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Research on key technology and system application of energy management coupled with liquid cooling and intelligent control algorithm

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Abstract: With the continuous progress and innovation of science and technology, the demand and requirements for energy in modern society are getting higher and higher. The system application of liquid cooling and intelligent control algorithm coupling energy management can adapt to this demand and provide more efficient, accurate and intelligent energy management solutions. On the basis of a brief introduction to the current energy problems, the principle of liquid cooling technology and intelligent control algorithm are expounded, the design and key technologies of liquid cooling system and intelligent control algorithm are analyzed. The liquid cooling system based on fuzzy control is studied. The liquid cooling system based on fuzzy control can quickly and accurately respond to equipment temperature changes, avoid equipment damage due to overheating, and improve energy utilization efficiency and reduce energy waste. On the basis of a brief introduction to the current energy problems, this study describes the principle of liquid cooling technology and intelligent control algorithm, focuses on the design and key technologies of liquid cooling system and intelligent control algorithm, and studies the liquid cooling system based on fuzzy control. The liquid cooling system based on fuzzy control can quickly and accurately respond to equipment temperature changes, avoid equipment damage due to overheating, and can improve energy utilization efficiency and reduce energy waste.

1. Introduction

With the continuous development of society, energy consumption is increasing, energy issues and environmental issues have become the focus of global attention. Traditional energy management methods have been difficult to meet the needs and requirements of modern society, and there are problems such as low energy utilization efficiency, uneven energy distribution, and excessive energy consumption [1].Therefore, research on new energy management technology and methods, improve energy efficiency, reduce energy consumption, reduce environmental pollution and other aspects of the problem is one of the urgent problems to be solved. At the same time, with the continuous progress and innovation of science and technology, new technologies and methods continue to emerge, providing more possibilities and opportunities for the research and application of energy management. For example, the emergence of liquid cooling technology provides a new solution for the cooling of battery energy storage systems, which can effectively improve the life and performance of batteries[2]. The development of intelligent control algorithms provides more accurate and reliable tools for energy monitoring, forecasting and optimization. Liquid cooling technology is a technology that uses liquid to replace air and take away the heat generated during the operation of heating devices[3]. In recent years, with the rapid development of data centers, cloud computing and artificial intelligence, liquid cooling technology has received more and more attention and application. The maturity of liquid cooling technology has been significantly improved, and the application field has been expanding, not only in high-performance computers, oil and gas exploration and other fields have been applied, but also gradually applied to data center servers and electric vehicles and other fields. The application of these new technologies provides new ideas and methods for the research and application of energy management.

Therefore, by applying liquid cooling technology and intelligent control algorithm to energy management, this study aims to study the key technologies and system applications of intelligent control, so as to improve energy utilization efficiency, reduce energy consumption, and reduce environmental pollution, and provide better energy management solutions for the development of modern society.

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2. Discussion

2.1. Application of liquid cooling and intelligent control algorithm in energy management

2.1.1. Energy management technology based on liquid cooling

With the rapid development of various industries, the energy density and power density of new energy vehicle batteries have gradually increased[4]. Electronic components to lightweight, micro development, its unit volume power increase, resulting in the chip temperature is getting higher and higher, and too high temperature will greatly reduce the performance of the equipment or system, seriously affect the quality of electronic products and the reliability of operation; At the same time, with the vigorous development of new technologies such as artificial intelligence and 5G, the number and scale of data centers have increased sharply, and the modular technology and electronic chip integration technology have been continuously improved[5]. The cooling limit of traditional air cooling technology is about 37W/cm2. Traditional natural heat dissipation and forced air cooling heat dissipation can no longer meet the heat dissipation requirements of a large number of integrated chips with high power level and other applications, so we need to adopt more efficient liquid cooling technology for heat management[6-8].

