THE INTEGRATION OF IoT WITH ENERGY STORAGE ADVANCEMENTS

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ABSTRACT

This thesis describes the applications of Internet of Things (IoT) technologies in different energy systems and advances in energy storage technologies and analyses the role and possibilities of IoT technologies in the corresponding application scenarios. In advanced energy systems and energy storage systems, the gradual shift to renewable energy sources is a major goal, and the combination of multiple storage systems related to this goal, as well as the upgrading of existing technologies, are also important, and these priorities invariably require the fast and stable transmission of data. The IoT technologies discussed in this thesis can be well integrated into such energy systems and energy storage systems. In this thesis, IoT-related technology models are shown to be feasible. However, the integration of IoT technologies with energy storage technologies and energy systems still faces many challenges and we need more attempts to push it forward.

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1. INTRODUCTION

1.1 Background

The Internet of Things (IoT) is a web or network, connecting the physical objects in our life in the digital way. It allows data to exchange between devices, instruments, vehicles and many other items with electronics.

Kevin Ashton firstly proposed the concept of IoT in 1999, and he referred the IoT as uniquely identifiable connected objects with radio-frequency identification (RFID) technology [1]. But the definitions and interpretations of the Internet of Things are still changing as technology advances and perceptions vary.

However, the concept may change, the core of linking objects into a digital network allows the applications of IoT to diversify into various categories. Besides the parts related to former part in this literature such as smart transportation, smart living and communication, IoT also shows capacity in fields of smart industry, embedded systems, wireless sensor networks, control systems and automation (including smart home and smart cities) that can be seen in figure 1 below.

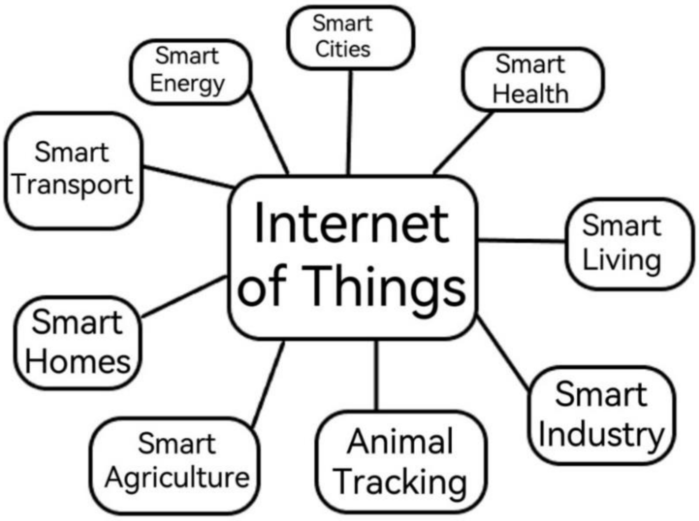

Figure 1. The IoT generic scenarios

In the context of climate change, the global preference for energy is gradually moving towards cleaner and renewable energy sources, therefore energy storage systems serving renewable and new energy sources are becoming more and more important. Because the possible applications of relating IoT to control systems and automation, this thesis will discuss and explore the integration of IoT in energy storage advancements.

1.2 Research purpose and problem statement

The purpose of this thesis is to explore how IoT is integrated to energy storage systems, what role does IoT plays in the systems, discuss the existing and possible enhancements and predict the future combination of two fields. The role of IoT with energy storage advancements. Discussion of cases related to applications of IoT based systems in energy storage advancements.

2. IoT and Energy Storage Systems

2.1 Usage of IoT

In previous literature, the concept, definition and possible fields of applications of IoT was introduced already. Therefore, the current application cases of IoT and its role in the applications will be mentioned. The following sections will first cover the overall fields of IoT based smart systems. After which, the thesis will discuss the field that relates more to energy storage systems, which is industry and smart grid.

2.1.1 Usage in smart systems

Smart systems are basically integrated interconnected networks of components that employ advanced technologies such as sensors and communication capabilities to intelligently collect, analyse data and respond to information. Smart systems can adapt, automate and optimize functions based on real-time data to improve efficiency, convenience and effectiveness in all situations. These systems are designed to provide smart solutions, improve decision-making processes, and leverage IoT to improve overall performance.

The smart system naturally has applications and manifestations in many aspects of our lives. There are two aspects this thesis will mainly focus on. First is the smart industry, second is the smart energy.

The smart industry consists of explosive and toxic gases consists of detection of gas level and leakage in industry [2]. Additionally, it plays a crucial role in monitoring the levels of oil and gas in storage tanks and pipelines. In the context of smart industry, maintenance and repair operations include the early detection of any related units. Moreover, service maintenance can be automatically assigned for specific failures, contributing to the seamless and efficient management of industrial processes.

The aspects of smart energy can be discussed separately from small to large scale and differentiated from different energy sources. Smart meters in each household can be connected to the Internet of Things to better analyse the consumption patterns of the users. All power controllers could have controllers linked to applications downloaded by the customer, and the effect would be the same as with smart meters.

Move on to larger scale, in solar power plants, photovoltaic installations can be integrated with the IoT to better monitor and optimize the performance of the solar power plant. In wind farms, devices can be set up to monitor wind turbines and power stations, and such devices can also interact bi-directionally with devices on the customer's mobile phone, achieving the effects mentioned above. And above all within previous context, is a smart grid to co-ordinate and manage it all.

2.1.2 Usage in smart grid

The smart grid, like IoT, is also a network. But more specific to the field of electricity grids. *One of the definitions for the smart grid is that the smart grid is a communication network on top of the electricity grid to gather and analyse data from different components of a power grid to predict power supply and demand which can be used for power management* [3].

This concept of smart grid shows great similarity with the definition of IoT. Showing that IoT is really part of smart grid system.

