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Home Energy Management with Internet of Things: A Brief Overview

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Abstract. The increasingly growing demand for power and the issue of energy crisis are gaining more attention. Nowadays, there is a sharp rise in electricity demand in household living, and the electricity structure is becoming more complex. With the development of Internet of Things technology, it has provided a better platform for improving energy management systems. Based on Internet of Things, the home energy management system emerges, which can integrate and manage all household power loads and distributed energy, achieve energy optimization configuration, and help users save electricity costs. This article first elaborates on the basic concepts of smart home energy management systems with Internet of Things, then describes the framework of the home energy management system. Finally, it summarizes the research status of the field from the perspectives of the data acquisition module, communication module, and management and optimization module, discussing the existing technical challenges and future research directions.

Keywords: Home energy management, Internet of things, Smart home.

1. Introduction

With the rapid development of the national economy and the urbanization process continues to promote, people's living standards continue to improve, the use of power equipment in all neighborhoods have greatly increased, which plays a very important role in the development of industry and society. Therefore, electricity has become an indispensable source of energy in modern society, at the same time the growth of electricity demand shows an irreversible situation, with the emergence of energy shortage, demand-side supply shortages, low energy utilization, and some other problems, which will lead to the need for users to carry out unplanned load shedding to ease the pressure of electricity consumption in the peak hours of electricity consumption. In addition, the massive use of traditional energy sources to produce electricity will emit excess greenhouse gases, which will have a huge impact on the environment. Therefore, there is an urgent need for a reasonable and effective energy management system to improve the efficiency of electricity consumption, save energy, and realize the balance between the supply measurement and the demand side, so as to meet the needs of the social development of energy-efficient and low-carbon economy.

There are various types of energy management systems, including home energy management system (HEMS), building energy management system (BEMS), smart home energy management system (SHEMS) [1], etc., which have almost the same purpose, which is to minimize energy consumption by scheduling equipment. Among them, the home energy management system is to manage the energy consumption of the smart home, using various functional sensor devices to collect data such as the temperature, humidity, light intensity, and the operation status of the power-using equipment in the home environment, combined with the information on the electricity price released by the power grid company. Through the analysis of these data, the system monitors and optimizes the scheduling of the energy supply and the use of power equipment, thereby improving energy utilization and power efficiency, reducing power costs and greenhouse gas emissions. The building energy management system focuses on optimizing the lighting and air conditioning systems in buildings to reduce overall energy consumption.

In recent years, the popularity of renewable energy sources such as photovoltaic power generation, wind power generation and the increasing number of electric vehicles have made the energy management system of homes and buildings more and more complex, and the energy management that used to be based on imperfect communication and user awareness alone can no longer solve the major problems of today's energy environment. However, with the popularization and effective application of Internet of Things (IoT) technology, it provides new opportunities and challenges for the research of energy management systems. Combining it with energy management helps to remotely monitor and control the equipment, which greatly promotes the improvement and innovation of energy management systems in order to achieve efficient energy management. In addition, the comprehensive construction of the national smart grid makes the power supply system and users share information with each other, and people can become active participants in the system, which allows for better energy management and energy saving and emission reduction [2].

Continuing from the first section, the second section of this paper describes the basic concepts of IoT smart home energy management system; the third section describes the framework of home energy management system; and finally, it provides an overview of the current state of research in the field and discusses the technological challenges from the three major modules, i.e., the data acquisition module, the communication module, and the management and optimization module, respectively.

2. Basic Concepts of IoT and Home Energy Management System

2.1. Internet of Things (IoT)

The Internet of Things is a network composed of physical objects. Based on the Internet, the sensor equipment and infrastructure around us communicate with each other through various wired and wireless communication network connections to generate, exchange and process data, and realize intelligent identification and management to facilitate people's lives. The basic three-layer architecture of the Internet of Things is shown in Figure 1. the architecture contains perception layer, network layer, and application layer [3].

(1) Perception Layer: The perception layer is the bottom layer of the Internet of Things, consisting of various types of sensors, radio frequency identification devices, cameras and other devices that sense physical parameters such as temperature, humidity, light and so on. Just like the five senses of a human being, it has the ability of comprehensive perception, which can realize the identification of objects and the collection of various types of data.

(2) Network layer: Network layer, also called transmission layer, has the role of the top and bottom, equivalent to the human nerve center, composed of the Internet, wired communication network, wireless

communication network and cloud computing platform, mainly responsible for the transmission and processing of different types of data information from the physical layer.

(3) Application layer: the application layer is the interface between IoT and users, which can store, convert and process the collected data, and consists of various application systems for accessing the devices connected to the physical layer and realizing real-time control and decision-making.

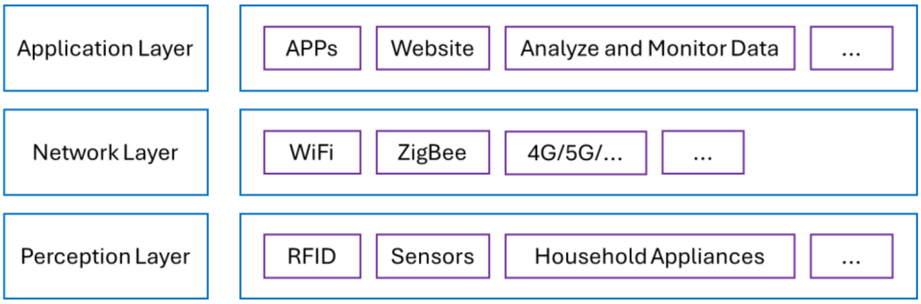

Figure 1. Three-layer IoT architecture.