2.1.1.1. Concept of liquid cooling technology

According to the cooling principle, the current liquid cooling technology can be divided into three main forms: cold plate liquid cooling, submerged liquid cooling and spray liquid cooling[9]. The cold plate liquid cooling technology is to attach a plate heat exchanger to the main heat source of the server (such as CPU and memory components), and use heat conduction to transfer heat to the coolant in the plate, and then take the heat out of the server through the coolant circulation[10]. The advantage of this method is that the coolant is not in direct contact with the heating source, which can avoid problems such as electrical short circuit. Immersion liquid cooling technology is to soak the server directly in the coolant, through the coolant directly absorb the heat generated by the server and cycle out[11]. The advantage of this method is that it has high heat dissipation efficiency and is suitable for data centers with high power density. The principle of spray liquid cooling is to use an injector to spray cooling fluid on the surface of the electronic device that needs to dissipate heat. A temperature boundary layer is formed on the surface of the device, and strong heat transfer occurs to take away heat[12]. Usually use a low boiling point liquid, has a high heat transfer rate, and liquid injection speed is very fast, so the cooling effect of electronic components is very ideal, can meet the electronic components continue to increase the heating power of heat dissipation requirements[13]. In the above three forms of liquid cooling, the most widely used is cold plate liquid cooling, and the liquid cooling technology described in the following content of the article refers to cold plate liquid cooling.

Liquid cooling technology refers to the cooling technology in which the cooling medium is liquid, and its principle is to use the flow of coolant to take away the heat generated by the components and reduce the temperature of the heating device[14]. The liquid cooling system is mainly composed of radiator, coolant, pump, water tank, etc. Specifically, the liquid cooling system cools the device by passing the liquid through the heating part of the electronic device, absorbing the heat of the device, and then transferring the heat to the heat exchanger through the pump and pipe, and finally discharging the heat to the external environment[15]. In this process, the liquid cooling system can achieve efficient heat dissipation, reduce the temperature of the equipment, and improve the performance and stability of the equipment. However, depending on different liquid cooling application areas and specific needs, the hardware composition of the liquid cooling system may vary. For example, in some applications, it may be necessary to use specialized hardware devices such as liquid cooling plates, liquid cooling pumps, liquid cooling pipes, condensers, evaporators, etc. As show in figure 1.

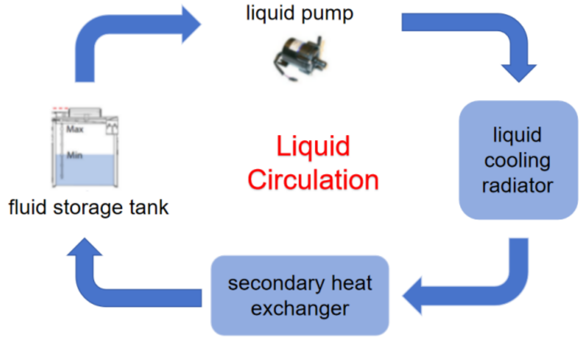

Figure 1. Basic schematic diagram of liquid cooling system[16].

According to the type of cooling liquid and circulation mode, liquid cooling technology can be divided into water cooling, oil cooling, evaporative cooling and other types[17]. Water-cooling technology is one of the most common, which uses water as a coolant to transfer equipment heat to the external environment through pumps and radiators. Oil cooling technology uses oil as a coolant, which has the advantage of stable operation at high temperatures and natural cooling in the absence of an external radiator. Evaporative cooling technology is the use of liquid evaporation heat absorption principle for heat dissipation, suitable for high temperature and high humidity environment.

Liquid cooling technology has the advantages of high efficiency, stability and safety. The advantage of liquid cooling technology is that compared with traditional air cooling technology, it can provide higher heat dissipation efficiency and reduce the temperature of the equipment, thereby improving the performance and stability of the equipment[18]. Since the specific heat capacity of liquid is greater than that of air, liquid cooling technology can absorb and transfer heat more quickly, reducing equipment temperature[19]. In addition, liquid cooling technology can also reduce equipment noise, reduce energy consumption and so on. In the trend of high density integration of electronic devices, liquid cooling technology has become an important cooling solution.

2.1.1.2. Combination of liquid cooling technology and energy management

In practical applications, liquid cooling technology is widely used in computer, server, communication equipment, photoelectric equipment and other high-performance electronic equipment. The application of liquid cooling technology in electric vehicles can shorten the charging time by 1/3[20], and liquid cooling can achieve accurate cooling in electronic equipment, which is much more efficient than air cooling. Especially in the field of high-performance computers, due to the increasing scale of supercomputers, traditional air cooling technology has been unable to meet the heat dissipation demand, so liquid cooling technology has been widely used[21]. Below are some examples of applications of liquid cooling technology in different fields related to energy management.