There are four main purposes of the smart grid that has been summarized.

1. Distribute energy resources: The smart grid needs to combine multiple energy storage methods and systems.
2. Grid management: The smart grid needs to enhance the performance of every part of the combined system.
3. Increase energy efficiency: By using various technologies, the smart grid can distribute electricity consumption according to the peak consumption of different customers to achieve higher efficiency.
4. Monitoring the system: The distribution and management of the components in the system requires the smart grid to monitor, analyse different situations and prevent problems.

From above functions of smart grid, we can see that all four main functions are deeply connected to data transmission. Especially the transmission of data in different components of the smart grid and to meet the situation, IoT can be applied to transmit data in high reliability to enhance the overall performance of the smart grid in various ways.

There are various points showing the applications of IoT, supporting its usage in grid management.

1. Within electricity generation, IoT applications enable the monitoring of diverse power plant types (including coal, wind, solar, and biomass), tracking gas emissions, overseeing energy storage, and predicting the required power output for consumer supply.
2. The utilization of IoT extends to acquiring data on electricity consumption, dispatch operations, monitoring and safeguarding transmission lines, substations, and towers, as well as efficiency managing and controlling various equipment within the power grid.
3. At the customer side, IoT finds application in smart meters, facilitating the measurement of various parameters, enabling intelligent power consumption, ensuring interoperability across different networks, managing the charging and discharging of electric vehicles, and overseeing energy efficiency and power demand.

From above points, a comparison can be made between the functions of the smart grid and usage of IoT. From which we can tell that the role of IoT in the field of smart is making the system more reliable and run more efficiently, in both technical and energy saving approach.

More specifically, there is a key component within the smart grid known as the Advanced metering infrastructure (AMI): *AMI as one of the key components of SG creates a bidirectional communication network between smart meters (SMs) and utility system to collect, send, and analyse consumer energy consumption data.* [3]. The AMI represents a significant advancement over traditional automatic meter reading systems. Unlike the one-way communication network of automatic meter reading, AMI introduces bidirectional communication capabilities. This enhancement allows for not only the automatic collection of data from various meters but also two-way communication between the meters and a central system.

As AMI is a component in the smart grid, IoT can be seen to have many scenarios to interact with AMI. AMI can integrate with IoT for data collection, detecting possible issues in the Smart Grid, facilitating information exchange among smart meters, overseeing electricity quality, monitoring distributed energy, and analysing user consumption patterns.

The application of IoT in AMI is a small scale while the usage of IoT in smart grid is a larger one. But from both scales we can say that the IoT has a great deal to offer in terms of stability of data transmission. This helps in almost all data-related operations and is significant in improving efficiency at multiple levels.

2.2 Overview of energy storage systems

The increasing focus on renewable energies and the demand for low CO2 emission transportation have invoked the world’s interest in energy storage systems, positioning it as a pivotal element in the realm of sustainable development. The basic components of an energy storage facility are seemingly the same, but the details may vary between different forms of energy being stored. *Generally, energy storage facility includes a storage medium,* *a power conversion system and a balance of system. The various storage technologies used in renewable electricity systems can be chemical, electrochemical, mechanical, electromagnetic or thermal.* [4].

And different types of energy storage technologies can be seen from the Figure 2 below.

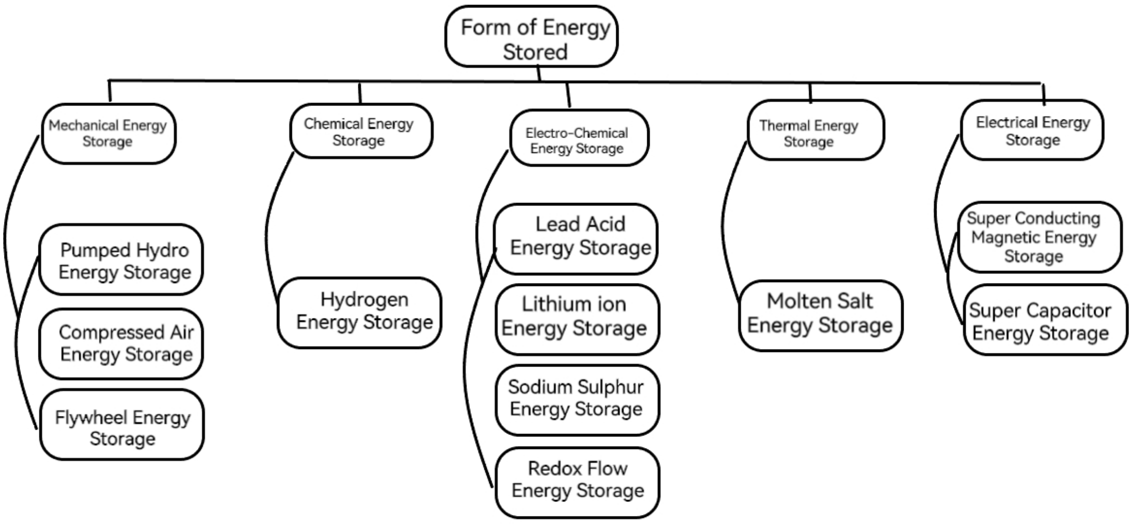

Figure 2. Classification of energy storage techniques

The next few sections will focus on the following energy storage technologies. They are flywheel energy storage systems, compressed air energy storage systems, and thermal energy storage systems.

2.2.1 Flywheel energy storage

Flywheel energy storage systems are energy storage systems that utilize kinetic energy (KE). The basic component within the system includes a cylinder with a shaft connected to an electrical generator. The model that illustrates one type of flywheel storage system can be seen in figure 3 below.