The Internet of Things (IoT) is used in many fields in daily life, such as smart home is a close-to-life application. By equipping homes with IoT technology, various devices in the home are connected together and managed in an integrated manner [4][5]. Making the home smart at the same time can check and control the status of the devices in its home anytime and anywhere, making decisions that can save energy and money in the process. The intelligent medical system based on the Internet of Things can remotely monitor and diagnose patients regardless of time and place, realize the instant transmission of medical information, and provide important data on the physical condition of patients before they arrive at the hospital, so that hospitals can serve patients better and faster and make the best use of limited resources [5][6]. In the near future, smart healthcare based on IoT will become more and more popular. IoT is also playing an increasingly important role in the transport industry, where RFID or sensors can be used to monitor physical objects and vehicles in real time from start to finish throughout the supply chain process [7]. IoT technology makes it possible to track, monitor, and predict the location of each vehicle, which provides strong technical support for ITS and parking applications, and will greatly reduce the pressure of traffic congestion as well as parking difficulties in the present time when the number of domestic cars is increasing dramatically [8].

2.2. Home Energy Management System

In the traditional household energy structure, electricity is produced centrally by the power plant, supplied by a single power grid, and communication with the power sector is only unidirectional or even non-communicative. Household users obtain electricity from the grid, supply the electrical load, and count the household electricity consumption through the meter, and finally the power sector collects the electricity bill by checking the meter, and the household user is only a consumer of electricity and passively participates in the operation of the grid. Smart home is an object in the Internet of Things (IoT) manipulation mode, which takes the residence as a carrier, comprehensively uses advanced computer technology, Internet of Things (IoT) technology, communication technology, etc., integrates the facilities related to home life, realizes intelligent control of household appliances and the living environment, and transforms the traditional static home environment into an intelligent residence with active intelligence [9], realizes humane electricity use, and creates a comfortable, convenient, intelligent and safe living environment. The smart home has fundamentally changed the structure of electricity consumption of the user compared with the traditional home. Smart home has the support of smart grid technology to achieve the security of access to distributed power sources, and energy flow and information flow can be two-way flow, home users can not only consume power from the grid, but also the local renewable energy generated by the surplus power back to the grid [10], to obtain the corresponding economic benefits.

Table 1. Related works to home energy management system (HEMS).

Research Direction		References	Description
System Architecture		[12]	Arduino is employed as a processing unit; design a model that would make home energy manageable.
		[13]	The system design uses data analytics and scalable storage for building a smart EMS.
		[14]	A smart energy management system; based on NodeMCU and Android.
		[15]	Develop an ontology-based framework for energy management system.
		[16]	Propose a Smart Plug device prototype that can recognize the type of electric appliances.
		[17]	Identify electrical appliances based on a novel hybrid Unsupervised Automatic Clustering-Integrated Neural-Fuzzy Classification (UAC-NFC) model.
		[18]	An IoT based real-time energy measurement and actuating framework is proposed.
		[19]	A smart energy meter based on IoT is designed.
		[20]	A semantic framework is introduced.
		[21]	Propose scheme that enable a generic communication architecture among the IoT devices with less interference.
		[22]	An IoT big data analysis system is proposed, which uses fog computing to solve real-time data processing.
		[23]	A smart home prototype model is built using two Arduino boards.
		[24]	Controlling the use of electricity for lights using smartphones.
		[25]	Design and implement an efficient lighting system to reducing power consumption in home.
System Management Strategy	Total Electricity Consumption	[26]	Present a self-learning home management system (SHMS).
		[27]	Propose a shedding algorithm for home energy usage.
		[28]	A fuzzy reasoning system is proposed to realize thermal comfort maintenance and energy consumption minimization.
		[29]	A flexible smart energy management system is proposed, which has a user configurable priority feature.
		[30]	A greedy algorithm is proposed for planning, according to user preferences and a maximum allowed power consumption.
	Distributed Energy Efficiency	[31]	A prototype consisting of an integrated battery management and load management system is designed and developed.
		[32]	Optimize energy supply from solar energy and grid supply.
		[33]	Maximizing the using of power of renewable energy sources and minimizing using the power of batteries.
	Demand Response	[34]	Energy management controller based on WBFA algorithm, which can automatically respond to demand response (DR).
		[35]	Controlling of thermostat by real-time price (RTP) with cloud server.
		[36]	Propose an innovative home appliance scheduling (IHAS) framework based on the fusion of the grey wolf and crow search optimization (GWCSO) algorithm.
		[37]	A new binary particle swarm optimization with quadratic transfer function is proposed for scheduling shiftable appliances in smart homes.

Home energy management systems mainly use sensors and other monitoring devices to collect information about the indoor and outdoor environments, user activities, and equipment operating status. By analyzing this information, automation and information technology is used to schedule and control power generation, storage and consumption [11], optimizing the operation schedule of appliances to improve power efficiency, reduce power consumption, achieve energy balance and protect the environment. The home energy management system is becoming an indispensable part of the smart home. A great deal of work has been carried out to cope with the growing demand for electricity. Currently, research in the area of home energy management systems focuses on two main areas: (1) the study of system architecture and (2) the study of system operation strategies. Table 1 shows some of the related work on home energy management systems. The research on the architecture of home energy management system mainly focuses on the improvement of various internal links of home energy management system and focuses on the optimization and improvement of home energy management system, such as system functions, smart meters, and smart interactive terminals [12-25]. The research on the system operation strategy mainly focuses on the optimization of the load management strategy to achieve the optimal allocation of energy. The optimization of load usage is the core problem of home energy management systems in the IoT environment, which can be classified into the following three categories depending on the optimization objectives of the management strategies: (1) reducing the total power consumption [26-30]; (2) maximizing the utilization rate of distributed energy sources [31-33], and (3) minimizing the cost of power consumption through demand response [34-37].

