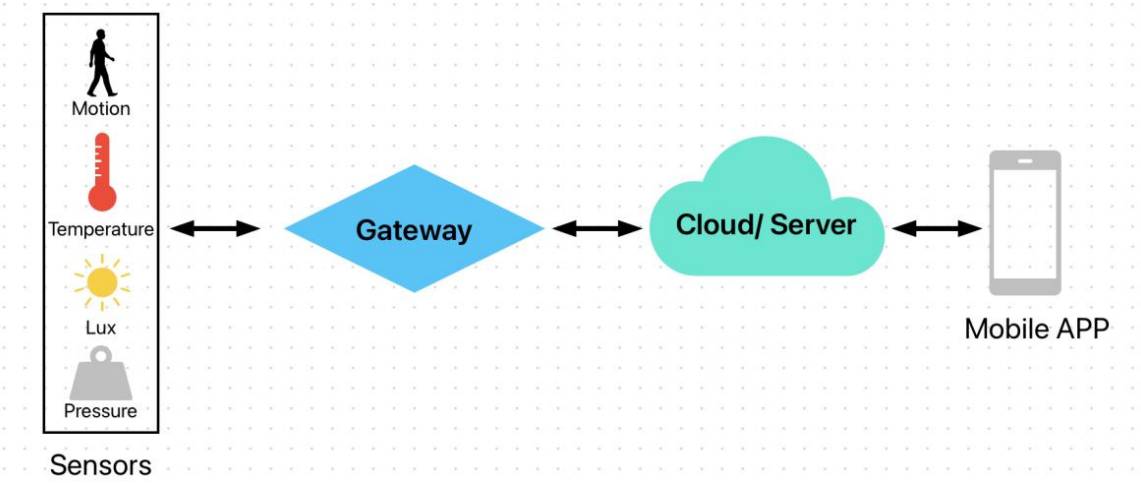

Figure 7. An example of “Flow chart of IoT work”.

Data can also be sent to edge devices for local analysis before being shared. The bandwidth usage will be minimized because less data is transferred to the cloud [28]. Sometimes, devices in the IoT “talk to” other related devices and take actions according to the data they “learn” from one another. Although people can interact with the devices, these devices do most of their work without human intervention. These network devices' networking, connectivity, and communication protocols are mostly determined by the particular IoT application which is being implemented. IoT can also use artificial intelligence (AI) and machine learning to help make the data collection process easier and more dynamic [29].

3 Smart gird

The smart grid is known as the electricity grid's intelligence. It makes use of sophisticated equipment technology, advanced control techniques, advanced sensing and measurement technology, and the application of advanced decision support system technology. It is built upon a high-speed two-way communication network. It is the result of advancements in science and technology in the modern period. To better understand the smart grid, we must first understand the traditional grid which preceded it.

3.1 Traditional electricity grid

The power grid has been an essential facility linking power plants and users since the beginning of human exploration of power transmission. The origins of the power grid can be traced back to the late 19th century, when people began to explore the possibility of delivering power over long distances through electricity transmission. The first commercially operated power grid was built in New York in 1882 and connected power plants and several consumers (As shown in figure 8) [30]. As the demand for electricity grows, more and more countries are beginning to build their own power grid systems.

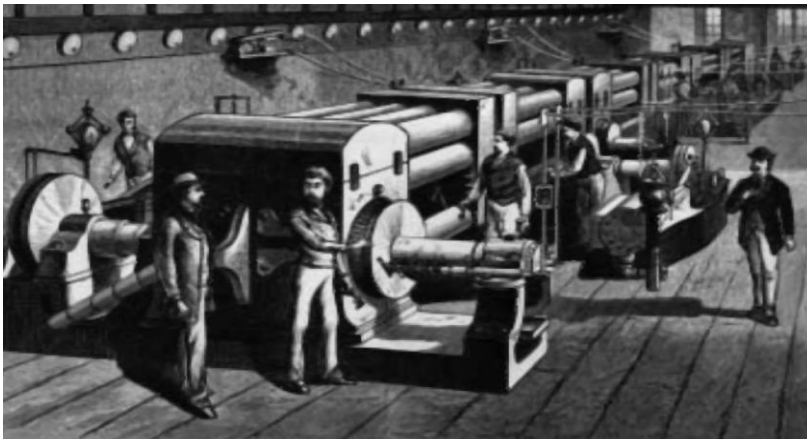

Figure 8. The generator at Pearl Street Station in Lower Manhattan adopted from [30].

In the early days of power grid construction, there was controversy over whether to use alternating current or direct current. Eventually, alternating current was widely adopted

and became the basis of the modern power grid. The advantage of alternating current is that it can increase and decrease the voltage through a transformer, thereby enabling long-distance transmission. In comparison, DC has a shorter transmission distance and is therefore suitable for specific areas, such as internal power supply in cities [31]. Figure 9 shows how the traditional power grid works

