

The Application and Development of Energy Conservation and Consumption Reduction of Automatic Control Technology in Agricultural Irrigation

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Abstract. Agriculture, as the cornerstone of global food security and economic stability, plays an irreplaceable role in maintaining the prosperous development of society. With the increasingly severe issues of global climate change and water scarcity, agricultural irrigation has become a key factor restricting the improvement of agricultural productivity and sustainable development. Among various irrigation methods, automated irrigation technology driven by automatic control technology can not only improve the efficiency of water resource utilization and reduce energy consumption, but also enhance the intelligent level of agricultural production, laying a solid foundation for agricultural modernization and sustainable development. However, the application of automatic control technology in agricultural irrigation still faces many challenges globally, such as difficulties in technology promotion, high costs, non - standard equipment, and poor system integration. These problems limit its wider application. To address these issues, this paper reviews the application status, challenges, and development directions of automatic control technology in agricultural irrigation. Specifically, it summarizes typical application methods, including the use of variable - frequency speed - regulation technology and the combination of automatic control and solar energy. These methods significantly improve the efficiency of water resource utilization and the degree of irrigation intelligence through precise parameter control and the use of renewable energy. In addition, this paper also analyzes the key challenges hindering its application and proposes potential development directions. This review aims to provide reference for practices in related fields, promote the better application of automatic control technology in agricultural irrigation, and contribute to the sustainable development of agriculture.

Keywords: Automatic control technology, agricultural irrigation, application status, challenges, development directions.

1. Introduction

As a crucial part of modern technology, automatic control technology has been deeply integrated into industries such as industry, transportation, and healthcare with the maturity of computer technology. In the industrial sector, it promotes the automation of production lines to reduce costs and risks. In the transportation field, it utilizes intelligent systems to ease congestion and improve safety. In the medical field, it enables automatic control of equipment. Its advantages of improving efficiency, reducing human errors, and optimizing resource allocation have become an important driving force for the development of various industries, with significant technological value and application potential. However, currently, the application of automatic control technology in the agricultural field is still relatively scarce, forming a significant gap compared with its deep penetration in other fields. The development of agricultural automation urgently requires more empowerment and breakthroughs from this technology. With the increasing severity of global climate change and water resource shortage, agricultural irrigation is facing huge challenges. Traditional irrigation methods often lead to serious water waste and high energy consumption, making it difficult to meet the needs of the sustainable development of modern agriculture. Especially in arid and semi-arid regions, agricultural irrigation consumes a large amount of water, but the water resource utilization efficiency

is low, further exacerbating the contradiction between water supply and demand. As a result, automated equipment for irrigated agriculture is being applied more widely around the world. Automatic control technology achieves intelligent management of the irrigation system by precisely controlling the amount of irrigation water, time, and method, thus effectively improving water resource utilization efficiency and reducing energy consumption. Taking China as an example, the irrigated area of cultivated land nationwide has reached 1.08 billion mu, and the area of automated irrigation has exceeded 200 million mu, accounting for about 20% of the total national irrigation area. More than 22 million various farmland water conservancy projects have been built, and the penetration rate of intelligent irrigation systems has also climbed to over 30%, and it is expected to maintain a rapid growth trend in the next few years. These data clearly indicate that automatic control technology is injecting strong impetus into the sustainable development of agriculture. While improving irrigation efficiency and saving agricultural resources, it also provides solid technical support for promoting the transformation and upgrading of agricultural production methods and ensuring the stable development of agriculture^[1].

The application of automatic control technology in agricultural irrigation has been practiced by many researchers. However, as far as the author knows, no researcher has sorted out review articles on the application of automatic control technology in agricultural irrigation. But with the increasing trend of journal article publications, it is necessary to conduct a detailed literature review of this kind of research, which will help enrich and improve the theory of agricultural water-saving irrigation. At the same time, this paper can also provide reference for relevant management and research personnel and promote the wide application of automatic control technology in agricultural irrigation.

2. Apply automatic control technology in agricultural irrigation for the purpose of energy conservation and consumption reduction

2.1. Application of Variable Frequency Speed Regulation Technology in Agricultural Irrigation for the Purpose of Energy Conservation and Consumption Reduction

The variable-frequency speed-regulation technology has advantages in the water-saving irrigation system of agricultural irrigation areas, such as avoiding waste of water resources, reducing the use of chemical fertilizers, and achieving the goals of energy-saving and high-efficiency. It provides strong support for promoting the sustainable development of agricultural electromechanical drainage and irrigation projects^[2]. Sun Shaojie et al. pointed out that variable frequency speed regulation technology can achieve stepless speed regulation of water pump motors, improve energy-saving effects and equipment service life. By realizing smooth start and stop of water pump motors, adjusting the motor speed according to actual irrigation needs, improving the overall system energy utilization efficiency, and combining with intelligent control equipment to achieve intelligent management. Under the energy-saving irrigation method of variable frequency speed regulation, the flow rate is proportional to the speed, the pressure is proportional to the square of the speed, and the shaft power is proportional to the cube of the speed. If 60% of the rated water volume is required, by adjusting the motor speed to 60% of the rated speed, the required power is only 21.6% of the original. Therefore, by controlling the frequency of the motor input power supply, the goals of controlling the water pump speed, water output, outlet pressure, and shaft power can be achieved, keeping the water pump in a high-efficiency operation state and achieving the effect of water and energy conservation^[3].