3. Architecture of Home Energy Management System based on Internet of Things

The traditional energy management system has a simple structure, the flow of electricity and information is unidirectional, and can only count the total amount of electricity consumption of the family through the traditional electricity meters and cannot be specific to the detailed electricity consumption of each electrical device, and the only energy management can only be carried out through the user's sense of conservation to turn off unnecessary electricity loads by themselves. The home energy management system based on the Internet of Things (IoT) uses communication technology to interconnect power generation, energy storage, electricity consumption and the outside world, so that the two-way flow of electricity and information can be realized in real-time monitoring, intelligent processing, and intelligent regulation. The architecture diagram of its system is shown in Figure 2. IoT-based home energy management systems can be broadly divided into three parts: (1) energy supply side; (2) management and control center, and (3) home appliances side.

3.1. Energy Supply Side

There are four sources of energy supply for home energy management systems: the power grid, renewable energy, energy storage, and electric vehicles [26].

(1) Power grid is the main source of power supply, which is characterized by high stability and large capacity and can meet most of the energy demand. However, grid power mainly originates from fossil energy, and the large amount of fossil fuel use for power generation will have a huge impact on the environment.

(2) Renewable energy is mainly based on photovoltaic power generation and wind power generation, which provides a new power source for power equipment and plays a very important role in improving energy utilization, enhancing power security, and protecting the environment. In the case study in literature [27],

the inclusion of a local renewable power generation system can reduce carbon dioxide emissions by almost 72% when all household appliances are only supplied by the grid. In this case, the designed hybrid energy system sets up wind power and photovoltaic power as the main source of household electricity, and the renewable energy system generates DC power to be used by DC loads and to charge storage batteries or inverted to AC power by an inverter to be used by AC loads. Excess power can also be sold to the grid for profit. In off-grid mode and in case of excess power, an additional DUMP load is installed to eliminate this excess. In grid-connected mode, the excess power is injected directly into the grid, which compensates for the household power supply when the renewable energy source does not supply enough.

(3) Energy storage devices mostly use batteries and can store excess power from the system and increase the utilization of renewable energy generation. In addition, they can be used to charge the grid at moments of low electricity prices and to supply households during peak periods, thus reducing electricity costs.

(4) Electric vehicles are a special category, which are loads when in use and energy storage devices when idle, with the advantage of energy saving and environmental protection. However, electric vehicles have large battery capacity and high charging power. It is necessary to control their charging using an energy management system to reduce the impact of EV access on the grid [38] and to avoid an increase in the peak demand for electricity leading to an imbalance between supply and demand and an increase in the cost of electricity.

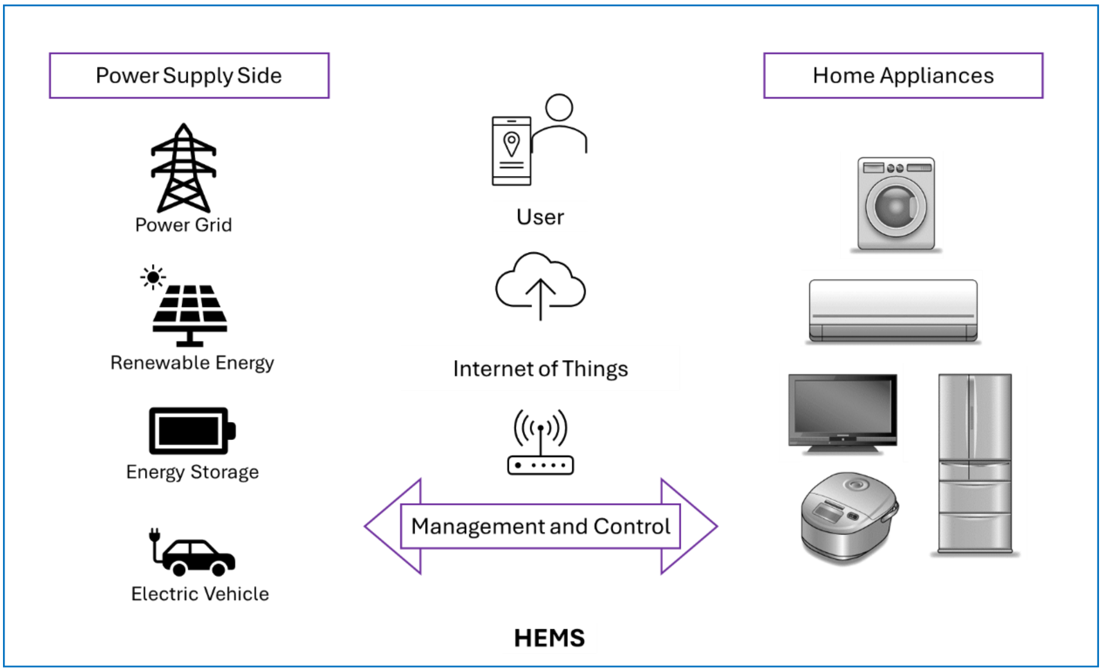

Figure 2. Architecture of IoT-based home energy management system (HEMS).

3.2. Management and Control Center

The management and control center is the core part of the home energy management system, which controls the operation of electrical loads as well as the distribution of energy on the supply side by analyzing and processing the electricity consumption data and environmental information obtained from sensors, smart sockets, and other components, and monitors the operating status of electrical equipment and current electricity consumption, providing real-time feedback to the user. With the increasing number of companies producing microcontrollers for embedded systems and the decreasing price of such products, microcontrollers (Arduino, Raspberry PI, etc.) have been set up as the main control unit for power measurement and control operations in some studies. By integrating temperature and humidity sensors also to measure the environmental conditions, current sensors can be used to measure the AC current to calculate the power consumption. Solid state relays are then utilized to control the on/off state of the device accordingly [13][14]. In addition, using a NodeMCU controller that communicates with the Blynk server via Wi-Fi (Blynk is an iOS and Android based application interface developer), which is capable of sending the data received from the controller unit to the Blynk server, the user can send control signals through the developed application to the Arduino, Raspberry PI and many other controllers to send control signals for remote monitoring and control of connected devices [14].