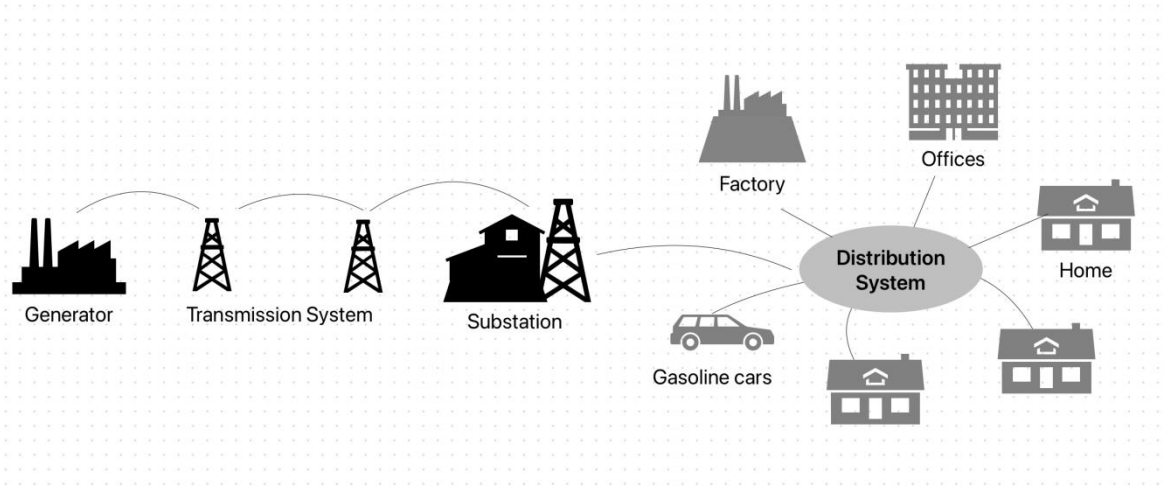

Figure 9. Elements of the Traditional electricity grid.

The traditional power grid mentioned in the article usually refers to the traditional power system, also known as the central or centralized power system. It is an electric power system composed of a central power station and transmission and distribution facilities that distribute power from the central power station to various users through transmission lines. The main characteristics of this system are: concentrated power generation, long transmission lines, large losses, high stability [32].

Figure 10. Traditional grid thermal power plants picture adopted from [33].

In the traditional power system, power stations are driven by traditional energy sources such as coal, oil, and natural gas (The traditional grid thermal power plant shown in figure 10). Therefore, the system has high requirements for stable energy supply. The power generation of this type of system is highly localized, while the distribution system mostly adopts a one-way transmission chain structure. There is a long distance between the place where the electric energy is generated and the place where the electric energy is used, which requires long-distance transmission and distribution. People will face problems with loss and instability.

3.2 Smart grid based on Internet of Things

The term "smart grid" first appeared in the report issued in June 2003 by the Smart Grid Working Group of the Future Energy Alliance of the United States. This report points out that the smart grid is "a transmission and distribution system with improved performance and functionality". It can provide users with a series of value-added services integrating traditional modern power engineering technologies, advanced sensing and monitoring technologies, and information and communication technologies." The terms "intelligent grid" and "modern grid" are also equivalent. While there are some specific differences between these definitions and titles, their general meaning aligns with the definition provided above [34]. Figure 11 briefly shows what a smart grid is.

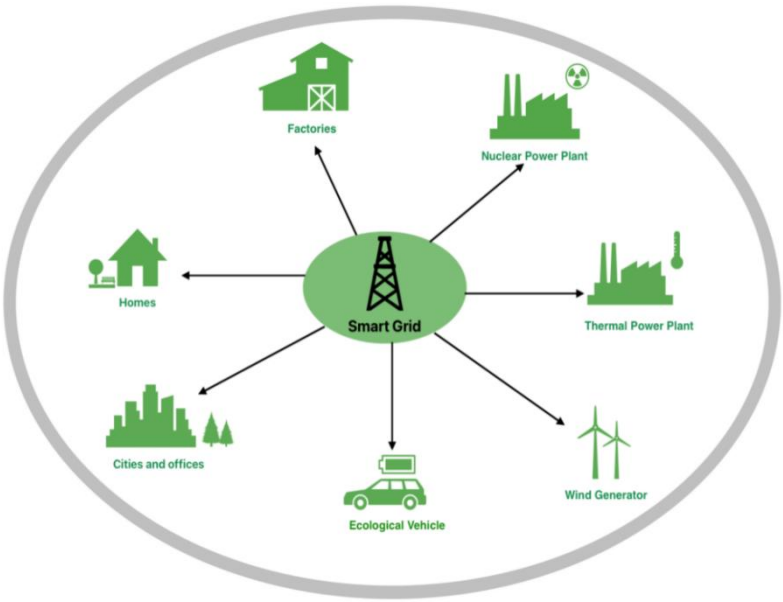

Figure 11. Smart Grid Technology Illustration.

Overall, smart grids are possible thanks to significant advances in power electronics and Internet communications technology. The integration of some new technologies has enabled the efficient use of energy production and consumption, provided opportunities for renewable energy sources (RES) such as wind energy and solar energy, and enabled the exchange of power generation from different sources and the two-way flow of electricity and communications. Additionally, new technology paradigms such as the IoT are impacting modern SG operations by improving communications, enabling better customer relationships, and processing the vast amounts of data generated by smart devices [35]. Smart grid is considered to be the industry which is most closely related to the IoT. In the future, the construction of smart grids will inevitably become the largest, most intelligent, and most comprehensive IoT in the world. Power production management, intelligent power consumption, asset life cycle management, and status detection of power equipment are all made possible by IoT technology.

3.3 The difference between smart grid and traditional grid

The following characteristics show how smart grids differ from traditional grids. First, in terms of technical architecture, traditional power grids primarily use mechanical, technical system of electrical and control components, whereas smart grids use cutting edge information, communication, and control technologies, such as the IoT and big data analysis, to create a power system architecture with data and information at its core. Security and dependability come in second. Because of their great intelligence and adaptability, smart grids can react to changes in load quickly, enhancing the power system's security and dependability. Traditional power grids are comparatively simple and have certain restrictions on the power system's security and responsiveness. Finally, Smart grids have a higher level of digitization and intelligence and can support multiple optimization algorithms, big data analysis, and fine-grained monitoring and control of the power system, thereby improving system efficiency and performance [36].

Smart grids are generally more intelligent, secure, reliable, and efficient, and can support the acquisition and use of clean energy. They also make it easier for users to manage and use electricity resources more efficiently than traditional grids [37].