Liu Shuai et al. developed an agricultural water-saving pipeline irrigation system based on an integrated intelligent valve controller. This system can accurately control the opening and closing state and angle of the valve, effectively saving water resources. Combining with the decision-making software for agricultural irrigation operations, this system can collect information such as soil moisture and temperature in real-time, make intelligent decisions through a fuzzy control algorithm, and achieve precise irrigation^[4]. In addition, sensors installed on the valve will monitor pressure, temperature, flow rate, valve position, and any other characteristics required to diagnose its functionality.^[5] The new intelligent water-saving and energy-saving irrigation system uses Internet

of Things technology to achieve remote monitoring and precise control. See Figure 1 for the water-saving and energy-saving irrigation system. This system is powered by batteries or solar energy and has good practicality^[6].

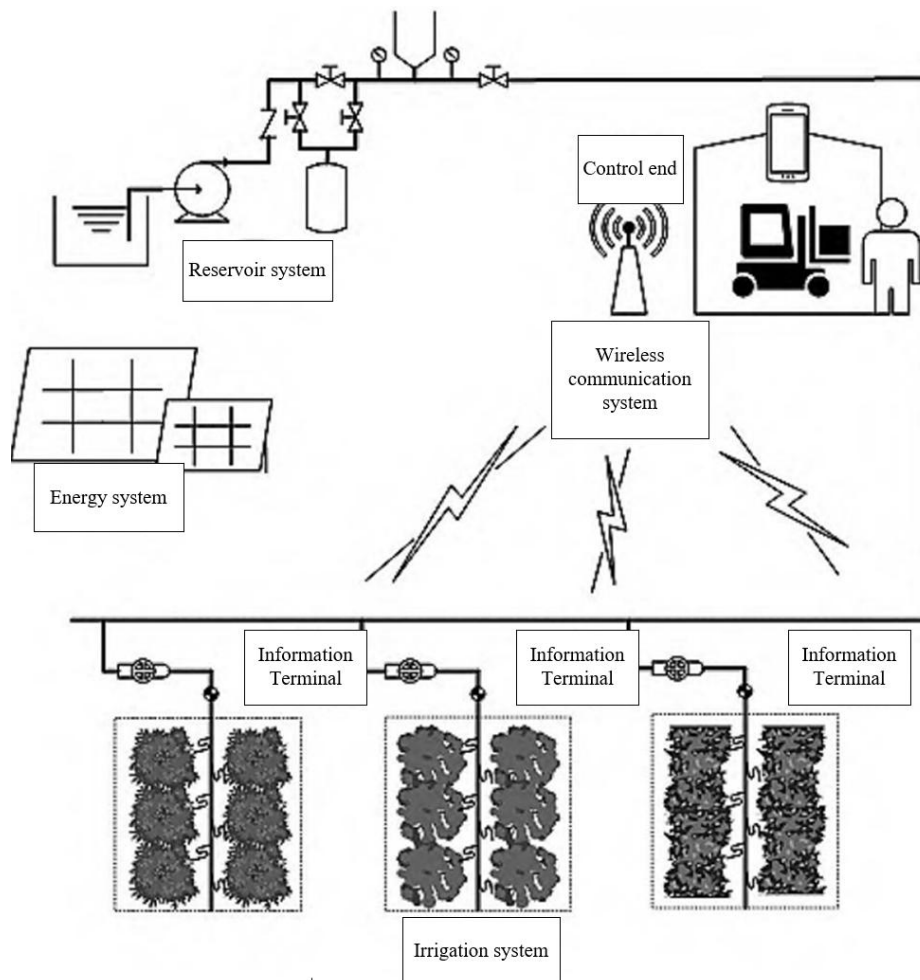


Figure 1 Water-saving and Energy-saving Irrigation System Diagram^[6]

The self-organizing network-type high-efficiency energy-saving and water-saving irrigation control system adopts technologies such as solar photovoltaic power supply, wireless networking, and meteorological data analysis. The structure of the self-organizing network-type high-efficiency energy-saving and water-saving irrigation control system is shown in Figure 2. It achieves the goal of high-efficiency energy-saving and water-saving. These systems not only have low operating power consumption, flexible and reliable networking, but also have a wide data monitoring range. They can obtain meteorological data in real-time, providing an intelligent and information-based solution for agricultural irrigation^[7]. As a core component of the self-organizing network technology, the Self-Organizing Map (SOM) realizes the spatial self-organizing modeling of unordered point clouds in the SO-Net architecture. This design innovatively introduces the self-organization principle in the communication field into 3D data processing. By constructing a neuron grid with a scale of $m \times m$, it establishes a topology-preserving mapping of point cloud data. This unsupervised competitive learning mechanism endows the network with an adaptive ability similar to that of the biological nervous system, enabling it to automatically capture the data distribution characteristics without central control^[8].