3.3. Home Appliances Side

The electrical appliances in a home energy management system can be classified into two categories: dispatchable and non-dispatchable appliances. The parameter descriptions of some common household appliances are listed in Table 2.

Table 2. Description of home appliances.

Category		Appliance	Power (kW)	Hours/Day
Adjustable Appliances	Time Adjustable	Washing Machine	3.0	2
		Tumble Dryer	3.5	1
		Dish Washer	2.5	2
		Vacuum Cleaner	1.5	2
		Electric Kettle	2.0	1
	Power Adjustable	Fan	01.-0.5	8
		Water Dispenser	0.8-2.0	24
		Induction Cooker	0.8-2.5	3
	Power and Time Adjustable	Air Conditioner	0.8-3.2	12
		Electric Water Heater	1.0-2.5	3
Non-adjustable Appliances		Refrigerator	1.5	24
		Lighting	0.15	12
		Monitoring Equipment	0.1	24

Schedulable equipment is equipment that can be scheduled to operate under certain conditions without affecting the user's comfort, such as air conditioners, washers, dryers, water heaters, dishwashers, and so on. In addition, the schedulable equipment can be further classified into time-adjustable equipment and power-adjustable equipment. Among them, power adjustable equipment can be flexibly adjusted in terms of rated power during operation. Time-adjustable devices are designed to operate at a fixed rated power, and the operating time can be adjusted according to demand. They are further categorized as interruptible (e.g., dishwashers, dryers and washing machines) and non-interruptible (e.g., electric water heaters and hoovers) during operation [34]. Non-schedulable equipment mainly includes some critical appliances and equipment such as refrigerators, lighting systems, security systems, etc., and scheduling these loads can cause problems leading to a serious impact on the user's needs. In practical applications, there will be devices in the home that have resource constraints and do not support IoT, or in areas where the penetration rate of smart devices is low, it will not be possible to manage them for energy saving leading to an imperfect home energy management system. To address this problem, literature [39] designed an IoT device (HomEnergy Box), which mainly consists of components such as Arduino Mega microcontroller, NodeMCU and relay module. It is used as an intermediary between the network side and the device side (both smart and non-smart), so that both smart and non-smart devices can be integrated into the IoT space, making home energy management for energy saving possible in less developed areas.

The above three subsections introduce the system architecture of an IoT-based home energy management system. In addition, researchers in literature [13] proposed a smart home energy management system using IoT and big data analytics approaches. The developed system is based on an easily scalable architecture that allows the implementation of energy management program on a local and national scale. They divided the system into two parts: hardware architecture and software architecture. In the hardware architecture, the microcontroller is used as a data acquisition module for the edge devices, which is integrated with various sensors to collect power consumption data and environmental information, and solid state relays are used to control the on/off switching of power consumption devices. The software architecture is divided into data acquisition module, middleware module and client application module. The data acquisition module has two functions: monitoring and control. The monitoring function transmits the ambient temperature, humidity and power consumption data collected by the sensors to the middleware module via MQTT protocol. Whereas the control function is used to receive commands from the middleware module to switch on and off the power-using devices accordingly. The middleware module, in turn, consists of several key servers including: an MQTT server, a highly scalable storage server, and an Analytics Engine server and web server. Finally, the client application module develops an application that allows users to view electricity consumption data as well as remotely control electrical devices from their mobile devices. Literature [15] describes an ontology-based energy management framework that divides the functional architecture of an energy management system into three interrelated modules and sets up a variety of flexible inference rules that can process various types of information from heterogeneous systems to comprehensively evaluate the entire residential scenario. For example, if the indoor temperature is high due to open windows, the traditional energy management system will directly control the air conditioner to reduce the temperature. This would lead to serious energy waste and inconvenience. In this case, an ontology-based energy management framework can save a lot of unnecessary energy wastage as opposed to a conventional energy management system that takes optimization measures by only evaluating information from various sensors.

4. Data Acquisition Module

The first step in managing the energy consumption of a home is data collection. The data collection module is the foundation of an IoT-based home energy management system, which requires the collection of data such as power usage information of various electrical devices and the home environment. Currently, a variety of IoT sensors (e.g., temperature and humidity sensors, light sensors, and air sensors) are usually used to impart monitoring capabilities to home appliances to collect data such as temperature, light intensity, humidity, and other data in the home, so that they can better understand their surroundings [40]. In addition, home energy management systems can be used to optimize the scheduling of device operation in smart home environments based on the presence or absence of users. Motion sensors (including infrared sensors, microwave sensors, etc.) or video surveillance devices are used to detect and identify the physical locations and behaviors of home users, or to detect user activities by embedding wireless transceivers in the surrounding devices based on the changes in the received signal strength [41]. From the above, it is known that IoT sensors play an important role in data collection for home energy management systems, Table 3 lists some of the major suppliers of IoT sensors for home energy power management [9].

Table 3. Major suppliers of IoT sensors for smart home power management applications.

Sensor Type	Leading Suppliers
Moton Sensors	Visonic, Optex, Leviton
Temperature and Humidity Sensors	Minotaur Engineering, Venstar, Intermatic
Smoke and Air Sensors	First Alert, Universal Security Instruments, Elgato
Light Sensors	Woods, Intermatic, Minotaur Engineering

In addition to the use of sensors for environmental detection, modelling can also be used to collect environmental data, in the literature [28], the researchers considered the conduction and convection mechanisms to establish a thermodynamic model representing the room to measure the data of room temperature changes to simulate the indoor temperature sensor.