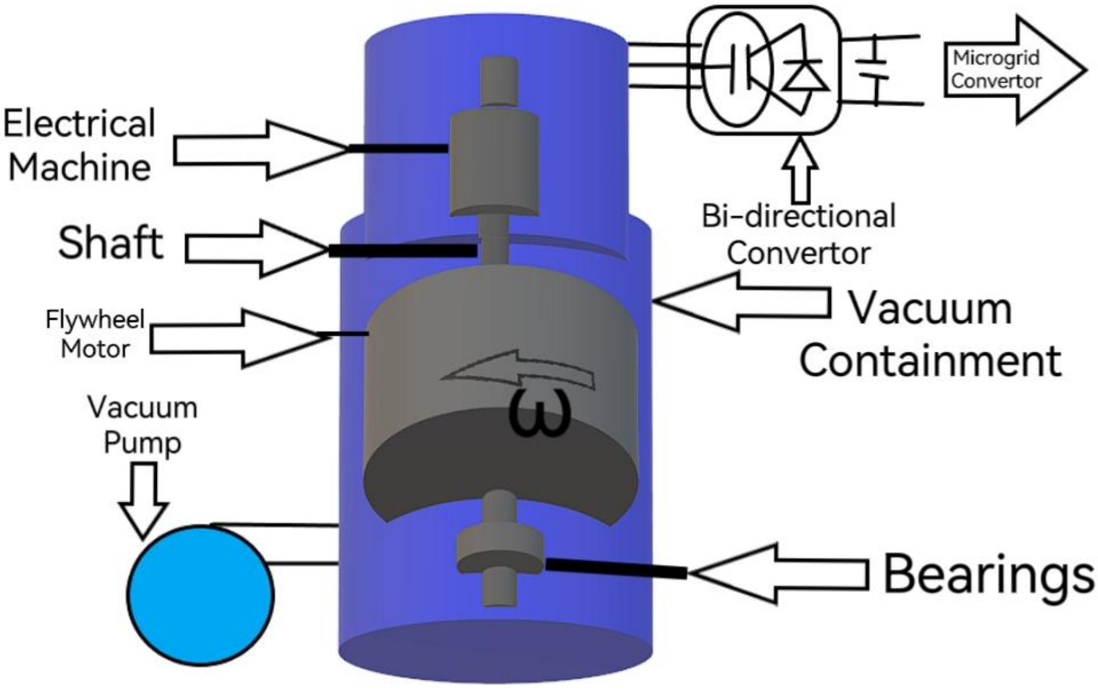

Figure 3. Structure of a type of flywheel energy storage systems (FESS).

In flywheel energy storage system, energy is stored in the form of mechanical energy. During the charging phase of the system, the electric machine in the system can be considered as a motor and the kinetic energy is absorbed. During the discharge phase of the system, the electric machine in the system can be considered as a generator and the kinetic energy is released. *While selecting a flywheel energy storage for an application some of the important points that should be considered are bearing, rotor material, container, generators characteristics, connection with the load, and cooling system* [5].

The usage of flywheel energy storage systems is grid storage with stabilization and vehicle propulsion. Due to the use of KE within the energy storage method, the pros and cons of flywheel energy systems is easy to tell. The benefits of a flywheel energy storage system include minimal pollution, substantial energy storage capacity, and a small footprint. However, a notable drawback is its inability to store energy for extended periods.

2.2.2 Compressed air energy storage

The basic principle of a compressed air energy storage system can be derived from the following graphical description of figure 4. Differ from the flywheel energy storage system, Compressed air energy storage (CAES) is based on the theory that cheap energy sources (e.g. wind power) are used to compress air by a compressor. The compressed air is then stored in a storage cavern as to be seen in figure 4.

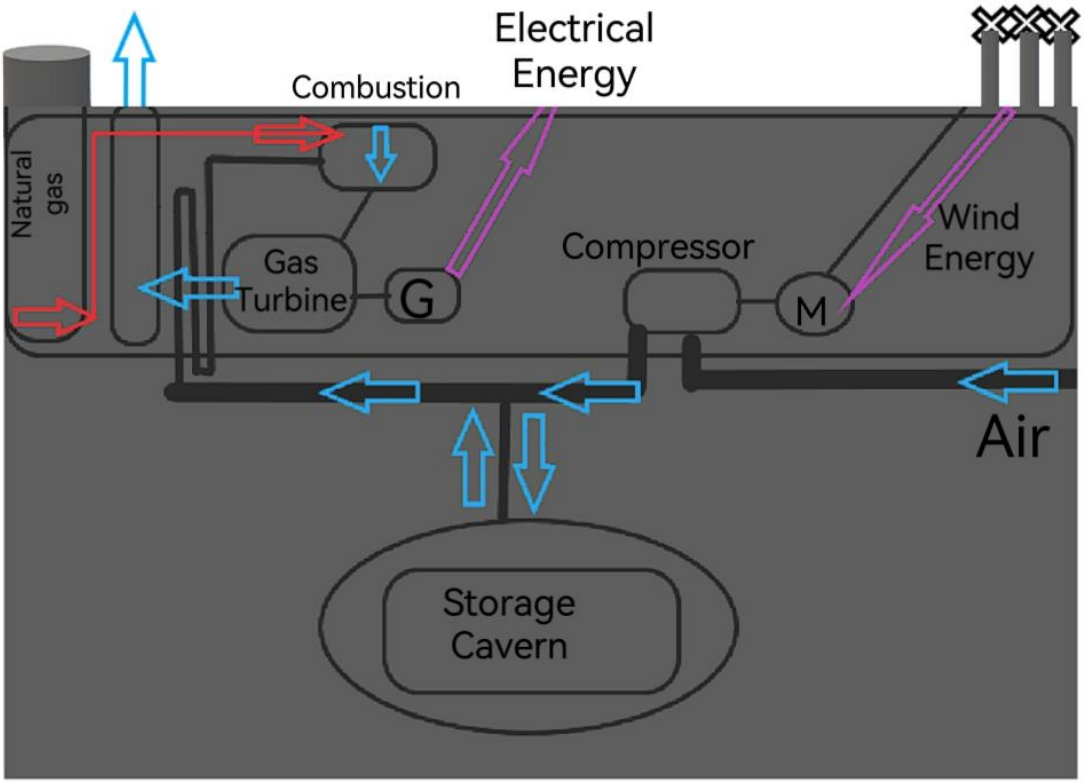

Figure 4. CAES basis with wind energy

During the energy demand or peak hours, the compressed air can be released to a turbine and generate electricity.