However, although the traditional power grid is not as efficient and intelligent as the smart grid, it still has its own advantages. First, traditional power grids are stable and reliable. Its operation process is relatively simple and relies on mechanical and electrical equipment, so its stability and reliability are relatively high. Secondly, traditional power grid technology is relatively mature, has a long history, is widely used, and has a complete technology system. The operation process of the traditional power grid is fixed, relatively stable, and the operating cost is relatively low. Finally, the operation process of traditional power grids is relatively independent and the management method is relatively simple, so it is easier to control and manage operational risks. Until intelligence completely replaces it, the traditional grid is still the way to go.

3.4 The components of smart grid

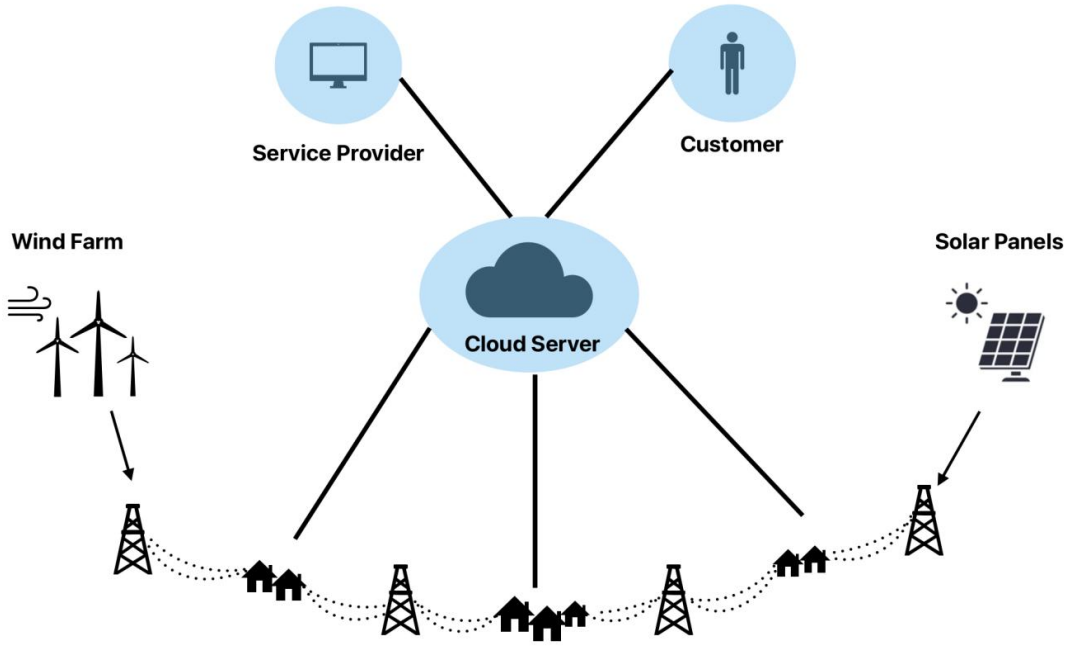

Figure 12. Smart transmission of smart grid.

Smart grid mainly consists of three parts: smart transmission network (as shown in the figure 12), smart distribution network and smart power grid. Among them, the smart transmission network is used to transport power from power plants to power conversion stations or transmission substations, while the smart distribution network is responsible for regulating and distributing power in the transmission network, and transporting power to

the distribution transformers of each user. Finally, The smart grid provides electric energy to users.

Smart transmission grid is the foundation of smart grid, which mainly consists of high-voltage transmission lines, power conversion stations, high-voltage power equipment and intelligent devices. The smart transmission grid uses high-voltage power as the medium to realize large-capacity power transmission between power sources, while ensuring the stability and reliability of power transmission [38].

4 Renewable energy

The significance of renewable energy to human is absolutely huge. It helps mitigate climate change by reducing greenhouse gas emissions. Secondly, the promotion of new energy reduces dependence on limited fossil fuels and improves the reliability of energy supply. At the same time, the research and development and application of new energy have promoted technological innovation and created new economic growth points and employment opportunities for society. In addition, new energy can help improve the energy structure and promote sustainable economic and social development.

4.1 How to define renewable energy

Renewable energy refers to an energy source in nature that can be continuously utilized and recycled, such as solar energy, wind energy, water energy, biomass energy, etc. With the emergence of the global energy crisis, people have begun to realize the importance of renewable energy. In fact, the energy sources that humans have relied on for a long time in history are all renewable energy sources, such as wood, straw, etc. , as well as water power, wind power, etc. Most of these energies come from the conversion of solar energy and are renewable energy resources [39].

Fossil energy sources such as coal, oil, and natural gas that have been developed and utilized on a large scale in modern human society actually come from the conversion of solar energy. However, they were formed and stored during the evolution of the earth in ancient times. For us humans, Once used up, it cannot be restored or regenerated [40].

4.2 Renewable energy applications in homes and businesses

The use of renewable energy in homes and businesses is critical because it helps protect the environment, improves energy security, and drives scientific and technological innovation.

4.2.1 Renewable energy sources commonly used in homes

When using renewable energy in the home, the most common options include solar, wind, and biomass. The first is solar energy. Since the area of the home is generally not very large, people must pay attention to the footprint and complexity of the equipment when using renewable energy. Solar energy is a widely used renewable energy source, and there will be sunshine in any area. By installing solar panels on the roof or balcony, it can convert sunlight directly into electricity (Solar panels on private residence as shown in the figure 13). Such a system could provide electricity to homes, reducing reliance on fossil fuels [41]. and Solar panels are very simple devices.

Figure 13. Solar panels on private residence adopted from [42].

Secondly, wind energy is also a common renewable energy option. By installing small wind turbines, wind power can be harnessed and converted into electricity. However, this method is limited to some areas with abundant wind resources. Additionally, biomass energy is a way to generate energy from biomass resources such as organic waste, wood, or waste crops. This can be achieved through processes such as combustion or fermentation, producing heat that can be used for heating or generating electricity. Such an

approach not only reduces the impact of waste on the environment, but also provides households with a renewable energy source [43].