In terms of collecting information on household energy consumption data, it is not only necessary to detect the total electricity consumption of household users, but also to refine the information to the specific electricity equipment, the time of electricity consumption, and the voltage, current, and power in the work of each device, which mainly uses detection elements such as sensors, smart sockets, and smart meters to complete the task. Sensor devices or smart sockets will be installed at each detection object node to collect the required power consumption information. Each household appliance can be equipped with a smart plug, and the consumer's usage habits can be recognized by collecting data on the number of times the smart plug is "switched on" or "switched off" and the power consumption [26]. In [14], ACS7102 sensors and ZMPT101B voltage sensor modules are used to measure the current and voltage values of the device. Researchers in the literature [16] designed a smart socket whose power interface is based on voltage and current sensors connected to an Arduino Uno to measure the voltage, current and power factor of the power-using device, which is then processed by a processing module using K-nearest Neighbors Algorithm (KNN) to recognize appliances plugged in real time. It also supports users to remotely control the smart socket via the Internet on the PC and manage the usage time of the device according to the demand.

The above methods that require intrusive monitoring of each household appliance are called intrusive detection methods, which are characterized by a large number of detection hardware, require a lot of time and money in installation and maintenance, cost more and are difficult to be accepted by users. Therefore, non-intrusive load detection methods have become the current research hotspot, non-intrusive load detection only needs to install monitoring equipment at the entrance of the power, the collection of total power consumption information can be decomposed to get the individual load categories and operation of the system, which can effectively solve the problem of difficult to install monitoring equipment, difficult to maintain and so on. The comparison of intrusive and non-intrusive detection methods is shown in Table 4. Although non-intrusive load detection methods have the advantages of using less equipment, low cost, easy installation, and maintenance, it is difficult to classify household appliances operating in multiple state transitions and to distinguish appliances operating under similar electrical characteristics, with reduced identification accuracy. To overcome this difficulty, Yu-Hsiu Lin et al [17] designed a hybrid unsupervised automatic clustering-integrated neural-fuzzy classification (UAC-NFC) model, which allows a non-intrusive load monitoring system to differentiate appliances operating under similar electrical characteristics, and the average and generalized recognition rate can reach 95.73%, which can be applied to an IoT-oriented home energy management system that can better realize demand-side management.

Table 4. Comparison of invasive and non-invasive detection.

Type	Number of Components	Installation	Maintenance	Cost
Invasive Detection	Low	Complex	Complex	Low
Non-invasive Load Monitoring	High	Simple	Simple	High

Smart meter is the core equipment of home energy management system, in addition to the traditional power metering and billing functions, it also increases the functions of power monitoring, data storage, two-way communication, and support for demand response, etc. In addition, the smart meter together with the data management system and the communication network constitutes the Advanced Metering Infrastructure (AMI). The information management in AMI can realize two-way communication between users and power suppliers, obtain real-time tariff information from power suppliers in a timely manner and provide feedback to power suppliers on users' power consumption [18]. Currently, there are still many traditional electricity meters in existence, which are single-function, and the collection of electricity usage and billing data needs to be done manually, which is inefficient, time-consuming, and labor-intensive, and increases the operating costs of the power suppliers. However, replacing all the old meters requires a lot of money and manpower, so Jai Krishna Mishra et al [19] used Raspberry Pi and other devices to slightly modify the old meters already installed, used light sensors to count the total number of LEDs flashing on the meter, calculated the energy consumption and billing based on the LEDs flickering counts, and developed a customized webpage and an application that can be used to A customized web page and application were developed to monitor energy consumption, remote control of the meter and payment of bills. In this way, the old meter can be used as a smart meter to solve the above problems.

The collection of home electricity and environmental information is not only limited to the use of hardware devices, but Vangelis Marinakis et al [20] utilized Java and Python applications to develop a data capture module, from which data from different sources, including building data, energy prices, weather information, and user feedback, are obtained. In addition, real-time processing of the huge amount of data collected is a major issue in physical network-based home energy management systems, and timely and effective data processing is the key to energy management. In [21], redundant data deletion is first performed in data processing, followed by dividing the data into real-time and offline data by using Hadoop ecosystem, which are sent to SPARK system and Hadoop ecosystem respectively to complete the processing of data, which can effectively improve the efficiency and minimize the time required to process the data in real-time. The researchers of [22] developed an IoT big data analytics platform with fog computing capabilities that can process and analyze energy consumption data from multiple homes in near real-time, making home energy management more efficient.

5. Communication Module

5.1. Communication Technology

Communication technology is an important part of energy management. A HEMS system needs to use communication technology to send the information obtained by the data collection module to the management, and also transmit the control signals issued by the main control system to the electrical equipment, and the capabilities of different equipment Consumption data needs to be unified and integrated into the same platform for management. In addition, the home energy management system also maintains communication with the smart grid, receiving information such as demand response control commands and dynamic electricity prices. All aspects of the entire home energy management system based on the Internet of Things use communication networks for real-time communication and data transmission. Therefore, the home energy management system requires the support of the Home Area Network (Home Area Network) and the Wide Area Network (Wide Area Network) [27], the relationship between networks is shown in Figure 3.

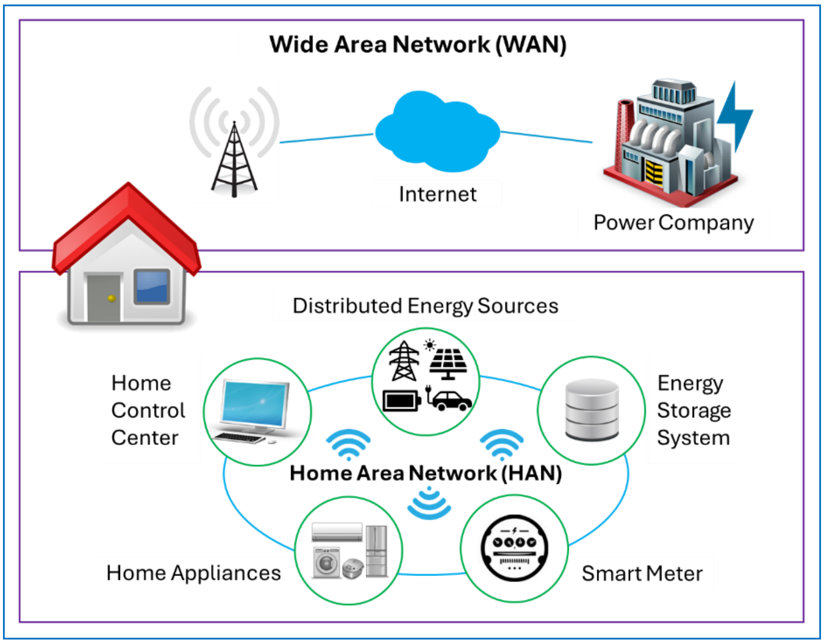

Figure 3. Network relationship of home energy management system.