Due to the use of cheap energy sources for gas compression and the system's features focusing on gas compression and storage, as well as is peak operating function, CAES requires low maintenance and operating costs. However, the amount of energy stored in a CAES system is tied to the volume of gas stored, and thus the main disadvantage of CAES systems is the low volumetric energy storage capacity and the need for a large energy storage volume.

2.2.3 Thermal energy storage

Sensible heat storage (SHS) is the most straightforward method of thermal energy storage technology. It simply means that the temperature of the selected medium is raised or lowered. For this reason, SHS is the most commercially available of the three thermal energy storage technologies (sensible, latent, and thermo-chemical heat storage).

Sensible heat storage technology is the storage of thermal energy by heating the storage medium to raise its temperature. The materials used for these media are usually cheap and safe. For example, water is commonly used as a sensible heat storage material, and large water tanks are used for energy storage. Soil and rock are also commonly used, leading to the usage of underground storage tanks, and *a system is known as a packed-bed (or pebble-bed) storage unit, in which some fluid, usually air, flows through a bed of loosely packed material (usually rock, pebbles or ceramic brick) to add or extract heat* [6]. Under the same conditions of temperature change, the amount of heat stored per unit volume is greatest for water, followed by soil and least for rock if heat loss is not considered.

The main applications of TES system are [4]:

1. *Industrial cooling (below -18 °C)*
2. *Building cooling (at 0-12 °C)*
3. *Building heating (at 25-50 °C)*
4. *Industrial heat storage (higher than 175 °C)*

2.3 Recent energy storage advancements

2.3.1 Hybrid energy storage systems (HESSs)

The hybrid energy storages systems (HESSs) are an improvement from the energy storage systems (ESSs). The improvement can be described as follows, *HESSs can integrate various*

ESSs, such as batteries, supercapacitors, flywheels, and pumped hydro storage. Hybrid systems can offer high power output, quick response times, and long-term energy storage capacity by mixing various types of ESSs [7]. Which means that HESSs will be responsible for the transmission, analysis and problem solving of a much more complex data stream than a typical ESSs.

HESS has the potential to extend the lifespan of ESS. HESS can distribute the charge and discharge cycles among various energy storage methods. This reduces the strain on individual components, decreasing the number of cycles each component undergoes to increase its overall lifespan.

According to the principle of HESS noted in previous paragraph, HESS is a combination of multiple technologies, therefore enables it to combine the advantages of multiple technologies to improve the overall efficiency of the ESS. HESS typically combines two or more energy storage technologies, including batteries, ultracapacitors, flywheels, or superconducting magnetic energy storage (SMES) systems. The goal of these combination is to maximize the advantages of each technology while decrease their respective drawbacks.

2.3.2 Battery energy storage system (BESS)

Battery energy storage technology is the most familiar energy storage technology currently in the hands of mankind, but at the same time, it is also the technology most likely to be phased out first in the future. However, until other storage technologies such as electrochemical, thermal and mechanical energy storage are available on a large scale, battery storage will need to be upgraded and integrated with new age smart technologies as the world's energy sources increase and renewable energy sources are promoted. There is even the possibility that the BESS may not become obsolete as battery technology continues to improve, but rather as battery technology continues to advance alongside other developing ESSs. Rather than going to a dead end, the BESS will help to bring the smart electric future to completion more quickly.

2.4 Summary of Integration of IoT in Energy Storage Technologies

In the literature review section, it is evident that IoT is characterized by the ability to connect and communicate between devices for seamless data exchange and intelligent decision making. As for the application of IoT technology, it is a very new area, and most of the discussion revolves around and emphasizes its application in smart systems and smart power stations, leveraging its ability to co-ordinate data.

Regarding existing energy storage technologies, these include flywheel energy storage, compressed air energy storage and thermal energy storage. Each of these technologies has its own unique advantages and applications, and there are different possibilities for combining them with IoT technologies in the future.

As can be seen in the section of the literature review on advances in energy storage technology, at the macro level, advances in energy storage systems are reflected in the convergence of energy storage technologies, and at the micro level, advances in energy storage technology are reflected in advances in materials and related technologies. For example, hybrid energy storage systems combine multiple energy storage technologies to improve overall performance and efficiency, while recent developments in battery energy storage technology demonstrate innovative technologies that contribute to higher energy density, longer service life and enhanced safety.

Next, this thesis will focus on cases of the integration of IoT with energy storage advancements. This thesis will discuss the technical feasibility, efficiency comparison and future possibility of mentioned cases.

3. METHODOLOGY

3.1 Overall structure

This thesis will continue to study cases of the integration of IoT with energy storage advancements from four approaches:

1. Residential energy Management
2. Renewable energy Integration
3. Microgrid Implementations
4. Application of IoT in remote monitoring and fault diagnosis of energy storage equipment
5. Summary

3.2 Research methods

The detailed methods will discuss cases from the four approaches mentioned in previous literature in two parts. The first is technology evaluation. The second is performance analysis. Economic and regulation applications will be mentioned if necessary. The possible structure of discussing the two parts mentioned are of below.