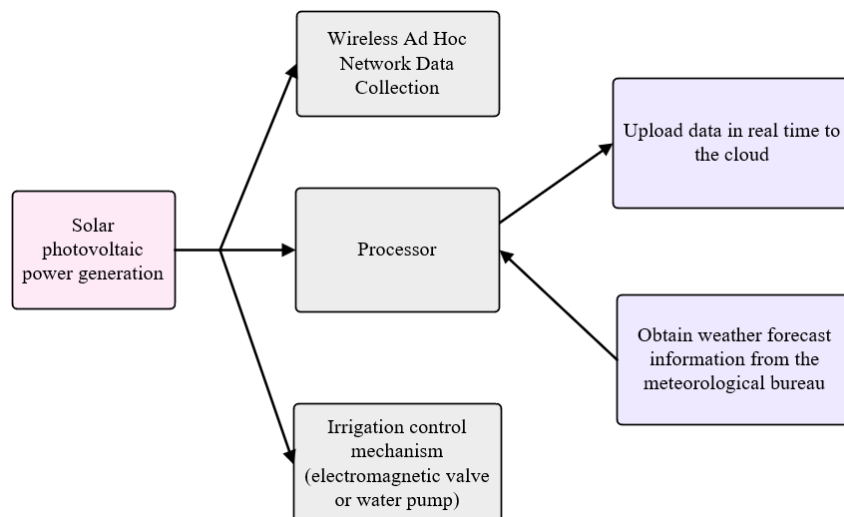


Figure 2 Structural Block Diagram of the Self-organizing Network Type Control System^[7]

The architecture of the intelligent irrigation management system based on the star network architecture is shown in Figure 3. Its core consists of two major modules: the field sensing layer and the remote management platform. The field sensing layer realizes environmental data collection and irrigation equipment control through the intelligent sensor node group and execution terminals deployed in the crop area. All terminal devices establish communication links with the central gateway through relay nodes.^[9] The central gateway uses GPRS wireless transmission technology to push the integrated field environment parameters (including soil moisture, temperature and humidity, etc.) and equipment status data to the wireless access base station. The control host of the management platform can obtain the on-site data in real-time through the serial communication interface (RS232).

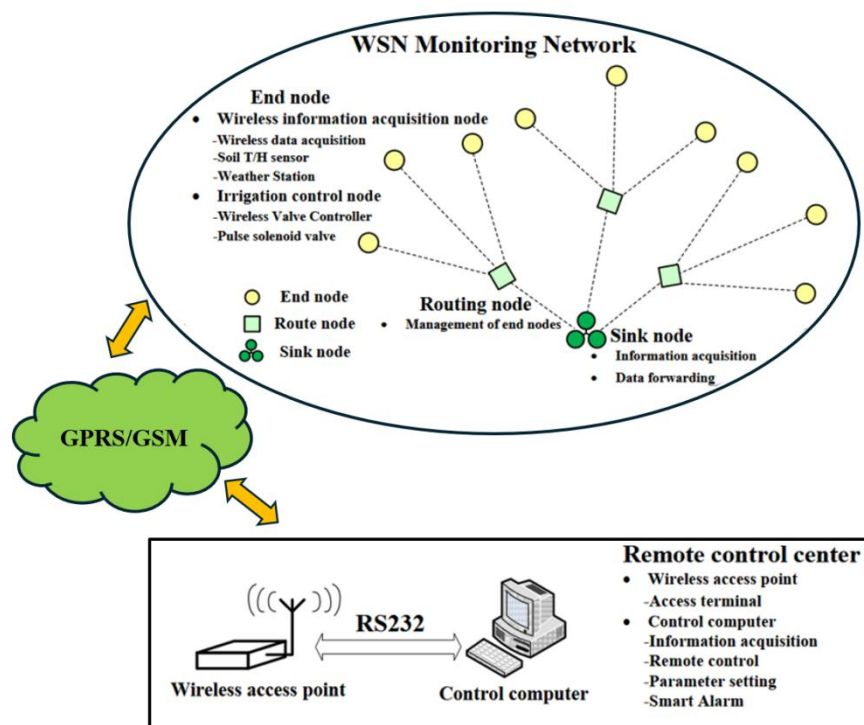


Figure 3 Architecture of wireless integrated irrigation control system^[9]

In terms of specific applications, Tian Yun et al. designed an agricultural irrigation system that uses a PLC combined with a frequency converter to achieve constant pressure and variable flow water supply. The system continuously collects the water pump flow rate and compares it with the set working pressure (0.25-0.35MPa), and changes the working frequency of the water pump motor in real-time to adjust the irrigation flow rate. Its flow chart is shown in Figure 4. The change of the

motor speed is achieved by changing the output frequency of the frequency converter. The output frequency of the frequency converter can be easily controlled by the analog quantity output by the PLC and the DA converter, with a fast response speed. The adjustment of the output frequency of the frequency converter by the PLC is controlled according to the actual value of the water outlet pressure of the pipe network. The pressure sensor can collect the actual water outlet pressure of the pipe network with a cycle of up to several tens of milliseconds, and the data is real-time, achieving the full-automatic real-time control of the system and avoiding the instability caused by users' negligent operations^[10]. Experiments have proven that this system can save 20%-69% more energy than the traditional mode, reducing both electricity consumption and labor costs^[10].