4.2.2 Renewable energy sources commonly used in business

The three main renewable energy sources used in businesses are exactly the same as those used in homes. Firstly, solar energy is the most predominantly used renewable energy source. Many commercial buildings have solar panels installed on their roofs (Figure 14 shows solar panels installed on the roof of a large shopping mall.). These systems can provide power to businesses and reduce the electricity bills and the reliance on traditional power grids. Next is wind energy, some large companies often considering building large wind turbines near their facilities. Such systems can provide businesses with stable power and reduce the need for traditional energy sources. Finally, it is biomass energy. Some companies use organic waste, agricultural by-products or other biomass resources to generate electricity and heat. This helps reduce the amount of waste while providing renewable energy.

Figure 14. Solar panels installed on commercial buildings adopted from [44].

4.3 Today's efficiency in using renewable energy

Renewable energy has the advantages of environmental protection and sustainability. It helps improve energy security, reduce dependence on harmful resources and promote

economic growth. But in recent years, whether it is household or business-used energy, non-renewable energy (fossil fuels) still accounts for a large proportion. Figure 15 shows the portion of the main energy sources used among the world.

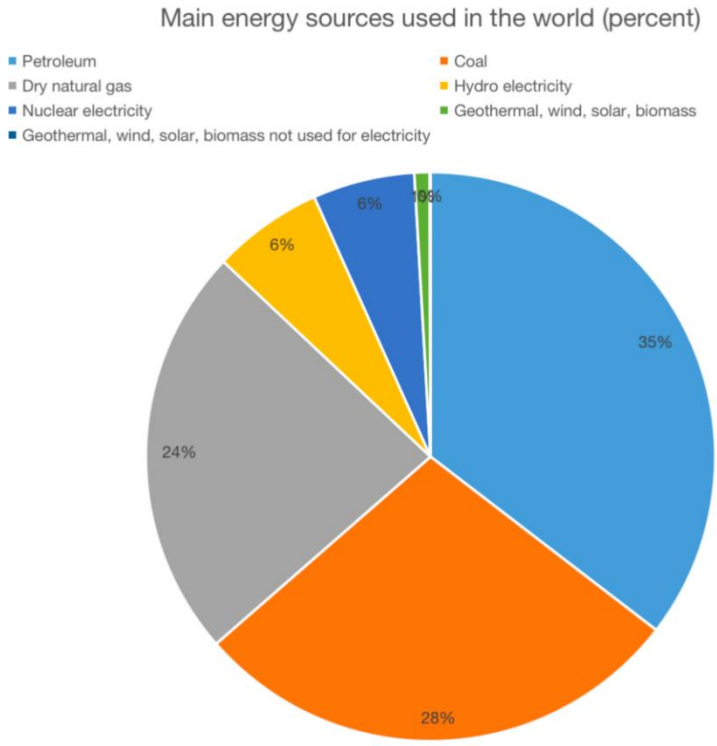

Figure 15. Main energy sources used in the world.

Although the fuel structure has changed, it is still dominated by petroleum. About 85% of humanity's energy comes from non-renewable fossil fuels [45]. The original reason for this phenomenon is also very simple, that is, human beings' utilization efficiency of renewable energy is too low. Taking solar energy as an example, first of all, the performance of the solar system is directly affected by weather conditions. The efficiency of solar power generation decreases when it is cloudy, rainy or at night, which limits its continuity and reliability. But this is not the main reason. The main problems are energy storage difficulties and technical limitations. Current energy storage technology is relatively underdeveloped and it is difficult to effectively store solar energy to provide energy when there is no sunlight. At the same time, the efficiency and output of solar technology still need improvement [46]. In most of areas, available solar resources may not be sufficient to meet demand. The financial losses caused by this technical problem are very obvious in the home, not to mention the business area where electricity consumption is larger.

5 How can IoT and smart grid enhance the efficient utilization of renewable energy in homes and businesses

Smart grid will interconnect all aspects of the power system through advanced communication, computing and control technologies to achieve interconnected sharing of information and efficient dispatch of energy. Smart grid can monitor the load status and energy usage of the power system in real time, so as to better allocate resources and dispatch the power grid. Through the application of smart grids, the balance between energy supply and demand will be more flexible, and energy utilization efficiency will also be greatly improved. Especially for the renewable energy, the function of smart grid solves most of its shortcomings during use.

5.1 Improving the efficient use of renewable energy in homes

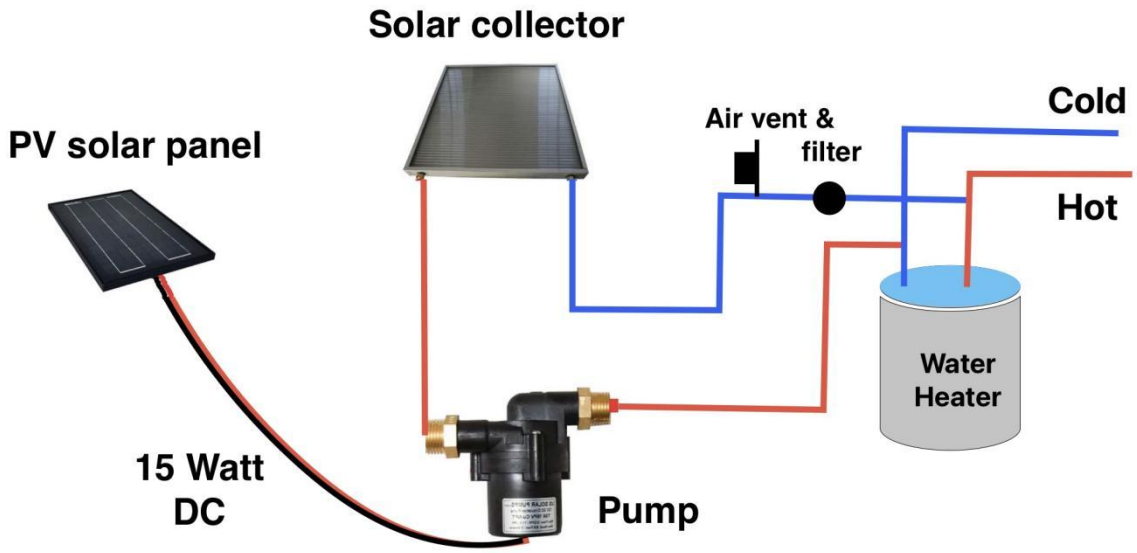

Figure 16. Working principle of household solar electric water heater.