Data center cooling: With the rapid development of cloud computing and big data technology, the scale of data centers continues to expand and the number of servers continues to increase, resulting in more and more prominent heat dissipation problems[22-24]. Liquid cooling technology, as an efficient cooling technology, has been widely used in the field of data center. Liquid cooling technology can provide higher heat dissipation efficiency, reduce equipment temperature, and improve equipment performance and stability. In addition, liquid cooling technology can also reduce energy consumption and operating costs, improving the energy efficiency of the data center[25].

Automobile cooling: automobile engine and transmission system will generate a lot of heat during operation, if the heat can not be dissipated in time, it will affect the normal operation and safety of the vehicle[26]. Liquid cooling technology can be applied to automotive cooling systems by flowing coolant through the engine and transmission system to rapidly absorb and dissipate heat, maintaining the normal operating temperature of the vehicle. Liquid cooling technology can improve the cooling efficiency and reliability of vehicles and extend the service life[27].

Electronic device cooling: Some high-heat electronic devices, such as computer CPU, GPU, etc., need efficient cooling systems to maintain stable operation[28]. Liquid cooling technology can be applied to the heat dissipation of these electronic devices by flowing coolant through the surface of the device to rapidly absorb and dissipate heat, reduce the temperature of the device, and improve the performance and stability of the device[29].

Industrial cooling: In the process of industrial production, some equipment will generate a lot of heat and need to be heat dissipated. Liquid cooling technology can be applied to the heat dissipation of these equipment, such as smelting furnaces, reactors, etc. Liquid cooling technology can provide efficient heat dissipation effect, reduce equipment temperature, and ensure the stability and safety of industrial production[30].

At the same time, liquid cooling technology is also widely used in energy management. For example, in the power energy system, the efficient cooling of liquid cooling technology can improve the operation efficiency of power equipment and reduce energy consumption[31]. In the petrochemical industry, liquid cooling technology can be used to cool oil and other products, and can also realize energy recovery and reuse[32]. Especially in the field of new energy, liquid cooling technology can be used in the cooling link of solar energy, wind energy and other new energy equipment, which can improve the charging and endurance of electric vehicles.

In short, liquid cooling technology has a wide range of applicability and advantages in different fields of application. By using liquid cooling technology, you can improve the heat dissipation efficiency, performance and stability of the equipment, reduce energy consumption and operating costs, extend the service life, and promote the development of the data center to the green and efficient direction.

2.1.2. Application of intelligent control algorithm in energy management

Intelligent control algorithm is a method that uses artificial intelligence technology and computer algorithm to realize automatic control, and can realize adaptive control and intelligent decision. It does not refer to a specific application or computational method, but rather an idea and technology that utilizes intelligent algorithms for control and optimization. The intelligent control algorithm can automatically adjust the control parameters according to the input and output information of the system to achieve the best control effect. Common control algorithms include PID control, neural network control, genetic algorithm, fuzzy control and reinforcement learning[33]. Usually combined with PLC, Matlab and other control.

Intelligent control algorithm has the characteristics of self-learning, prediction and decision, nonlinear control, multi-objective optimization, integration and intelligence. According to the input and output data of the system, the intelligent control algorithm can continuously optimize the control strategy and parameters through self-learning and self-adaptive adjustment to adapt to the changes of the environment and objects. In terms of prediction and decision-making ability, intelligent control algorithm can use artificial intelligence technology to predict the future state of the system and make intelligent decisions based on the predicted results to achieve more efficient and accurate control[34]. At the same time, the intelligent control algorithm can integrate multiple control modules and functions together, and realize efficient coordination and resource sharing of the system through intelligent management and scheduling.