The home area network is the key network that connects smart meters, electrical devices, control centers and other internal user links, enabling connectivity between the device layer and the management layer to make the whole home energy system a whole. The communication methods that currently exist can be mainly categorized into wireless and wired connections. However, due to the complexity of the types of household appliances, users move, increase, or decrease power loads and other operations will cause frequent changes in the network topology, while the wired network, once wired, is not easy to move, and does not facilitate the integration and adjustment of the equipment in the later stage. Wireless communication technology can cover the entire home network, with low installation costs in the absence of pre-existing networks in the region to provide fast connectivity, and to solve the wiring difficult and inconvenient to expand the problem. Therefore, nowadays, wireless communication technology is mainly used in home local area networks. Table 5 shows the differences of popular license-free wireless communication technologies in smart homes.

Table 5. Comparison of different common wireless communication technologies.

	Bluetooth	WiFi	ZigBee
Frequency Band	2.4 GHz	2.4 GHz 5 GHz	Worldwide: 2.4 GHz Europe: 868 MHz USA: 915 MHz
Transmission Rate	721 kbps	300 Mbps	250 kbps
Transmission Range	1~100 m	50~100 m	30~50 m
Power Consumption	Medium	High	Low
Cost	Medium	High	Low

The ZigBee protocol can work on batteries and can run for years without battery replacement, and has the advantages of proximity, low power consumption, low complexity, flexible topology, low cost, and the failure of one node will not affect other networks [42]. It is particularly suitable for places with small communication range and low power consumption and is the most commonly used communication technology for home energy management system home LANs. The models built in [23, 29] all use the XBee series of modules to establish a Zigbee connection to enable wireless communication between the two main hardware devices. Literature [27] uses a wireless sensor network based on ZigBee technology to enable the establishment of a home energy system that can capture the output of the renewable energy generation system, as well as indoor and outdoor environmental parameters such as temperature, solar radiation intensity and wind speed in a timely manner. [43] proposed a smart home remote controller using Zigbee wireless protocol, which can be set up in two modes, manual control, and automatic control, depending on the user preference, the latter allowing the controller to use fuzzy logic to automatically control the operation of the loads based on dynamic electricity signals. [44] designed a Zigbee-based energy metering unit for monitoring the energy consumption of household appliances and lighting. The results show that accurate monitoring of energy usage can be achieved using ZigBee communication network in this system.

Homes contain a wide variety of devices produced by different manufacturers using different communication standards with varying compatibility. Although ZigBee technology is widely used in this area, a unified communication standard has not yet been developed. This will lead to difficult interoperability between different devices. Therefore, the interoperability problem in IoT-based home energy management system is still a hot research topic. The system proposed in literature [13], on the other hand, adopts IoT communication protocols based on mature standards such as MQTT to make the system scalable. to achieve seamless integration of all home devices. Moreover, the impact on communication becomes greater when multiple communication technologies such as Bluetooth, ZigBee, Wi-Fi, etc. co-exist within short range communication. To address such issues, Javed Iqbal et al [21] used Poisson distribution statistical model to deploy sensors in the home environment to achieve uniform distribution of sensors. And there are relay nodes to effectively expand the distance between the sensors. In this way, the interference of communication can be effectively reduced.

When information is exchanged between individual households and the cloud platform or power company, a wide area network (WAN) is required, usually using fiber optics for connectivity, which provides minimal latency and high data rates. In addition to this, wireless technology can also be deployed, such as LoRaWAN, LPWAN, WiMax, 4G/5G, NB-IoT, and LTE-M. The proposed home energy management system in literature [27] uses WiMAX communication to establish a flexible connection with the grid sector to receive information including peak demand points and real-time tariffs, etc. WiMAX can provide high-capacity and long-distance wireless connectivity with low latency and flexible broadband connectivity, which simplifies the deployment when fiber optics is not available or is too expensive.

5.2. Communication Security

In the future, smart homes will become an essential part of people's lives and will use a large number of IoT devices, but many IoT devices do not encrypt and protect the communication between the Internet and the local network and are therefore vulnerable to hacking to illegally manipulate connected smart devices and infer personal information about users. A study by [45] demonstrated that it is possible to analyze the network traffic of a Nest thermostat and smoke detector in a room while they are working to infer whether there is a user in the home at that time. Moreover, home energy management systems capture a large amount of user data with user privacy built in. Illegal network intrusion into the equipment and system will not only cause user privacy leakage but also threaten the safe operation of the system. Therefore, the security of communication should not be ignored, in the smart home environment, the research of information security technology is very important to ensure the safe operation of home energy management system. S. G. Priyadharshini et al [18] in the energy management system data security using SSL (Secure Sockets Layer) for encryption and protection of transmitted data, the user can use SSL to encrypt and protect the data transmitted, the user can use SSL to protect the data. of data and users can securely transmit sensitive information through SSL protocol. The work [46] proposed a lightweight secure session key establishment scheme for smart home environments, which requires lightweight mutual authentication before each entity joins the home network and establishes a secure session key, which can effectively prevent some unrelated people from accessing randomly. The work [47] proposed an internal security framework for smart home devices using self-signature and access control techniques to provide security services for ensuring device authentication, data integrity and availability, and preventing security threats such as data tampering and leakage.