Technology Evaluation:

1. Evaluate existing IoT technologies and platforms relevant to battery management, remote monitoring, fault diagnosis, and energy storage systems.
2. Assess their capabilities, scalability, security features, and interoperability.

Performance Analysis:

1. Conduct a performance analysis of the objective system, measuring its effectiveness in optimizing energy systems if possible.
2. Assess the impact on efficiency, reliability, and overall performance.

4. CASE STUDY

4.1 Residential energy management

In residential energy storage management, the energy consumption of users affects the energy exchange within the energy community. Thus, the system architecture for data management in the energy community is very important. And to optimize users' energy storage and management, the energy community *needs to be purposely instrumented by IoT devices that are able to interact with the physical components and inject smartness into the management of the whole energy community.* [8].

In such an IoT architecture, the IoT-connected components and networks and the data management systems involved can form the Advanced Metering Infrastructure (AMI) mentioned earlier in this literature. The AMI is designed to record energy consumption and power production, creating a unique bi-directional flow of information between the user and the transmission system, thus enabling a bi-directional link between each user's energy community and the power delivery system. The role of the AMI is to record energy consumption and power production to form a unique bi-directional flow of information that bridges the gap between users and the transmission system, thus enabling a bi-directional linkage between the energy community formed by each user and the transmission system.

In such an architecture, the simplest components include advanced hardware and software devices in residential users. The point of these devices is to measure and collect data in real time or at specific times. Then there is the Internet and the remote data centers with which these devices have established an Internet connection. With the collaboration of the software and hardware in the home, the Internet and the remote data center, the AMI can play a full role as a two-way bridge, communicating commands through the characterization of the data, which are transmitted through the Internet so that the smart device receives the commands and acts accordingly. *Common IoT devices used in this context are electronic platforms such* *as the Arduino, with a limited computing capacity, and the Raspberry Pi, which is more powerful. In both cases, communication is established on an Internet connection.* [8].

In addition to AMI, completely new IoT systems have been proposed in different energy community optimization model designs. In the corresponding model, an energy district is composed of a number of energy consumers that are able to form an energy community. And each energy consumer, i.e. household, is equipped with the corresponding components [8]:

1. *A nanogrid system, which manages the energy exchange between the prosumer and the distribution grid, the local energy production plants, and the storage system.*
2. *A home automation system, which manages the activation and deactivation of the loads hosted inside the dwellings.*

In such a system architecture, there exists a centralized component, which is responsible for communicating with all consumers in the energy community, and thus the centralized component is responsible for the communication management of the entire energy community. Under such a communication requirement, each consumer in the community must have a way to interact with the centralized component, which leads to the introduction of the e Smart Energy Aware Gateway (SEAG). SEAG is responsible for managing the nanogrid and the home automation system at the same time, in addition to communicating with the centralized component, which is itself a two-way bridge system.

But what's special about SEAG is that the system is incredibly adaptable. In reality, the components of an energy system, including storage systems, energy delivery systems, etc., contain different components from different suppliers, and the adaptability of the different devices varies, but SEAG is designed to be heterogeneous in a changing environment.

In addition to the special features mentioned above, the details of SEAG's functionality as an IoT system encompass two parts that can also be seen in figure 5:

1. A comprehensive profile of each consumer's energy storage and consumption is generated by controlling the devices in each consumer's residence, which in turn interacts with the smart meters in the local energy storage system.

2. When interacting with the centralized component, which includes the district aggregator and consumer service providers, SEAG is able to obtain the detailed information needed to optimize the local services from each service provider, thus improving the stability of its own system.

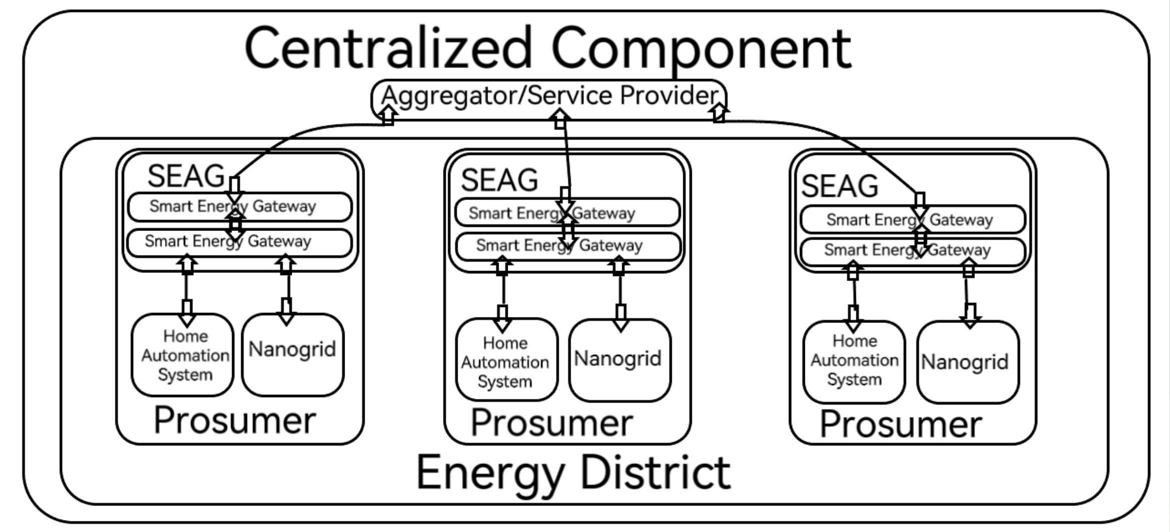

Figure 5 energy district (*Andrea Giordano (2020)*)

In figure 5 we can see that the centralized component consists of the aggregator and the service provider. Of these two components, the role of the aggregator was mentioned earlier, i.e., to manage the exchange of energy from user to user and from community to grid. While the service provider's role is to obtain information from two sources. First, a forecast of energy production/consumption for each time period generated on the basis of weather forecasts and specific details of the community's counterpart power plant. Second, an energy prices data monitored in real time by energy markets.