The first is the energy storage and management capabilities of smart grids, which can support home energy storage systems such as home batteries. This enables households to store excess energy during peak renewable energy production and use it when needed,

improving energy efficiency. Taking solar energy as an example, usually household solar panels are connected to household electric water heaters (electric water heaters' working principle is shown in figure 16). When the weather is sunny, solar panels will continuously convert solar energy into electrical energy, and then use the obtained electrical energy to heat household water or household drinking water. This is why on sunny days, the maximum temperature of the bathing water provided by an electric water heater will be extremely hot.

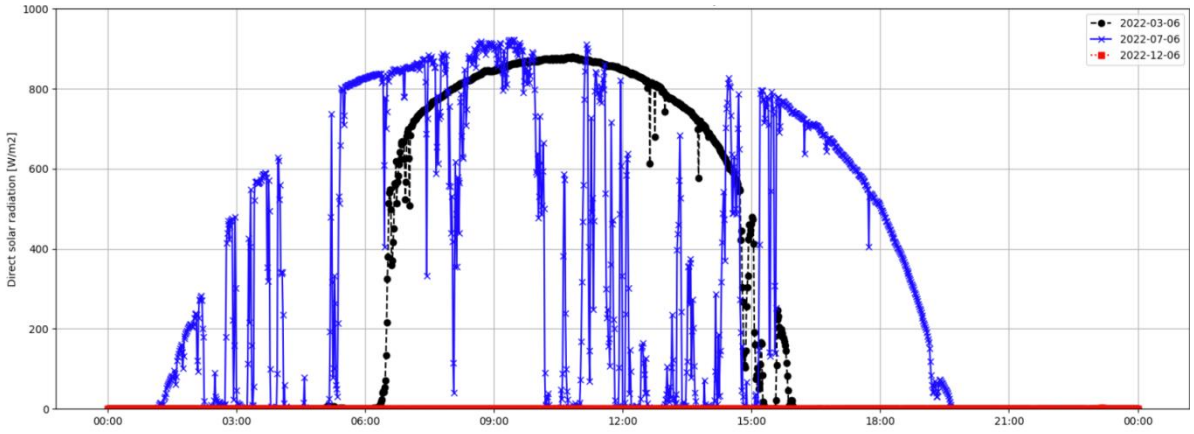

Figure 17. Solar radiation intensity in Helsinki on the same day in different months (data comes from [47]).

On the contrary, if resident encounter some rainy weather or cloudy weather, there will be insufficient sunshine. Then the solar panel is almost in a non-working state. Then there will be no electricity generated. At this time, the water provided by the electric water heater is very cold, which is obviously not suitable for taking a bath. Moreover, for some countries like Finland which located at higher latitudes in the northern hemisphere. The intensity of light at different times of the year is huge. As shown in Figure 17 above, the light radiation intensity data collected by a base station in Helsinki. The light intensity in Helsinki on the same day in March, July and December have been shown. It can be seen that there was almost no sunlight in Helsinki on December 6th.

If a home only has solar panels installed alone without a smart grid system. Then they will waste a lot of solar energy on sunny days, and make equipment like solar electric water heaters a useless items on days when the sun is not sufficient. This also makes the solar panel lose its meaning of existence. In addition, the maintenance cost of the solar panel is very high and there is a risk of damage at any time [48]. So many people do not choose

solar panels as a home generator, but rely on traditional grid power. But with the help of smart grid, the situation is very different. Electricity generated when the sun is shining is stored and used when the sun is not shining. Even so, some solar energy will be lost, but the overall solar energy utilization will be greatly improved.

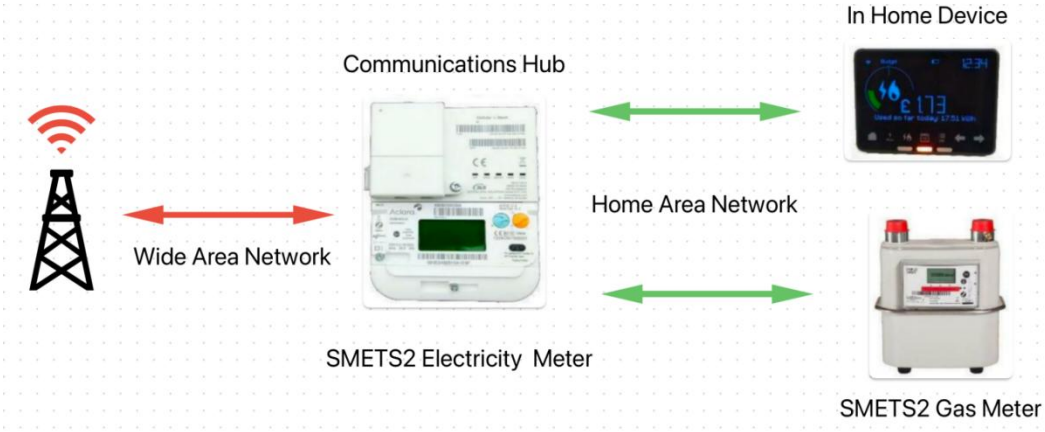

Figure 18. How smart meters work.