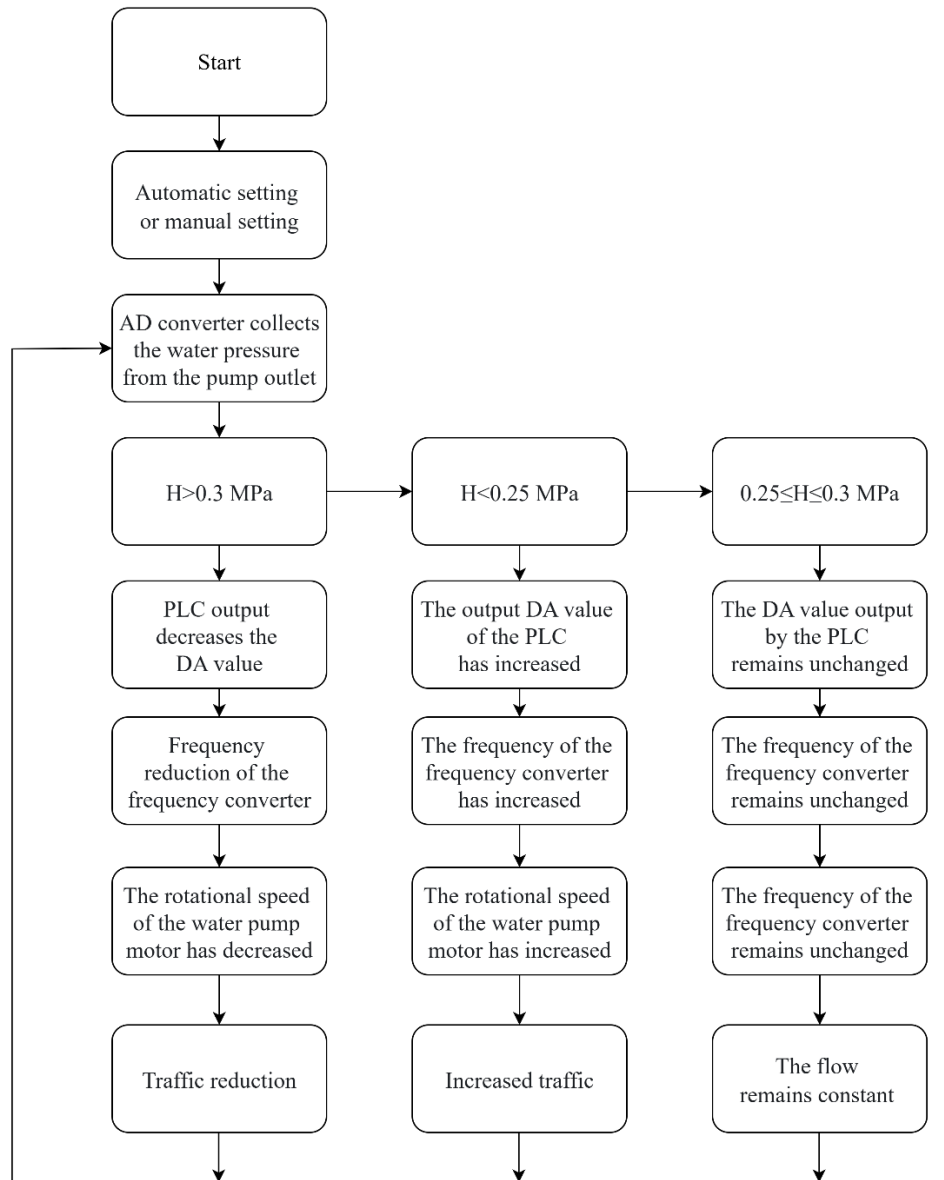


Figure 4 Flowchart of the control process^[10]

Guo Yingfang et al. elaborated on the basic principles of variable frequency speed regulation technology in detail, provided the basic schematic diagram, and derived from the speed formula of the asynchronous motor^[10,11]:

$$n = \frac{60 f (1 - s)}{p} \quad (1)$$

It shows that the output frequency of the frequency converter is adjustable, thus enabling continuous adjustment of the motor speed^[12]. This technology is applied to the speed regulation of water pump motors in agricultural irrigation. Energy savings of 20%-69% can be achieved according to the size of the water pump's outlet flow. For example, when the flow rate decreases from 0.9m³/h to 0.3m³/h, the energy-saving effect increases from 20% to 67%. The variable frequency speed regulation technology adjusts the speed of the water pump, causing the power consumption to decrease in a cubic relationship with the speed. It saves 40%-50% more energy compared to traditional valve control, indicating that the variable frequency speed regulation technology saves 20%-67% more energy than valve control under different flow rates^[11].

In addition, Wang Xiaojian and others introduced the 7890 series of variable-frequency constant-pressure water supply automatic control devices and the 789: series of variable-frequency constant-pressure water-saving irrigation automatic control devices they developed. These devices adopt AC variable-frequency speed regulation technology, adjust the speed of the water pump by changing the frequency of the motor power supply, and achieve constant-pressure variable-flow water supply. In actual projects, these devices can save 17% of electricity and 19% of water^[13]. Not only that, in mechanical systems such as pumping machines, the motor loss is reduced through VF-VR coordinated control (measured energy savings of 9%-23%), and the load torque is optimized by combining the kinematic model of the four-bar mechanism, enabling a single device to save more than \$2,300 in annual electricity costs^[14].

Variable-frequency speed-regulation technology is also applied to the energy conservation and consumption reduction of electromechanical equipment in agricultural irrigation pumping stations. By changing the input frequency of the motor, it breaks through the mechanical synchronization limitations of traditional fixed-frequency systems (such as decoupling the rotational speed of wind turbines from the power grid frequency), achieving a dynamic match between the equipment operation state and the power grid demand^[15]. In addition, in the asynchronous interconnection of power systems, the flexible connection of cross-regional power grids is achieved through a Variable-Frequency Transformer (VFT). Compared with the traditional HVDC scheme, the reactive power demand is reduced by 30% and the fault recovery time is shortened by 40%^[16]. By updating the pumping station equipment and introducing variable frequency speed regulation technology to optimize the operating conditions, the intelligent upgrade of irrigation management is achieved. Combining intelligent control methods such as PLC and the Internet of Things to form an efficient irrigation system further strengthens the energy conservation and consumption reduction effect^[17]. The solar photovoltaic water-lifting irrigation system can dynamically adjust the irrigation strategy according to the light intensity and crop water demand. The structural diagram of the photovoltaic grid-connected power station is shown in Figure 5. The maximum power point tracking technology is used to optimize energy utilization and improve the overall operating efficiency and economy of the system^[18].