From the previous discussion we are able to analyse that the SEAG system evolved from AMI has a strong information integration capability as well as good adaptability in the energy community consisting of aggregators and service providers. This capability enables SEAG to achieve energy sharing among users through information integration, which in turn ensures the efficient use of energy in the system. And after analysing the high and low peaks of users' electricity consumption, it can control the acquisition and storage of necessary energy through algorithms, which can optimize residential energy storage systems while saving users' costs of purchasing energy. The drawback is that with the expansion of the community and the increase in the amount of data, the complexity of computation will be increased exponentially.

4.2 Renewable energy integration

In today's world, sustainable development and renewable energy are becoming increasingly important. However, the question of how to adapt to renewable energies and how to transform energy systems compared to the already familiar fossil energy sources and their associated energy systems is one of the major issues of the day. *The grid integration of renewable energy systems represents many challenging tasks for system operation, stability, reliability, and power quality* [9].

In response to this, the Hybrid Renewable Energy System (HRES) was developed. HRES is a small power system that combines a power source and an energy storage module. the basic function of HRES is to manage and optimize the production and consumption of energy in a holistic way. It is very important that the people who operate and maintain the system have access to real-time data when the HRES is in operation. Real-time monitoring and accurate information allow operators to analyse data more accurately to assess system performance and identify abnormalities.

In fact, the real-time data transmission capabilities required by HRES, the need for system stability and data accuracy coincide with IoT technology. In fact, HRES is very similar in basic concept to the HESS mentioned earlier in this paper, which is a system framework for the combined management of multiple energy storage systems, and HRES, which also has an IoT-based HRES architecture.

This IoT-based HRES architecture can consist of a wind turbine, a battery storage system, a diesel generator and a photovoltaic system together. And in a related study, this architecture was categorized into four layers [9].

Namely power

Data acquisition

Communication network

Application layers

Due to the instability of renewable energy sources, such as the environmental demands of photovoltaic and wind power, the integration and management of a large number of different renewable energy sources into the grid, which HRES involves, is a very challenging endeavour. IoT-based HRES and HRES-related information systems are able to integrate and consolidate information at multiple levels. figure 6 is the corresponding HRES integration diagram.

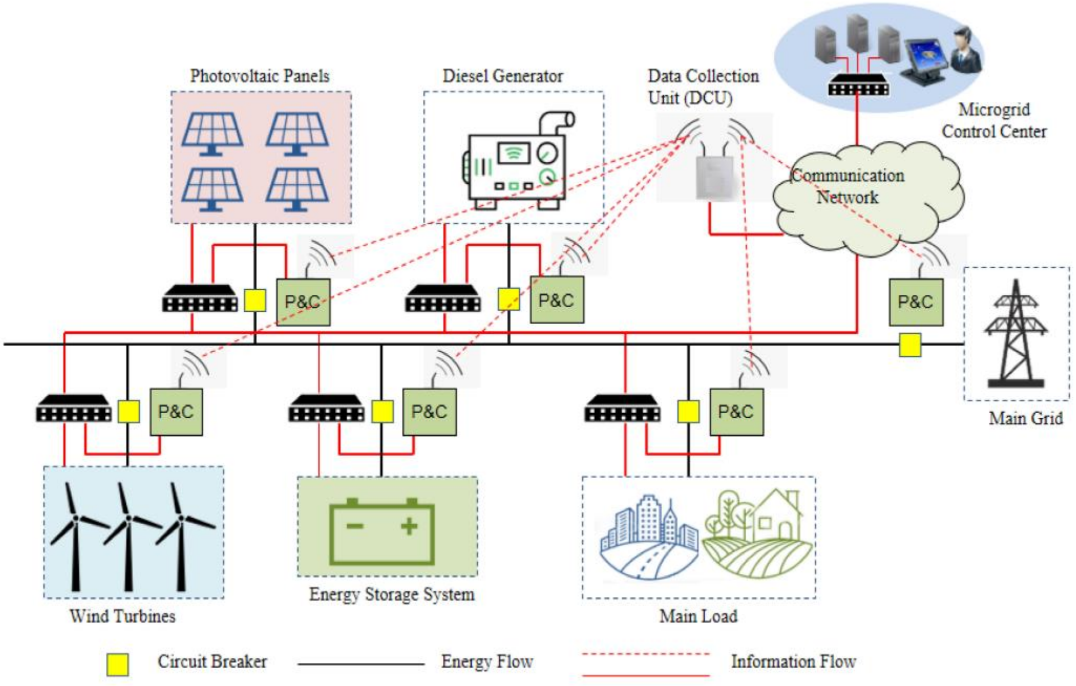

Figure 6. Grid integration of HRES. (*Sustainability 2021*) [9]

In such a system, the ability of HRES to act primarily as an information system is demonstrated. HRES is at this point divided into two tiers, the first of which encompasses the power infrastructure and the second of which encompasses the communications infrastructure. This is why the energy flow and information flow are highlighted above in figure 6.

As can be seen in figure 6, the power infrastructure consists of a variety of energy sources (e.g., solar panels and diesel generators shown in the figure), energy storage systems, main grid, main load, and other related facilities (e.g., transformers, converters, etc.). The communication infrastructure consists of the Data Collection Unit (DCU), the P&C modules (Protect and Control) in each facility, the Microgrid Control Center, and the communication network that links these together.

In the communication infrastructure, the DCU collects data from the nodes of the power infrastructure through the P&C modules in each facility, supports their operation and maintenance, and connects the components of the system into a network. In this way, a local control center is able to manage the operation of the various systems for more favourable storage and utilization of renewable energy. With this integration, HRES is upgrading renewable energy systems while transforming the traditional grid into a smart grid.