6. Management and Optimization Module

The Management and Optimization module is the core of energy management. The main purpose of the Home Energy Management System is to schedule and manage electricity equipment, distributed energy and energy storage equipment within the home environment to reduce electricity costs, improve electricity efficiency and energy utilization, and ultimately to achieve intelligent and efficient energy saving and emission reduction. This is achieved through the Management and Optimization module.

In order to reduce the idle losses of household appliances and reduce electricity consumption. Literature

[13] used a Business Intelligence (BI) platform to analyze the data collected on electricity consumption and then provide it to the user in the form of reports, graphs and charts to help the user to develop an appropriate energy management plan. Literature [14] designed a smart energy management system based on NodeMCU and Android, which monitors the home electricity consumption information in real time, including current, voltage, power, energy consumption value, and running time. Users can view the data and remotely control the devices at home through the Android interface. Literature [48] uses sensors and microcontrollers to monitor and analyze the energy consumption of electrical loads, then the analyzed data is sent to a web server, and finally the user can monitor the energy consumption of home appliances in real time and control them remotely through the developed mobile application. The system in literature [49] developed IoT metering device and cloud based database of appliances. The intensity of appliance usage can be observed to find out the usage habits of the users, thus enabling better management of energy. All of these studies aim to provide details of appliance usage by monitoring the usage and energy consumption of the devices in the house, providing real-time feedback to the users about their energy consumption habits. Users can remotely switch on and off the appliances and can reduce the energy consumption of the house by comparing the past electricity consumption data and planning the rational operation of the appliances. However, the management of these appliances is user-driven, and there is no automated mechanism to control the operation of the appliances.

Therefore, in some designs of home energy management systems, control units are added, and various artificial intelligence algorithms as well as machine learning techniques are combined to make the home energy management system more automated and multifunctional. For example, Weixian Li et al [26] used computational and machine learning techniques to develop some additional features to enhance the capabilities of home energy management systems, including the use of LSTM-RNN models for electricity price prediction, which can reduce the cost of electricity by scheduling the electricity load based on the prediction results. Price clustering using the K-mean clustering algorithm allows historical price data to be divided into "off-peak" and "peak" periods to determine the price of electricity worth purchasing. A power alert system has also been developed using K-mean clustering algorithm, which helps the user to know whether his power consumption is above average or not based on his historical data and alerts the user when the power consumption is above the expected level. Krishna Prakash N et al [31] designed a home energy management system integrating battery management and load management at two levels using fuzzy logic algorithm applied to battery management and load management. So that the battery decides whether to charge or discharge based on a created rule base and the load automatically switches between grid and renewable energy powered battery packs in an intelligent way, the daily energy consumption can be reduced by 35% using this system. [50] Creating appropriate rules in the energy management system reduces the peaks of power by setting the priority of each household appliance, collecting the consumption data of all the appliances, and determining whether the power used exceeds the set power threshold, or automatically controlling the load shedding of the power-using devices in order of priority when the power demand exceeds the power supply. Here, [29] specifically included self-diagnostic algorithms to handle unresponsive devices in a similar system, in order to avoid the system sending signals to appliances with no response to disrupt the sequence of data transmission.

In recent years, HEMS based on demand response is also a hot research topic, according to different response methods, demand response can be divided into incentive-based demand response and price-based demand response, as shown in Figure 4.

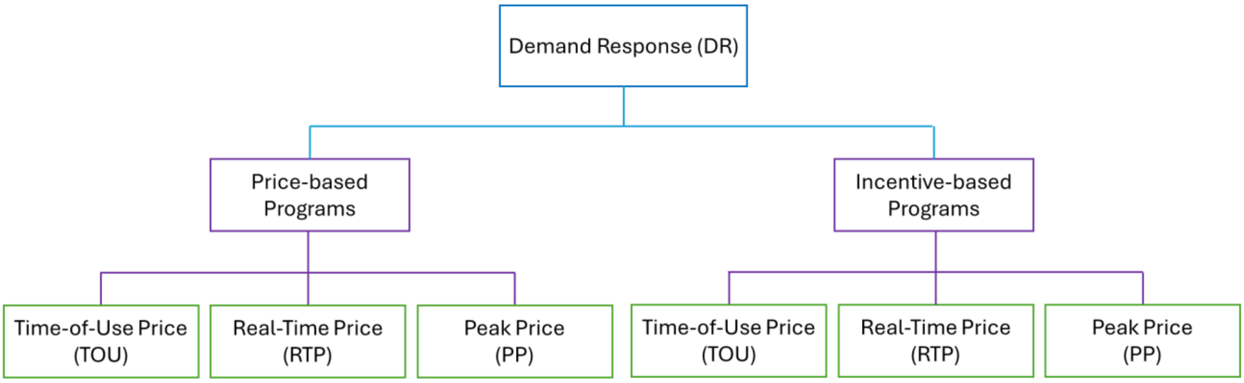

Figure 4. Categorization of demand response program.

Customers participating in demand response can reduce the cost of electricity by developing appropriate schedules to control the use of equipment or changing the consumption pattern of the customer to reduce the consumption of electricity during peak hours and shift it to off-peak hours [51]. The work [29] introduced a cost optimization algorithm in load controllers to control the usage of dispatchable devices based on time-of-day tariffs to maximize their work from 22:00 to 06:00 in order to get the appropriate incentives. An improved Wind Driven Bacterial Foraging Algorithm (WBFA) algorithm is proposed in the literature [34] for the energy management system of a customer's house, which can automatically respond to the price-based demand response issued by the electricity supplier, scheduling the operation of household appliances with the optimal electricity plan, effectively reducing the cost of electricity and the peak-to-average ratio, as well as maximizing the comfort of the user. Comparison with binary particle swarm optimization algorithm, genetic algorithm, and genetic wind-driven optimization algorithm is also made to prove the superiority of the algorithm.