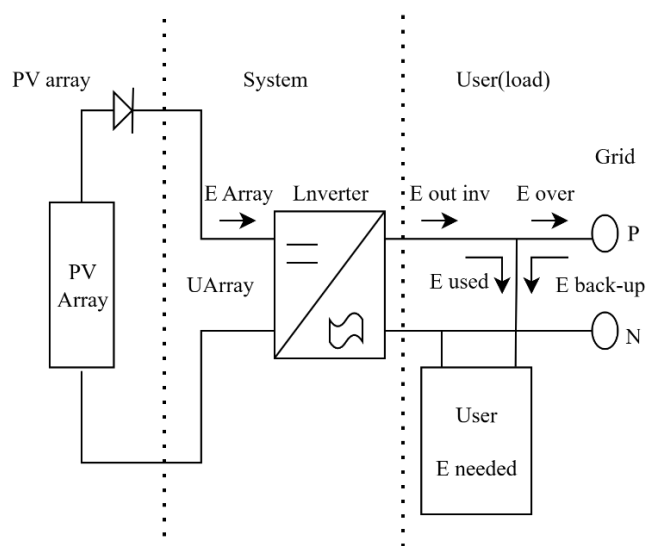


Figure 5 Structure Diagram of 100kW Photovoltaic Grid-connected Power Station^[18]

The wireless low-power irrigation controller adopts a solar-powered solution, establishing a stable communication link with the main control center through the ISM band. It has characteristics such as low power consumption, simple construction, and reliable operation, and performs outstandingly in cost control. This device breaks through the traditional control mode of computer plus software, supports the script technology to build a distributed irrigation control network, can work in coordination with mainstream configuration software, and quickly build an automated control system. In terms of human-machine interaction design, the low-cost model is equipped with a Chinese-character liquid-crystal display and physical buttons, powered by alkaline batteries, greatly reducing the complexity of on-site installation. The high-end ASE controller, through technological innovation, has achieved a leap in irrigation control from a single device to a system-level solution, meeting the diversified needs of modern agriculture for precision irrigation^[19].

2.2. The Contribution and Application of Automatic Control Technology Combined with Solar Energy in Energy Saving and Consumption Reduction of Agricultural Irrigation

In the field of agricultural irrigation, the self-control technology combined with solar energy, as an innovative self-control technology, is gradually demonstrating its huge potential in energy conservation and consumption reduction^[20,21]. This technology directly uses solar photovoltaic panels to convert solar energy into electrical energy, driving water pumps for irrigation, achieving renewable energy utilization and automated control of the irrigation process^[22].

In the Dashishan area of Guangxi, solar photovoltaic water pumping technology has brought revolutionary changes to agricultural irrigation. Wu Weixiong and others pointed out that this technology generates electricity through a 15kW photovoltaic panel, with an average daily radiation of 248W/m² (in August). As shown in Figure 6, this system effectively drives the water pump to lift water, solving the irrigation problems in areas lacking water and electricity. In Zhenliang Village, Silin Town, Tiandong County, Guangxi, the solar photovoltaic water pumping station has successfully irrigated crops such as pitayas, with an average daily power generation of 9kW·h and an effective power generation of 8kW·h. The application of this technology not only improves the irrigation efficiency but also promotes agricultural production increase and income growth, increasing the single-yield of pitayas by 40.5% and the per-mu yield increase by more than 1000 yuan^[23]. The advantages of combining automatic control technology with solar energy lie in its independence from the power grid, flexibility, wide adaptability. It is especially suitable for remote areas without electricity, providing reliable power support for agricultural irrigation^[22].

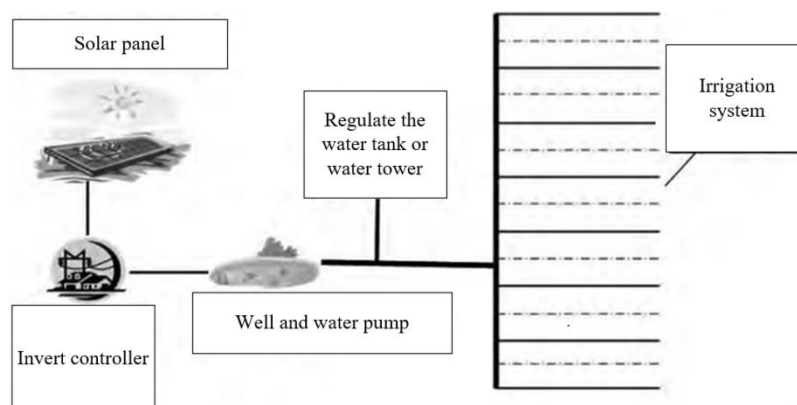


Figure 6 Composition Diagram of Solar Photovoltaic Irrigation Project System^[23]

Taking the solar-powered mobile sprinkler irrigation unit independently developed by Liu Kenan et al. as the research platform, this paper deeply explores the matching design between the walking power demand of the solar-powered sprinkler irrigation unit and the photovoltaic power. As shown in Figure 7, this sprinkler irrigation unit is equipped with a 70-meter-long water-conveying truss, with a maximum flow rate of 48 m³/h, a maximum walking speed of 1 m/min, and is powered by 260-watt solar panels with a system voltage of 72V. Through experimental tests, the rationality and effectiveness of the design of the solar-powered system, as well as the high reliability of the photovoltaic power-supply system, have been verified^[24]. This technology combines solar energy technology with mobile sprinkler irrigation technology, improving irrigation efficiency, saving energy, providing new ideas for the solarization of mobile sprinkler irrigation units, and demonstrating the broad application prospects of self-control technology combined with solar energy in the field of agricultural irrigation^[25].