Intelligent control algorithm has a wide application prospect and can realize intelligent control and management of complex systems in various fields. For example, the intelligent control algorithm is applied to the field of industrial automation, which can carry out intelligent control of various equipment in the production process[35]. For example, in intelligent manufacturing, intelligent control algorithms can be used to control robots, automated assembly lines and other equipment to improve production efficiency and product quality. Intelligent control algorithm can also be applied to the field of intelligent agriculture to achieve intelligent management of agricultural production[36]. For example, sensors are used to collect farmland environmental data, and intelligent control algorithms are used to intelligently regulate agricultural production processes such as irrigation and fertilization, so as to improve agricultural production efficiency and resource utilization.

The application of intelligent control algorithm in energy management is reflected in many aspects, which can predict energy demand through the analysis of energy data, so as to optimize energy distribution and avoid energy waste. At the same time, the intelligent control algorithm can detect the running state of the energy equipment in real time, predict the possible failure of the equipment, and improve the operating efficiency, which has a good application in industrial production.

2.1.3. Coupling of liquid cooling and intelligent control algorithm

The combination of the efficient heat dissipation performance of liquid cooling technology and the intelligent control ability of intelligent control algorithm can better meet the heat dissipation needs of modern data centers and other facilities, while reducing energy consumption and carbon emissions, and achieving the goal of high efficiency, energy saving and environmental protection[37]. This coupling is of great significance for promoting the progress of energy management technology and realizing green and sustainable development.

The coupling of liquid cooling system and intelligent control algorithm aims to combine the efficient heat dissipation performance of liquid cooling technology and the intelligent control ability of intelligent control algorithm to realize the optimal utilization and efficient management of energy. The coupling system can monitor the operating status, energy demand and supply of the liquid cooling system in real time, and use the intelligent control algorithm to analyze data and optimize decisions, so as to realize the intelligent control and scheduling of the liquid cooling system[38].

The coupling system of liquid cooling system and intelligent control algorithm has the following steps. First, establish a liquid cooling system to ensure that it has an efficient heat dissipation capacity. Then, the operating state of the liquid cooling system is monitored in real time by setting sensors at key parts. These sensors transmit the collected data to the data processing equipment, which is processed and analyzed by the intelligent control algorithm, and the system automatically adjusts the operating parameters of the liquid cooling system, such as the flow rate of the coolant or the speed of the pump, to achieve the optimal use of energy. At the same time, continuous monitoring and data collection can help further optimize control strategies and improve energy efficiency. This coupled system can reduce energy consumption and carbon emissions, improve the efficiency and stability of data center operations[39].

The coupling of liquid cooling and intelligent control algorithm will be more widely used in the future, and its advantages will be reflected in more fields. With the continuous development and improvement of technology, this coupling will be applied and innovated in more fields, bringing more convenience and benefits to our life and work.

2.2. System design and case analysis of energy management based on the coupling of liquid cooling and intelligent control algorithm.

2.2.1. System design and key technologies used

The energy management system based on the coupling of liquid cooling and intelligent control algorithm is an integrated system, and its architecture design includes the following main parts:

(1) Data acquisition layer: The main function of this layer is to collect the operating data of various energy equipment, such as temperature, humidity, power, etc. This data is collected by various sensors and meters and then transmitted to the data processing layer.

(2) Data processing layer: The main function of this layer is to process and analyze the collected data. The data processing layer includes data cleaning, feature extraction, model training and other steps to extract useful features and patterns.

(3) Intelligent control algorithm layer: The main function of this layer is to generate control instructions according to the data processing layer analysis results and preset control strategies. These instructions act on the temperature and flow of the coolant through the liquid cooling control layer to achieve efficient cooling of energy equipment.

(4) Liquid cooling control layer: The main function of this layer is to adjust the temperature and flow of the coolant according to the control instructions generated by the intelligent control algorithm layer to achieve cooling control of the energy equipment.

(5) human-machine interface layer: The main function of this layer is to provide a user interface, so that users can view the operating status of energy equipment and the setting of control parameters.

The architecture design of the energy management system based on the coupling of liquid cooling and intelligent control algorithm aims to realize the real-time monitoring and data collection of the running state of energy equipment, and at the same time, intelligent control algorithm and liquid cooling technology are used to efficiently cool and control the temperature of energy equipment. This helps to improve energy efficiency, reduce energy consumption and achieve sustainable development.

