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Research on the Green Path of Building Electrical Engineering in the Context of Digitalization

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Abstract

In today's digital era, the greening of building electrical systems has become a crucial path for the sustainable development of the construction industry. Judging from the current research status at home and abroad, although certain achievements have been made, there are still many areas that need further exploration. Digital technologies have brought transformative opportunities to building electrical systems. In the field of intelligent lighting, they can achieve precise dimming and scene adaptive control; in the application of high-efficiency and energy-saving equipment, their performance can be optimized with the help of digital monitoring and regulation; after the digital upgrade of energy management systems, refined energy consumption analysis and intelligent dispatching can be accomplished; in the process of integrating renewable energy with building electrical systems, digital technologies can help solve the problems of intermittency and stability. However, this process is faced with challenges such as technology integration, cost control, standards and regulations, and user awareness. Looking ahead, with technological innovation and policy promotion, the greening of building electrical systems will thrive in the directions of intelligence, high efficiency, and synergy, laying a solid theoretical and practical foundation for the sustainable development in the construction field.

Keywords

Digitalization, Building Electrical Engineering, Greening.

1. Introduction

In the context of the era when global attention is highly focused on sustainable development and environmental protection, the construction industry has drawn significant attention due to its huge scale of energy consumption. The green transformation of its electrical systems has already become an urgent and crucial task. With the surging wave of digitalization, it is like a key opening the door to a new era, pioneering unprecedented innovative paths for the greening of building electrical systems. Through the comprehensive application of digital means, it is possible to conduct precise and meticulous control over building electrical equipment at the micro level, carry out real-time, efficient, and intelligent monitoring of their operating status, and promote the optimized operation of the entire electrical system based on massive data and intelligent algorithms. In this way, not only can the energy consumption of the construction industry in terms of electricity be significantly reduced, alleviating the severe situation of the current energy shortage, but also the environmental pollution problems caused by excessive energy use can be remarkably mitigated, thus contributing to the protection and restoration of the global ecological environment and creating a greener, healthier, and more sustainable living and working environment for mankind.

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2. Current Research Status of Building Electrical Greening at Home and Abroad

2.1. Current Research Status Abroad

Foreign countries started their research on building electrical greening relatively early and have achieved fruitful results. In Europe, many research institutions are dedicated to the development of intelligent building control systems. For example, the Fraunhofer Society in Germany has conducted in-depth research on Building Energy Management Systems (BEMS). Through digital technology, it has realized the comprehensive allocation and optimal utilization of various energies within buildings. Its research findings have been applied in some newly built green buildings, effectively reducing building energy consumption. The United States is in a leading position in the world in terms of the integration of renewable energy and building electrical systems. The research team at Stanford University focuses on the highly efficient integration technology of solar photovoltaic power generation systems in buildings. By using digital modeling and simulation technologies, they optimize the installation positions and angles of photovoltaic panels as well as their matching relationships with building electrical systems, significantly improving the efficiency of photovoltaic power generation and its proportion in building energy supply. In addition, some large international enterprises such as Siemens and Schneider have also actively engaged in the research and development of products related to building electrical greening, launching a series of digital intelligent electrical equipment and energy management solutions, which have been widely applied on a global scale.

2.2. Current Research Status in China

The research on building electrical greening in China has developed rapidly in recent years. Many universities and scientific research institutions have successively carried out relevant research projects. The Building Energy Conservation Research Center of Tsinghua University has conducted in-depth exploration on the energy consumption monitoring and analysis technologies of building electrical systems. It has developed a building electrical energy consumption analysis platform based on big data, which is capable of real-time collection, analysis and early warning of the electrical energy consumption data of large buildings, providing strong data support for the energy-saving renovation of building electrical systems. At the enterprise level, technology enterprises such as Huawei have also set foot in the field of building electrical digitization, devoting themselves to constructing intelligent building electrical network architectures, enhancing the communication efficiency and stability of building electrical systems, and promoting the collaborative work among various electrical devices to achieve efficient utilization of energy. Meanwhile, with the policy promotion of the state for the development of green buildings, certain progress has also been made in the formulation of green building electrical standards in China, providing regulatory basis for the practice of building electrical greening. However, compared with foreign countries, there is still a certain gap in the original research on building electrical greening technologies and the development of high-end products in China, and the maturity of the integrated application of technologies also needs to be further improved. In addition, many green materials, process technologies, etc. have been successively used in the field of electrical green energy-saving design, which is one of the effective measures for the construction industry to implement relevant international policies. [1]

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3. Application Status of Digital Technologies in the Greening of Building Electrical Systems