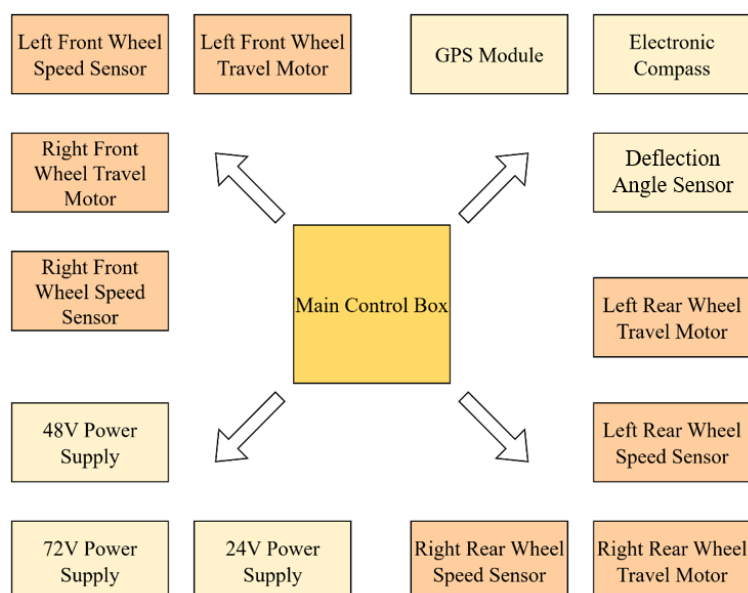


Figure 7 Layout of Sprinkler System

At the Zhejiang Provincial Irrigation Experiment Central Station, through comparative analysis, the economic, energy-saving and emission-reduction advantages of photovoltaic pumping stations were demonstrated. The research used a 15kW photovoltaic panel to drive a 10m³/h water-lifting pumping station. The results showed that compared with the grid-powered pumping station, the photovoltaic pumping station can save 4500kW·h of electricity annually, saving about 39.85% of the electricity cost; compared with the diesel-powered pumping station, it can save 1680L of diesel annually, saving about 58.65% of the expenses^[26].

Hoque et al. used four different sensors, such as temperature sensor, light sensor, humidity sensor, and soil moisture sensor, to continuously collect data on these four key parameters. The main device

of the greenhouse monitoring and control system is Arduino Uno R3, which is used to store the data collected by the above-mentioned different sensors and process this data. An Android application was also developed to monitor and control greenhouse information anywhere in the world and at any time via a smartphone. In addition, if there are any changes inside the greenhouse system, the users of the greenhouse system will receive notifications via text messages, which is accomplished by the GSM module. Moreover, the entire greenhouse system is powered by a solar energy system, which includes solar panels and rechargeable batteries. Here, the rechargeable batteries are used to store electrical energy and provide a continuous power supply to different devices of the greenhouse system^[27]. The system can play a huge role in the field of solar irrigation. Figure 8 below shows the basic block diagram of the greenhouse monitoring and control system:

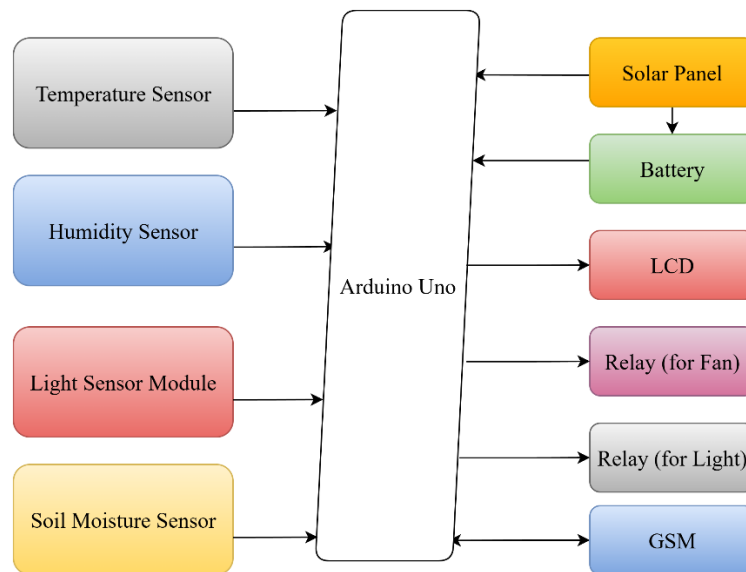


Figure 8 Block Diagram of the Greenhouse Monitoring System^[27]

Camacho E F, Berengue I M, et al. systematically elaborated on the control strategies and technical challenges of parabolic trough collector (PTC) power plants. Based on practical cases such as the ACUREX power plant in Spain and the Mojave project in the United States, the literature revealed the core control challenges of PTC power plants: not only to achieve precise tracking of the sun's trajectory through the collector structure (Figure 9), but also to dynamically adjust thermodynamic variables such as the outlet temperature^[28]. At the technical method level, Model Predictive Control (MPC) has been proven to be a key means. Through the performance comparison of the Mojave power plant under sunny and cloudy weather, the ability of MPC to maintain system stability by adjusting the main pump speed is verified. In addition, the distributed cluster control strategy divides the collector field into independent units and combines the hydraulic model to optimize the flow distribution, effectively solving the thermal balance problem of large-scale power plants^[28]. Through this document, new ideas for power supply in solar irrigation can be opened up.