4.3 Microgrid implementation

The concept of microgrid was also mentioned earlier, and specialists from the U.S. Department of Energy have provided a widely accepted definition of the term below: "*A microgrid is a collection of interconnected loads and distributed energy resources that operate as a single controllable entity in relation to the grid and are contained within well-defined electrical boundaries. A microgrid may connect to the grid and disconnect from it, allowing it to function in grid-connected and island modes* [10]."

From this widely accepted definition we can summarize several characteristics of microgrid technology. First, microgrids are independent, allowing them to operate in interaction with the wider grid practically regardless of whether they are connected or not. Second, microgrids are aggregations of interconnected loads and distributed energy sources, implying that the energy connected to the microgrid is not being managed by a remote resource. Last but not least, areas adjacent to and affected by the microgrid can also be separated from the power system.

And along with the reform of the microgrid management system, the addition of the Internet of Things (IoT) adds a whole new element to the functionality of the microgrid, which has some similarities with the HRES mentioned earlier. With the integration of IoT technologies into microgrids, more direct and faster data connectivity allows for faster information processing and allows local power networks to perform additional services beyond their basic capacity. These additional services are based on the microgrid's own service characteristics, which are listed below [10]:

Full duplex communication

Advanced metering infrastructure

Renewable and energy resource integration

Distribution automation and complete monitoring, as well as overall power system control

The additional services provided by these features include but are not limited to: balancing local energy consumption, unblocking local grid mobility, supporting the energy market through data capture, and responding to requests from energy suppliers or grid operators. These multiple additional features provide users with more choices and benefits while offering more quality services.

In addition, microgrids combined with IoT technology can reach economic advantages in their own unique way. By applying the microgrid as an entity system similar to a synchronous generator system in the utility grid, and at the same time taking advantage of its characteristic of being able to operate in an islanded manner, the microgrid can control the distributed energy sources to be dispatched and balanced in the required manner, thus gradually realizing the intelligence of the microgrid, reducing the loss of energy, and realizing the economic operation of the microgrid.

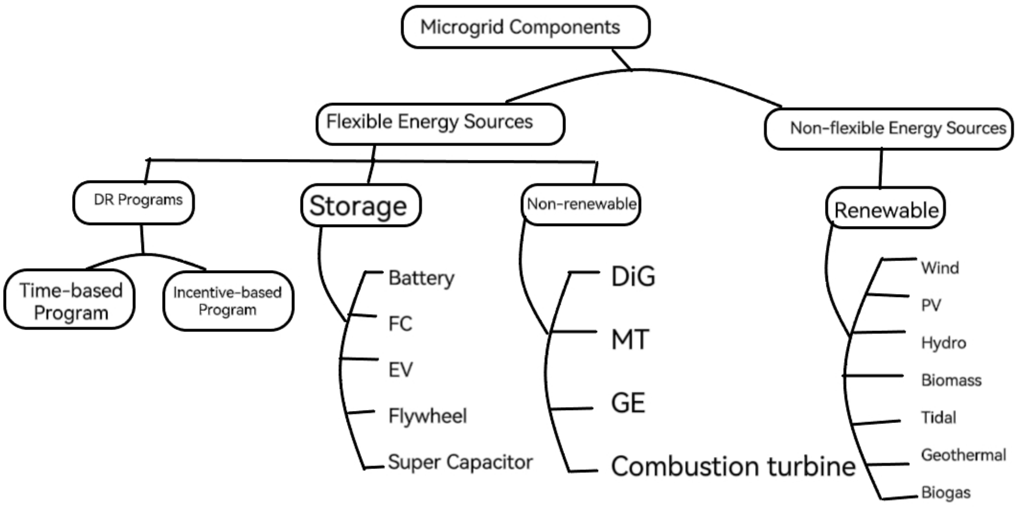

Figure 7. Components of Microgrid

In some areas where the weather is harsh and the infrastructure is not complete enough, the economic impact caused by extreme weather is huge. *The Northeastern United States is one of the main areas of activity, where aging infrastructure and regular extreme weather events have caused billions of dollars in damages in recent years. As a result, states are looking at the possibility of expanding microgrids beyond essential facilities to service entire towns, and they've started sponsoring demonstration projects* [10]. In these areas, IoT technology-enabled microgrids are becoming the new choice. And that's what microgrid technology achieves due to its excellent independence when it comes to maintaining critical infrastructure. And as microgrids move from infrastructure to city building, the IoT is also able to add more available energy systems to the microgrid, for example the components in figure 7. And then, using its own flexible load system, IoT can be combined with distributed energy and energy storage technologies to balance energy supply and demand over a larger scale.

Despite the many benefits of microgrids, their shortcomings cannot be ignored. One of the most obvious is that microgrids must be equipped with an energy storage system to achieve autonomous and stable operation. At the same time, sophisticated microgrids often encounter stability problems caused by different factors (e.g. power matching and voltage fluctuations). The key to solving these problems lies in acquiring data from the system and analysing it more efficiently and accurately. IoT technology has been introduced to solve these problems.

With the intervention of IoT, the microgrid of the future will be able to reduce line damage while reducing unnecessary technical service costs and reduce the unnecessary experience of customers in terms of outages and line inspections. This combination also demonstrates the potential of microgrid technology for energy storage and automation when combined with the IoT.