3.1. Widespread Application of Intelligent Lighting Systems

Digital technologies have provided solid support for the widespread popularization of intelligent lighting in the field of building electrical systems. The core operating mechanism lies in the close connection between light sensors, body sensors and intelligent lighting controllers. The light sensors are like sensitive visual nerves, continuously capturing the slightest changes in the ambient light intensity; the body sensors are like precise motion detectors, monitoring the movement tracks of personnel in real time. The two work in collaboration and quickly transmit the sensed information to the intelligent lighting controllers. When there is abundant natural light outside, the lighting controller will automatically trigger commands to dim or even turn off the lighting fixtures, making full use of natural lighting and reducing power consumption. And after people leave a specific area, the controller activates the delayed shutdown function based on the signals from the body sensors, skillfully avoiding the phenomenon of lights being left on due to human negligence, thus eliminating unnecessary energy wastage.

Taking large commercial buildings as an example, the advantages of intelligent lighting systems are even more prominent. Due to the diverse functional zoning of commercial buildings, such as shopping areas, office areas, and leisure areas, and the varying lighting requirements at different times, intelligent lighting systems can fully demonstrate their capabilities. They can meticulously formulate highly targeted and personalized lighting strategies based on the unique usage functions of each area and the actual needs at different times. With the unified allocation and management of the central control system, these strategies can be implemented precisely. This not only significantly improves the comfort level of lighting, creating a suitable light environment for consumers and staff, but also achieves remarkable energy-saving results, enabling energy savings of approximately 30% - 50%. In this way, empowered by digital technologies, intelligent lighting systems play an extremely important role in promoting the greening process of building electrical systems and become a crucial force in building energy conservation and emission reduction.

Energy conservation is a very complex issue, especially the energy-saving design of building electrical lighting. It is essential to reasonably select lighting methods, adopt advanced design technologies, research and promote new technologies and products, utilize electrical energy efficiently, save electrical energy to the greatest extent possible, and construct green ecological projects. [2]

3.2. Digital Upgrading of the Energy Management System

In the journey towards the greening of building electrical systems, the digital energy management system has already become an indispensable core supporting force. Its operation begins with the comprehensive and real-time collection of consumption data of various energies such as electricity, water, and gas inside the building by means of a series of advanced devices like smart meters and data collectors. These data are then gathered together through an efficient transmission network.

Big data analysis technology is like a wise housekeeper with extraordinary insight, delving into the mysteries hidden behind these massive amounts of data. It can accurately depict the trend of energy consumption, clarify the detailed distribution of energy consumption in each area and for each type of equipment, as well as the specific energy consumption situation of each individual piece of equipment. Based on these detailed and intuitive information, managers are like holding a precise navigator, being able to quickly identify those high-energy-consuming equipment like "electric tigers" and the peak hours when energy consumption surges like tides.

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With clear targets in sight, highly targeted energy-saving strategies can be formulated accordingly. For example, the operation schedule of equipment can be cleverly optimized to avoid the electricity peak hours, or the temperature setting range of air conditioners can be reasonably adjusted to reduce energy consumption while ensuring comfort.

Meanwhile, the digital platform is like a powerful energy control center, endowing managers with the superpower of remote monitoring and dynamic management of energy usage. No matter where they are, they can have a clear understanding of the building's energy usage situation just by clicking the mouse or swiping the screen. Once there are loopholes of energy waste or abnormal situations, the system can quickly detect them and send out alarms in a timely manner, prompting relevant personnel to take immediate measures to handle them. Such a refined and scientific management mode is like injecting powerful impetus into building energy management, significantly promoting a substantial increase in energy utilization efficiency and laying a solid foundation for the realization of building electrical greening.

3.3. Digital Integration of Renewable Energy and Building Electrical Systems

In the process of building electrical greening, digital technologies help renewable energy to integrate better. Taking the solar photovoltaic power generation system as an example, through the digital photovoltaic monitoring system, parameters such as the power generation, voltage, and current of solar panels can be monitored in real time. Data analysis is used to optimize the installation settings such as the orientation and inclination angle of the photovoltaic panels to improve the power generation efficiency. Moreover, the connection between solar power generation and the building electrical system is coordinated and controlled through digital intelligent inverters and energy management systems. Solar power is reasonably distributed according to the electricity load situation of the building to realize the storage of surplus electricity or grid connection. In terms of wind power generation, digital technologies can also be used to monitor the running status of wind turbines, wind speed, wind direction and other data to ensure their stable and efficient operation and effective integration with the building electrical system, increasing the proportion of renewable energy in the building energy supply and reducing the dependence on traditional fossil fuels.