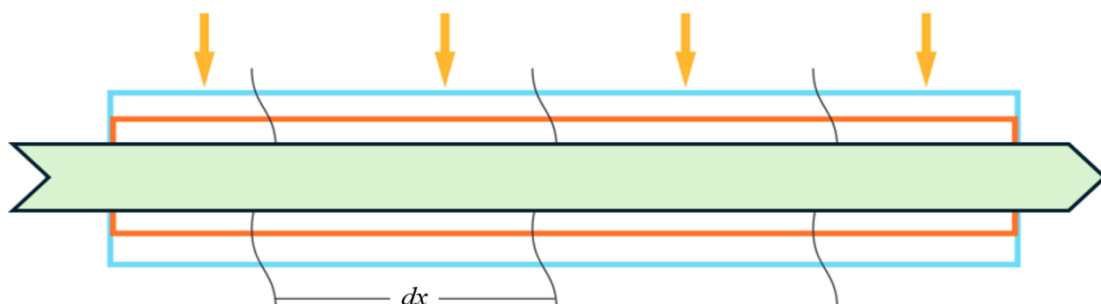


Figure 9 Metal Pipe of the Parabolic Trough Loop^[28]

Christopher I W et al. introduced a low-cost automatic solar tracking system (ASETS). The core innovation of this system lies in using the sun as a dynamic reference source, and achieving the vertical alignment of the solar panel with the sun through hardware collaboration (Figure 10, the schematic diagram of the system architecture shows the connection relationship among the solar panel, sensors, and motors). The system uses a photosensitive resistor array as an active sensor to continuously monitor changes in the direction of sunlight. Its serpentine plastic-coated structure enhances the sensitivity of light intensity perception. When the position of the sun deviates, the resistance difference of the photosensitive resistors triggers the control circuit. The signal is amplified by a transistor to drive the relay, and then the gear motor is controlled to adjust the angle of the solar panel, forming a closed-loop control chain of "perception-decision-execution"^[29]. Experimental data shows that this design increases the energy output by 25%-30%, while its own power consumption is only 0.5W, which is significantly better than the traditional fixed system^[29]. This solar-centered tracking mechanism, combined with low-power hardware and efficient control algorithms, provides an economically feasible solution for distributed solar irrigation technology^[25].

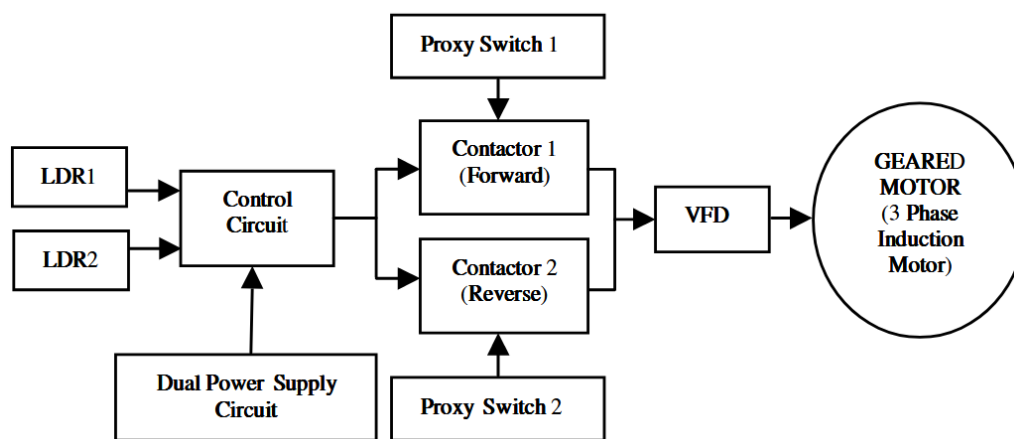


Figure 10 Automatic Solar Tracking System^[29]

Pei Jiuling et al. designed a solar-powered automatic drip irrigation system. The system uses a 1.5kW photovoltaic water pump and combines with advanced maximum power point tracking technology to achieve maximum utilization of solar energy. This system not only solves the irrigation problems in areas lacking water and electricity, but also improves the utilization rate of irrigation water and reduces environmental pollution^[30]. The application of solar photovoltaic drip irrigation technology provides an efficient irrigation solution for regions rich in solar energy resources and promotes the sustainable development of agriculture^[21,31]. Liu Xiaochu et al. proposed an intelligent irrigation system with complementary power supply of solar energy and mains electricity. The system combines a 500W polycrystalline solar panel and mains power supply, and realizes intelligent irrigation through a PLC control system. In the application case of the Maoming citrus industrial park, the system preferentially uses photovoltaic power supply, reduces the consumption of mains electricity, and reduces the irrigation cost^[32]. The advantages of this system lie in its improvement of the reliability and economy of the irrigation system. It is particularly suitable for areas with complex geographical, climatic and hydrological environments such as mountainous and hilly regions, providing a more flexible and economical solution for agricultural irrigation.