Smart grids also have real-time monitoring and optimization capabilities. It monitors home energy production and consumption in real time. By using smart meters and monitoring systems, households can better understand how renewable energy is being produced and how their appliances are being used [49]. Figure 18 shows the work process of the smart meter. Often, homes with solar panels or wind turbines have no idea how much power the devices produce. Then he blindly purchased a lot of unnecessary electricity from the power grid without knowing it. In the end, it resulted in waste. Or households may not have purchased spare power in advance but the power generated by household renewable energy sources is not enough. The inconvenience and economic losses caused by this are irreversible.

Whenever it comes to smart grid, IoT technology must be mentioned. IoT-based smart home technology also enables homes to manage energy use more intelligently. Smart home devices can automatically adjust the running time of home appliances based on factors such as energy production and price to optimize energy efficiency. In addition, it is based on the powerful connection capabilities and cloud computing capabilities of the Internet of Things. Smart homes can also come up with optimal energy usage plans based on collected weather data to avoid unnecessary waste. And with the help of the IoT system, home can realize a multiple distributed renewable energy system (as shown in the figure 19). Such as

solar panels and small wind turbines, which can be integrated into smart grids. Through distributed energy systems, households can generate and use renewable energy more flexibly and reduce their reliance on the traditional grid [50].

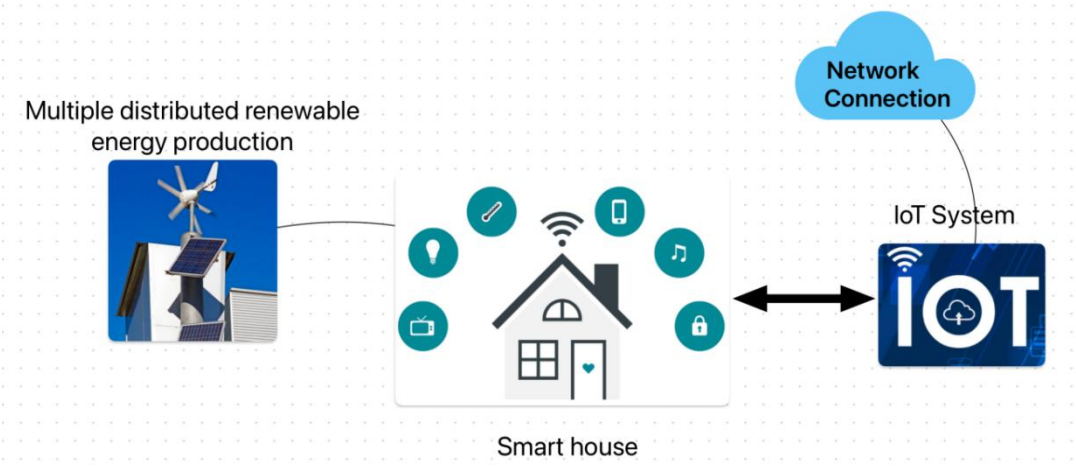

Figure 19. Smart home and multiple distributed renewable energy system.

5.2 Improving the efficient use of renewable energy in business

Compared with the energy usage in the home, the energy usage of business is very huge. The saying "efficiency is money" seems very reasonable here. As mentioned above, smart grid has real-time monitoring and prediction functions. Likewise, smart grids can monitor the production capacity and overall energy consumption of commercial renewable energy facilities in real time. Then, with the support of IoT technology, through data analysis and prediction algorithms, the system can more accurately predict the production and consumption needs of renewable energy, thereby arriving at the optimal energy usage plan. Secondly, the advantages brought by the energy storage and management functions of smart grids are infinitely magnified in business. Some commercial buildings will be equipped with large-scale battery energy storage systems. This helps to store excess energy when renewable energy production fluctuates so that it can be released during peak demand, improving energy efficiency [51]. It is worth noting that the amount of renewable energy power generation in business is very large. If used properly, there will be a lot of power left. Therefore, some businesses can sell part of the excess electricity to the power grid to earn profits while ensuring that their own electricity consumption is sufficient. Some companies can even make back all their previous investment in renewable energy

equipment such as solar panels within 15 years through this method. The figure 20 shows the world's largest battery energy storage system, the figure 21 shows the plan that buy back the renewable energy electricity "GREENMATCH" proposed by the British government .

Figure 20. The world's largest battery energy storage system adopted from [52].

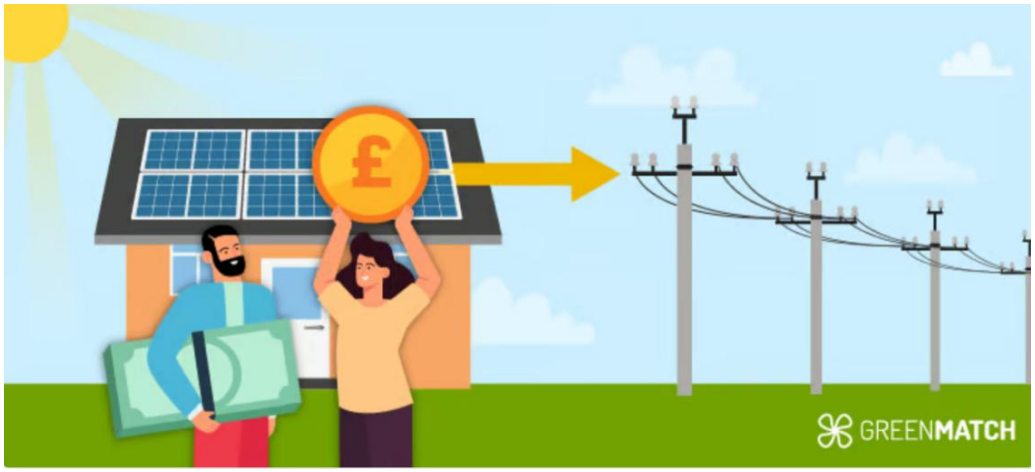

Figure 21. Selling extra solar electricity back to the grid program adopted from [53].