In this system, every part is very critical, but the most important is the design of intelligent control algorithm layer and liquid cooling control layer. When designing the intelligent control algorithm layer, it is necessary to consider the characteristics and requirements of the application itself. The core of intelligent control algorithm is the model, and different models are suitable for different application scenarios. When selecting the model, it is necessary to select the appropriate model according to the characteristics and requirements of the application, and at the same time, it is necessary to adjust and optimize the model in order to better adapt to the actual application scenario. At the same time, for different application scenarios, the design of the liquid cooling control layer may have some differences. In the design of the liquid cooling system, it is necessary to consider what kind of channel used in the liquid cooling plate will have better heat dissipation performance, the thickness of the liquid cooling plate, the flow rate of the coolant inlet and the temperature[40].

The key technology of liquid cooling plate design is reflected in many aspects, among which the heat dissipation performance is the core element in the design of liquid cooling plate, which is affected by various factors[41]. First of all, the temperature distribution is one of the key factors, through simulation analysis can optimize the temperature distribution of the liquid cooling plate, so as to improve the heat dissipation effect. In addition, the heat transfer coefficient plays an important role in the heat dissipation performance, and optimizing the shape, size and coolant flow rate of the flow channel can effectively improve the heat transfer coefficient[42]. At the same time, flow resistance is also a factor that needs to be considered, and reducing flow resistance can improve heat dissipation performance. In terms of material selection, the properties of metal materials such as copper and aluminum have a significant impact on heat dissipation performance. The size and weight of the liquid cooling plate are also factors to be considered when designing, and they need to be matched with the equipment to ensure heat dissipation. In addition, sealing, strength and stiffness, lightweight, corrosion resistance, cycle efficiency and manufacturing processes are also key technical points in the design of liquid cooled plates. Tightness is necessary to maintain fluid pressure and circulation, while strength and stiffness are required to meet mechanical and thermal load requirements. Lightweight design helps to reduce system weight, while corrosion protection requires attention to material selection and surface treatment[43]. Cycle efficiency and manufacturing processes also directly affect thermal performance and cost. Finally, adequate testing and verification is an important link to ensure the performance and reliability of the liquid cooled plate. In summary, the key technologies of liquid cooling plate design involve many aspects, which need to be selected and optimized according to specific application scenarios and needs.

In the design of the liquid cooling system, it is necessary to consider the flow rate, the choice of cooling liquid, the temperature of the coolant, the shape of the channel and other factors to determine the optimal cooling effect during cooling. Zhang Senhao[44] studied the selection of cooling liquid and cooling plate materials in the liquid cooling system and the influence of different structure of liquid cooling plates on the heat dissipation effect of electric vehicle batteries, focusing on the study and simulation of the heat dissipation effect of three shapes of liquid cooling plates: square, snake and honeycomb. The square liquid cooling plate used in this study is a simple structure cooling plate, that is, the whole liquid cooling plate is placed at the bottom of the power battery; The serpentine liquid cooling plate passes through the middle gap of the two rows of batteries and attaches to the side of the cylindrical battery; Honeycomb liquid cooling plate is equivalent to a combination of multiple hexagonal prism shapes, through comparison with the data of the uncooled battery pack, it is found that the cooling effect of the liquid cooling battery pack of the three different structures of the liquid cooling plate is significantly improved than that of the uncooled battery pack, and at the same discharge rate, the honeycomb cooling effect is the best, indicating that for the battery pack of the electric vehicle, Choose honeycomb shape liquid cooling structure can achieve the best heat dissipation effect.

To sum up, the realization of the energy management system based on the coupling of liquid cooling and intelligent control algorithm requires the comprehensive use of a variety of technologies and methods, through the reasonable design and optimization of all levels and links, to achieve an efficient, stable and real-time energy management system.

2.2.2 Fuzzy control of airborne electronic equipment

When liquid cooling systems and intelligent control algorithms are applied in different fields, their specific compositions and algorithms will be different. Next, take electronic equipment as an example to analyze the application of liquid cooling technology and intelligent control algorithm coupling energy management.