3. The challenges faced in applying automatic control technology in agriculture for the purpose of energy conservation and consumption reduction

Variable frequency speed regulation technology, as an advanced technology that achieves high-efficiency energy conservation by adjusting the frequency of the input power of the motor, shows great application potential in agricultural water-saving irrigation projects. However, in the actual process of promotion and application, this technology still faces some bottlenecks, mainly including

equipment aging and low efficiency, mismatch between technology and demand, high initial investment cost, as well as technical complexity and maintenance difficulty. Specifically, in some areas, the irrigation facilities are severely aged, and the electromechanical equipment has been running for too long, resulting in low irrigation efficiency and high energy consumption. At the same time, traditional water pump motors are usually designed to operate at a fixed speed and cannot adjust the flow rate according to actual needs, causing energy waste. In addition, the variable frequency speed regulation system needs to be equipped with devices such as inverters and programmable controllers, and the initial investment cost is relatively high, which restricts its promotion and application in less-developed areas. Finally, variable frequency speed regulation technology involves knowledge in multiple fields such as power electronics and automatic control, with high technical complexity, and the maintenance and upkeep of the system also require professional technicians, increasing the operation and maintenance difficulty and cost.

Automatic control technology combined with solar energy, as an innovative approach that combines renewable energy and modern agricultural irrigation, has received widespread attention in recent years. However, in practical applications, this technology still faces some bottlenecks. The main bottlenecks include high purchase cost, dependence on sunlight, high energy storage cost, immaturity of technology and standardization issues, as well as geographical and environmental limitations. Specifically, the purchase cost of solar photovoltaic irrigation systems, especially the core components such as solar panels and inverters, is significantly higher than that of traditional irrigation systems, which increases the initial investment burden on farmers or agricultural enterprises. At the same time, this system is highly dependent on sunlight, and its power-generation efficiency is significantly affected by weather conditions. In cases of insufficient sunlight, the irrigation guarantee rate of the system will decrease. In addition, in order to ensure irrigation can still be carried out when sunlight is insufficient, energy storage devices usually need to be configured, but the cost of energy storage devices is high, and the energy storage capacity is limited. In terms of technology, the combination of automatic control technology and solar energy is not yet mature in some fields, resulting in uneven product quality in the market. Finally, the application effect of this system is also affected by geographical location and environmental conditions. For example, in areas with insufficient light resources or complex terrain, the system performance may be greatly reduced.

4. Summary and Prospect

At present, the development trend of precision irrigation control technology has become increasingly prominent. The degree of attention it receives in research can be seen from the sharp increase in the number of academic publications in recent years, which has also prompted researchers in the field of agricultural engineering to focus on this direction for in-depth exploration. In the current research on agricultural irrigation automatic control technology, although the core applications related to water-saving and efficiency-increasing, smart farms, sustainable resource utilization, and precision agriculture have been elaborated in detail, under the technological trend of the comprehensive development of smart agriculture, it is still necessary to further explore the integration and innovation points of this technology with cutting-edge fields such as artificial intelligence, edge computing, and multi-source energy collaboration. A new round of innovation in automatic control technology is constantly driving agricultural engineers to study intelligent adaptation solutions suitable for regional planting, heterogeneous soil, and multi-climate scenarios. Through a review of the technology integration of agricultural irrigation automatic control systems, the following core insights can be summarized:

1. In agricultural irrigation, the efficient utilization of water resources is achieved through stepless speed regulation, with PLC and frequency converters working in coordination. The 7890 series frequency conversion device developed by Wang Xiaojian adopts AC frequency conversion speed regulation technology, achieving a power saving of 17% and water saving of 19% in practical projects. By combining PLC with the Internet of Things, a highly efficient irrigation system is formed. The

team led by Guo Yingfang verified that when the flow rate drops from 0.9m³/h to 0.3m³/h, the energy-saving effect increases from 20% to 67%. The technology integrates the star architecture of the Internet of Things, collects data through intelligent sensing nodes, and the central gateway pushes the data to the management platform via GPRS, forming a "perception-decision-execution" closed loop. The frequency conversion technology is applied to the electromechanical equipment of agricultural irrigation pumping stations to improve the matching efficiency of operating conditions. In addition, the intelligent valve control system uses a fuzzy control algorithm to collect soil temperature and humidity data in real-time to achieve precise irrigation. The combination of Internet of Things technology enables remote monitoring, and the solar-powered design reduces operating costs. The self-organizing network structure integrates photovoltaic power supply and meteorological data analysis, supporting low-power networking.

2. The technology combines with solar energy. The solar photovoltaic panels directly convert solar energy into electrical energy to drive the water pump for irrigation. The low-cost automatic solar tracking system (ASETS) senses the light intensity difference through the photosensitive resistor array, drives the gear motor to adjust the angle of the battery panel to achieve vertical alignment with the sun. Its energy output is increased by 25%-30%, and its own power consumption is only 0.5W, with a 30% increase in efficiency at noon. The control circuit amplifies the signal through transistors to drive the relay, controlling the forward and reverse rotation of the gear motor to ensure real-time capture of the maximum light intensity. The contactor realizes the on-off of the motor power supply. Combined with the mechanical structure of the gear motor, it supports the flexible rotation of the battery panel. The inductive proximity sensor prevents over-limit. The solar-utility complementary system switches between a 500W polycrystalline silicon photovoltaic panel (annual attenuation rate < 2%) and 220V utility power, and reduces costs by combining with the PLC control strategy. The solar-utility complementary system switches between a 500W polycrystalline silicon photovoltaic panel (annual attenuation rate < 2%) and 220V utility power, and reduces costs by combining with the PLC control strategy.

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