4.4 IoT in remote monitoring and fault diagnosis

BESS has been mentioned in previous paragraphs. And the foundation of large-scale BESS application comes from Battery Management System (BMS). *BMS can be revolutionized as a result of further investigation of the Internet of Things (IoT) technologies* [11]. However, there are some design flaws in the current BMS that are hard to ignore. It is these design flaws that hinder the integration of large-scale battery systems. The source of these defects is complex, and it is difficult to solve them at once. First, complex wired communications are used in battery systems, and these lines can lead to serious wiring harness problems. These problems range from physical connection failures to imaginable electromagnetic interference, which can lead to increased O&M costs for the entire system. At the same time, the complex design of the battery packs makes the associated automated manufacturing very difficult. The lack of automated manufacturing is also one of the reasons why the system lacks real-time fault diagnosis and prediction algorithms. Even if there is an algorithm, it requires a lot of computing resources to support the design of the BMS system.

The opportunity to change the overall design of the BMS lies in the introduction of IoT technology, whose powerful stability and high efficiency and accuracy of data transmission can help the system to quickly identify the health status of the battery, thus enhancing the stability, safety and economic benefits of large-scale BESS. Recently, battery energy storage analysis and management systems related to IoT and cloud technologies have emerged in some developed cities for small electric vehicles. Thus, the progress of IoT research on battery energy storage is actually paving the way for the design of large-scale BESS systems.

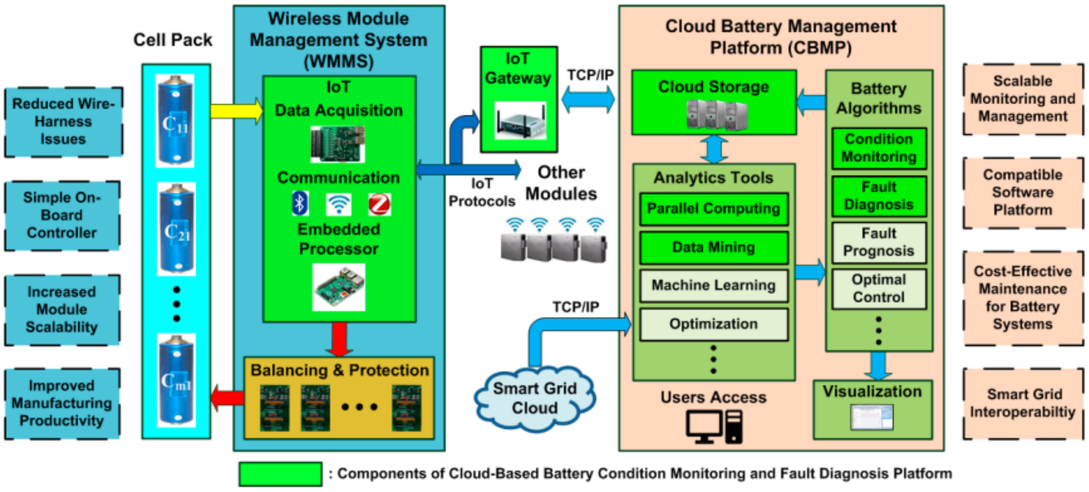

Figure 8. Cyber-physical battery management system (*Energies 2018*) [12]

Figure 8 explains the data acquisition of the management is performed by sensors in different components which measure the battery voltage, current and temperature at a given sampling time in the WMMS. The sampled data is stored in the communication component of the IoT device, which is secured according to various IoT protocols. After that the data is transferred from the communication component to a cloud server for storage. *Ideally, in near real time via an IoT gateway/router using Transmission Control Protocol/Internet Protocol (TCP/IP) protocols* [12]. In this way, the management system is able to receive system monitoring reports as well as improvements and optimizations from the cloud battery management system. In addition, the IoT gateway will collect huge amounts of data from various IoT devices, which will require efficient data collection, indexing, storage and processing capabilities for the corresponding IoT system. With the help of IoT and cloud data, the system can reduce module redundancy and thus simplify the controller on individual user carriers, thus increasing the developability of the battery modules.

5. DISCUSSION

The Internet of Things (IoT) is a technology with many possibilities, but at the present time, most of the practical applications of IoT remain in the realm of conceptualization, modelling and simulation. However, the efficiency of data processing and the stability of data transmission of IoT technology have been recognized in various real and simulated environments.

In fact, based on the analyses in this thesis, we can conclude that an energy system with the participation of IoT will greatly solve the problems related to energy storage, transmission and energy loss in the existing energy system. Whether it is the HESS, BESS, HRES or SEAG systems mentioned in the paper, all of them have unlocked their potential and optimized their energy efficiency and economic viability with the addition of IoT technologies.

In conclusion, the application of IoT in energy systems and energy storage systems requires more experimentation and support from more advanced energy technologies. Nowadays, technology is limiting us to develop traditional energy storage systems such as BESS, which can be interpreted as preparing for the later intervention of IoT technologies, but it also represents the direction of some researchers. And the application of IoT technologies is therefore lacking more experimentation and application. Regardless of how perfectly modelled and structured, technology can only prove its worth if it is applied, as is the case with the feasibility of IoT technology in energy systems and energy storage systems.

6. CONCLUSION

Based on the discussions and analyses throughout the paper, the application of IoT in energy systems and energy storage systems is not impossible or out of reach. Although IoT technology still needs some economic support and technological advancement for large-scale applications, there are many small-scale applications and good enough energy system models that have emerged.

Energy systems incorporating the IoT have the following advantages: firstly, in large integrated systems, IoT technology ensures high efficiency, stability and accuracy of data transmission, a characteristic that guarantees the large-scale data volumes required for data analysis. Secondly, the combination of IoT technology and energy systems usually results in a bi-directional transmission of data in the system, which ensures the flow of data between the user side and the power supply side and improves the efficiency of energy utilization in the corresponding control system. In addition, the stability of IoT technology enables it to form large-scale energy networks and increase the stability of energy supply in less developed regions by virtue of its stability. Finally, as the global energy system is gradually shifting to clean energy, IoT technology is also greatly improving the stability of recyclable energy in storage and supply, which has a good impact on global sustainable development.

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