With the development of airborne electronic equipment towards miniaturization, integration and high density, the heat flux of electronic equipment is getting higher and higher, and the cooling efficiency of liquid cooling technology is at least 100 times higher than that of natural cooling and air cooling technology[45]. This application example takes the fuzzy control of airborne electronic equipment as an example to study heat dissipation and reduce energy waste.

In the fuzzy control design of the liquid cooling system, the flow rate of the liquid cooling system is controlled by a fuzzy algorithm to ensure that the temperature of the electronic equipment is within the set temperature range. Therefore, the difference u between the real-time temperature and the target temperature of the electronic equipment components and its conversion rate are selected as the input of the control system, and the flow rate v of the coolant is taken as the output of the control system. The fuzzy control structure diagram is shown in figure 2 below.

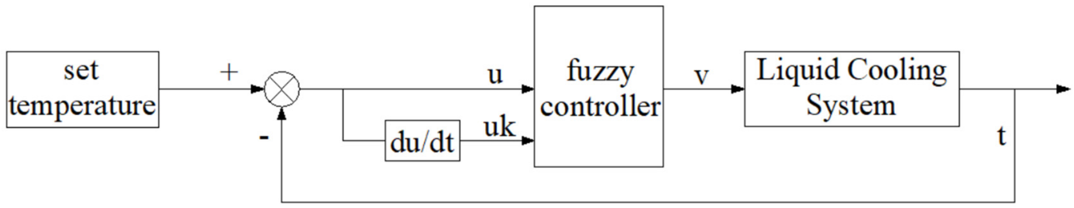

Figure 2. Fuzzy control structure diagram.

The liquid cooling system of airborne electronic equipment has the characteristics of nonlinear and time-varying. Fuzzy control has the advantages of strong adaptability, good real-time performance, strong fault tolerance, etc. Fuzzy controller does not need accurate mathematical model, and can quickly respond and control the controlled object in a short time[46]. Therefore, the combination of fuzzy control algorithm and liquid cooling system of airborne electronic equipment can solve the energy waste caused by the original characteristics such as time variability.

The application of the energy management system in other aspects is similar to the fuzzy control of airborne electronic equipment. It is necessary to select the most appropriate control algorithm and the configuration of the liquid cooling system according to the specific characteristics of the application instance, and make full use of the intelligent control algorithm for energy prediction, advance allocation, real-time control and other functions to reduce energy waste. Maximize energy efficiency.

2.3 Closing remarks

With the increasing demand for energy and the increasing shortage of energy supply, energy management has become a common challenge facing the world. The combination of liquid cooling technology and intelligent control algorithm provides a new solution to this challenge. Liquid cooling technology has brought innovation to energy management with its advantages of high efficiency heat dissipation and low energy consumption. The intelligent control algorithm further optimizes the efficiency of energy use through accurate and intelligent control strategies.

In the system design and case analysis, we discuss the application of liquid cooling and intelligent control algorithms in energy management, and how they work together to achieve more efficient energy management. Through the application of key technologies and the implementation of fuzzy control strategy, we hope to provide new solutions for energy management of high energy consumption systems such as airborne electronic equipment.

However, the application of liquid cooling and intelligent control algorithms in energy management still faces some challenges. How to further improve the efficiency of heat dissipation, reduce energy consumption, and how to achieve a more accurate and intelligent control strategy is a problem worthy of our continued research. In the future, we expect to bring more breakthroughs in energy management through continuous technological innovation and in-depth research.

3. Conclusion

This paper describes the related concepts of liquid cooling system and intelligent control algorithm, and further studies their application in energy management and the key points of their technology. Liquid cooling technology provides a new solution to solve the heat dissipation problem of high-density energy equipment with its efficient heat transfer and heat dissipation performance. The application of intelligent control algorithm further optimizes the use and management of energy, and achieves more intelligent and accurate energy control. This research not only deepens our understanding of the efficient use of energy, but also provides certain technical support for green and sustainable development in the future. With the continuous progress of science and technology, this efficient and environmentally friendly energy management method will be applied in more fields and make greater contributions to the sustainable development of human society. It is believed that there will be more research in the future to further tap the potential of liquid cooling and intelligent control algorithms, providing more possibilities for our energy management.

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