The business renewable energy usage model based on IoT technology has the capability of remote monitoring and control. That is to say, it can realize remote monitoring and control of renewable energy equipment. This means that the device's operating mode can be adjusted in real time to take maximum advantage of environmental conditions and energy needs to optimize system performance. For some large enterprises, they have enough ability to develop in various places. Each region has its own unique renewable energy advantages, so the installation of renewable energy equipment is also different. For example, the most suitable areas for wind power generation are usually those with strong

wind resources. These areas include areas with complex terrain such as mountains, coastlines, and plateaus, as well as flat areas such as grasslands and deserts [54]. Solar power generation is suitable for most areas around the world, but the most suitable areas are places with plenty of sunshine. Tropical and subtropical regions generally have more abundant sunlight resources. Then combined with the remote control function of IoT, the utilization efficiency of renewable energy can be maximized.

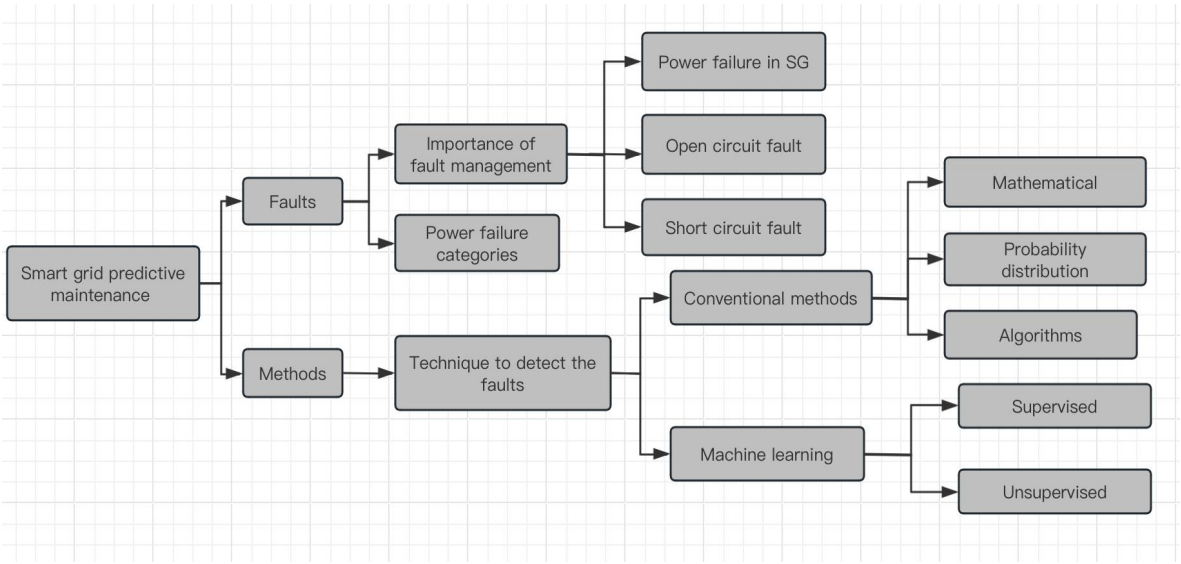

Figure 22. Predictive maintenance capabilities of smart grids.

Finally, smart grid has the function of predictive maintenance (as shown in the figure 22). IoT sensors can monitor the operating status of equipment and predict potential failures in advance through data analysis. This helps implement predictive maintenance, reducing equipment downtime and increasing the reliability and uptime of renewable energy equipment. This is very important for a large enterprise.

5.3 Examples of IoT and smart grids improving the efficiency of renewable energy use

Germany has adopted distributed generation to make up for capacity shortfalls. Due to geographical and environmental advantages, Germany has abundant wind resources, sunshine hours and land resources, wind energy and photovoltaic, many private households have small solar installations on their roofs, and some even have small wind generators in their backyards, which not only satisfy the households' demand for electricity, but also

allow them to sell the excess electricity to the power grid. As a result, the large energy mass provided by centralized thermal and nuclear power plants has been replaced by smaller energy masses scattered throughout the region (Figure 23), from left to right, 2000, 2005, 2010, 2013. Red - wind, yellow - photovoltaic, green – biomass [55].

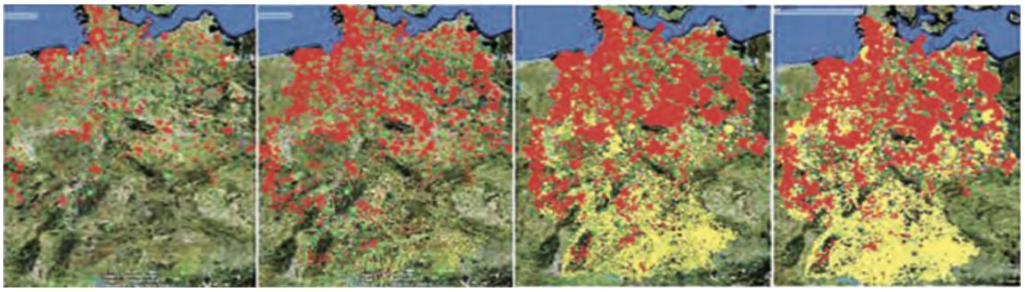

Figure 23. Germany's new energy installations adopted form [55].

At the Brandenburg University of Technology, there is a research project on future energy technologies called Smart Capital Region. It is the epitome of a large energy system in Germany, with photovoltaic power generation, combined heat and power (CHP) as the generator, a smart grid as the transmitter, and a stabilized lead-acid battery, 2-3 electric vehicles, and a heat storage and steam generator as the load side of the energy consumption. Figure 24 shows the energy flow diagram of the Smart Capital Region project, which shows that the project has improved energy utilization through the combined use of smart grids and the Internet of Things (IoT). The following are three valuable features of this project [56] [57].