Heating, ventilation, and hot water systems within the home environment account for a large portion of the energy consumption of a dwelling, and therefore many scholars have devoted their research to this area. Qurat-ul Ain et al [28] developed a fuzzy inference system applied to a home energy management system for optimal control of heating and air conditioning equipment. The energy management controller utilizes a fuzzy rule-base inference system (FIS), which takes humidity as an additional input parameter and using indoor temperature changes as feedback to the FIS, and then making energy consumption decisions by triggering the appropriate rules based on a combination of collected values from various sensors and smart grid tariffs. The developed system is able to control the energy consumption minimization while maintaining the user comfort. Emilio Orsi et al [30], on the other hand, proposed a greedy algorithm to optimize the power consumption of the water heater so that the heat is kept within a reasonable range and the power consumption of the water heater is shifted. Up to 38.9% reduction in water heater turn-on time is achieved compared to the non-optimized scheme. And the scheme is able to optimize multiple devices simultaneously without reducing user satisfaction.

Home energy management systems are important to optimize the scheduling of renewable energy generation and storage systems within the home environment, in addition to reducing the cost of electricity consumption by reducing the idle losses of electrical loads. In this regard, the work [12] designed a monitoring system that combines hardware and software by customizing the peak and off-peak hours of electricity consumption, so that when in the set peak hours, the electrical loads will be automatically shifted from the grid to the solar power supply. The work [27] manages the energy storage system by setting rules to control the charging and discharging timing of the battery to maximize the utilization of renewable energy generation, reduce the amount of electricity purchased from the grid and sell the excess electricity generated by renewable energy to the grid. Literature [32] addresses the problem of uncertainty in the generation of solar power during cloudy and rainy days by proposing an energy management system that optimizes the supply of energy from solar and the grid and minimizes the energy expenditure by cleverly switching between the two energy sources.

In addition, the Internet of Things (IoT) mainly relies on wireless sensor networks, so the use of a large number of energy-intensive sensor devices in an IoT-based home energy management system will generate a considerable amount of power consumption. Therefore, many articles discuss the optimization of the operation of wireless sensor network devices in smart home environments. Literature [21] adds relay nodes in sensor deployment and proposes an Electronic Device Sleep Scheduling Algorithm (EDSA) that can control sensor activities during different operating states including active, dormant, and idle modes to achieve better energy consumption. Literature [52] designed an intelligent power distribution power management system by first developing an adaptive classification scheme (ACS) to classify all the sensor devices in the home according to the power type, and further proposed a dynamic distributed energy management algorithm (DDEM) to adjust the energy distribution and provide constant and reliable current control for each sensor node, which not only effectively optimizes the home sensor network's the overall power consumption, but also improves the network quality of service.

When investigating management strategies for energy management systems, researchers tend to ignore some factors without considering them very comprehensively, which will lead to unsatisfactory results in practice. Habib Elkhorchani [27] ignored the possibility that household appliances may be interrupted during work and affect the user's experience by setting the priority of the devices, and scheduling loads during peak hours based on the availability of local renewable energy sources and the usage of devices at all levels. The proposed pricing algorithm also reduces the cost of electricity by setting a tariff threshold with the aim that appliances will delay their work in order to start at a lower tariff. However, the uncertainty of the tariff will lead to excessive delays in the work of appliances and a steep increase in the power demand during the low price hours. Aadesh Kumar Arya et al [35], on the other hand, aimed to minimize the energy consumption of air conditioner operation by controlling the power of room air conditioners based on real-time tariffs, which is effective in reducing the electricity cost but at the expense of the user's comfort. In addition, many ordinary household users do not have the ability to have energy storage systems, generate electricity from renewable energy sources and sell electricity to the grid at the same time, and the awareness of energy conservation and household energy management is relatively low, remaining in the traditional conservation management, with insufficient participation in the power management and scheduling [24-25]. All of this will make the research fail to achieve the expected results when it comes to practical application.

7. Conclusion

Family power consumption is an important part of power consumption, with the development of intelligent technology and the emergence of smart grid, people's family life power structure is also gradually changing, and the power network of residential users will be more and more comprehensive, with power loads, energy storage systems, distributed power supply and other equipment. However, the power consumption in this field is inefficient and wasteful. In the present context of continuously rising power demand but energy scarcity, smart home energy management has received the attention of many experts and scholars, and the research of home energy management system has gradually become a hotspot, and the home energy management system based on the Internet of Things (IoT) can ensure the optimal use of distributed energy sources and implementation of the demand response on the residential side in the environment of smart grids, and prompt the Home users actively participate in electricity management and help to scientifically plan the use of electricity, improve the efficiency of electricity use in the neighborhood, and achieve the purpose of energy saving and emission reduction. In the future, home energy management systems will become an integral part of smart grids and smart homes. This paper firstly describes the basic concept of IoT smart home energy management system, then describes the framework of home energy management system, and finally reviews the current research status in this field from three major modules, namely, data collection module, communication module, and management and optimization module, respectively.

With the growing demand for smart homes, the development prospect of home energy management will be even broader. At present, many researchers have conducted in-depth studies on the structure of home energy management systems, communication systems, various optimization algorithms and other neighborhoods. However, the living habits of various types of users are varied and their needs are very different, so inappropriate optimization of the system may lead to a decrease in user comfort or even cause additional energy waste. In addition, in terms of security, although some research proposals have been put forward that can solve the security problem to a certain extent, the current smart devices and technologies are changing rapidly, and there is an urgent need for further research. Therefore, future research work on IoT-based home energy management systems should focus on the following two points: (1) Home user comfort. The system must ensure that the basic needs of users are met while improving the efficiency of electrical energy; (2) Information security of home users. Continuous improvement of network communication technology and increased research on information security technology are required.

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