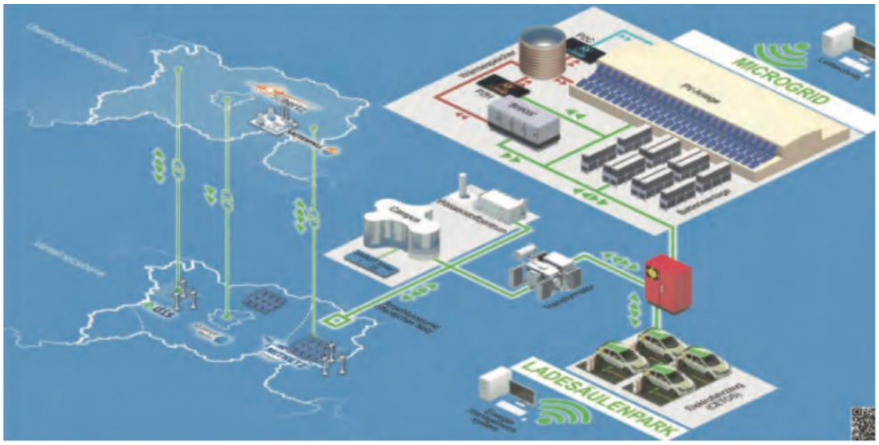

Figure 24. Energy flow for the Smart Capital Region project adopted from [56].

1. The energy flow in Germany is holistic. From the transmission grid to the distribution grid, the energy of the user load is irreversible. However, the relationship between the

secondary power producers and the transmission grid is a two-way flow, for example in the case of photovoltaic power producers, because in the state of Brandenburg, the production capacity of renewable and conventional energy sources is often higher than the energy consumed by the users, and the two-way flow is designed to reduce the overloading of the grid so that excess energy can be returned to the grid and redistributed. This integrated approach increases the flexibility of the grid system, and at the same time increases the possibility of connecting more renewable energy sources to the grid .

2. Adopting the concept of distributed power generation The smart grid test site on the BTU campus fully utilizes the concept of distributed power generation: the campus can produce and consume its own power, and the excess power can be exported to the outside world or stored (storage batteries, heat storage devices, and E-Cars). By eliminating the monopoly of a single power plant, distributed generation reduces or even replaces centralized power supply, reduces the burden on the environment, and leads to greater autonomy in the use of energy.

3. Smart Grid Information Center: The BTU campus has a separate office called BIENe (As shown Figure 25), where all data is processed and analyzed. The smart grid records load profiles and usage (loads mainly include campus office buildings, laboratory buildings, and storage facilities), and then transmits the data to the BIENe for network recording, evaluation, analysis, and optimization. Similarly, the university's medium- and high-voltage power grids are monitored and controlled in this way. In this way, the energy flow is visualized and the interactions between the different components of the overall energy grid can be studied and optimized more clearly [58].

Figure 25. Smart Grid Information Center BIENe Appearance.

6 Summary and Discussion

Overall, IoT and smart grids play a key role in improving the efficiency of renewable energy utilization. They provide a series of solutions through real-time monitoring, data analysis and intelligent control technology to optimize the production, transmission and consumption of renewable energy.

The first is the renewable energy used in the home. The IoT-based smart grid has an intelligent battery energy storage system. This can perfectly solve the problem of uneven use of renewable energy or waste caused by the inability to store it. At the same time, the real-time monitoring function of smart grid technology combined with its powerful information sharing function can collect energy system data in real time at any time, and then analyze these data in real time through the Internet of Things platform to provide users with detailed information and improve the utilization efficiency of renewable energy. In addition, IoT technology can connect any object to the network, and then exchange information through information communication media. Smart homes can better integrate information through this method and then implement a multiple distributed renewable energy system applications. It can diversify the use of renewable energy and improve efficiency.

About the application of renewable energy in business. Smart grid and IoT technologies also play a role that cannot be ignored. The advantages brought by smart grid battery energy storage systems can be better reflected here. The smart grid based on the Internet of Things can monitor and manage the battery energy storage system within the enterprise to achieve a more effective energy storage and release process. Through real-time data analysis, the system can optimize charge and discharge cycles, improve the overall performance of the energy storage system, and ensure that energy is released when needed, allowing enterprises to use renewable energy more efficiently. Businesses can also make more informed decisions based on the data collected. For example, the excess electricity produced by solar panels is sold to the grid to obtain profits. This can encourage companies to pay attention to the use of renewable energy from another aspect. besides, With the support of IoT technology, smart grids also have the function of predictive maintenance.

Improve reliability and uptime of renewable energy equipment. For enterprises, this is undoubtedly a significant improvement in efficiency.

Nowadays, many developed countries have begun to apply IoT technology to the use of renewable energy in homes and businesses. At the same time, the renewable energy equipment in the home and business is connected to the smart grid. Taking Germany as an example, it has achieved great success in increasing the efficiency of the use of renewable energy. These successful cases prove that the IoT and smart grid technology are the key link in realizing the comprehensive replacement of traditional energy sources with renewable energy. However, the IoT and smart grid technologies in some developing countries and some relatively backward countries are still in the theoretical stage. These countries are almost blank in the utilization of renewable energy. This has left these countries still in the stage of sacrificing the national environment for economic development. This has ultimately led to the growing gap between rich and poor countries, while the global environmental quality continues to deteriorate. Therefore, this article ends with a look to the future. It is hoped that countries that have mastered the IoT and smart technologies can help some relatively backward countries. Improve their utilization efficiency of renewable energy and make a contribution to the earth's environment.

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