3.4. Digital Monitoring, Operation and Maintenance of Electrical Equipment

Digital technologies have brought a new model for the monitoring, operation and maintenance of building electrical equipment. Various electrical equipment such as transformers and distribution cabinets are equipped with multiple sensors like temperature sensors and current transformers. These sensors convert the operating parameters of the equipment into digital signals and transmit them to the monitoring platform. Through real-time analysis of these data, potential hidden faults of the equipment can be detected in advance. For example, an abnormal increase in the oil temperature of a transformer may indicate an internal fault, and timely warnings can prevent the occurrence and expansion of faults. Meanwhile, predictive maintenance technology based on big data is gradually emerging. By in-depth learning of the historical operating data of the equipment, a fault prediction model is established to predict the time and type of possible faults of the equipment, so as to reasonably arrange maintenance plans, reduce the downtime losses caused by sudden faults, extend the service life of the equipment, improve the overall reliability and stability of the building electrical system, and ensure its green and efficient operation.

3.5. Digital Collaboration in Building Electrical Design and Construction

During the building electrical design stage, digital design software such as CAD, EPLAN and BIM technology are widely used. Designers use these software to draw schematic diagrams of electrical systems, select equipment, design wiring, etc. Meanwhile, they can conduct collaborative design with other majors such as architecture, structure, and water supply and

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drainage. Through the BIM model, the design information of each major is integrated on the same platform, enabling the early detection and resolution of collision and conflict problems between electrical pipelines and other majors, optimizing the design scheme and reducing design changes during the construction stage. During the construction process, digital technologies continue to play a role. Detailed construction plans are formulated through project management software, and the installation quality of electrical equipment and potential construction safety hazards on the construction site are monitored in real time by using digital monitoring equipment. Construction workers can carry out precise construction according to digital construction drawings and models, improving construction efficiency and quality, and ensuring that the design concept of building electrical greening is effectively implemented in the construction link. We should utilize advanced scientific technologies and concepts to effectively promote it to move towards the path of intelligence and environmental protection to the greatest extent. [3] By formulating effective energy-saving schemes for building electrical equipment, we can ensure that during the construction and application of buildings, positive contributions can be actually made to energy conservation and emission reduction work, so as to promote the standardized and green development of the building industry, thus enabling building applications to exert better economic and social benefits. [4]

4. Challenges Faced by the Greening of Building Electrical Systems

4.1. Difficulties in Technological Innovation and Integration

The greening of building electrical systems requires the integration and innovative application of multiple advanced technologies. For example, the integration of renewable energy generation technologies such as solar and wind power in buildings faces problems of intermittency and poor stability. Although energy storage technologies can alleviate this dilemma, current energy storage devices have high costs, limited energy density, and short lifespan, which limit their large-scale application. In addition, there are also challenges in the collaborative work between different green electrical technologies. For example, the docking of smart grids and distributed energy systems requires precise control strategies and communication protocols to achieve efficient energy scheduling and management. At present, the relevant technologies still need to be improved.

4.2. Pressure from Initial Investment Costs

The progress of building electrical greening is often hindered by the excessively high upfront investment costs. In the process of achieving this goal, a large amount of funds are required for the procurement and installation of high-efficiency and energy-saving electrical equipment, renewable energy generation devices, and intelligent control systems. Taking the solar photovoltaic system as an example, although from a long-term perspective, its operating costs in the subsequent stage are relatively low and can save users a lot of money, at the initial stage of the project, the amount of funds required to purchase core devices such as photovoltaic panels and inverters is quite huge. For those building projects with relatively limited budgets, such a high initial expenditure is undoubtedly an unbearable heavy burden. In addition, new green electrical technologies are in the process of continuous research and development and innovation. The high research and development costs incurred during this period will often be apportioned to a certain extent to the selling prices of related products, further driving up the product prices. This situation undoubtedly worsens the situation, greatly increasing the economic pressure on building electrical greening in the initial investment stage, and consequently causing many construction parties to adopt a cautious wait-and-see attitude when facing greening renovation projects and not dare to get involved easily.

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4.3. Insufficient Standards, Regulations and Policy Support

Currently, there are still many deficiencies in the standards and regulations in the field of building electrical greening that urgently need to be improved. Due to significant differences in geographical environment, climatic conditions and economic development levels among different regions, and different functional uses, scales and structural forms of different types of buildings, there is a lack of a unified and clear national standard system in the design, installation and acceptance of green electrical systems. This current situation makes the practice of building electrical greening like walking in a fog, lacking precise and effective guidance and regulatory constraints, and it is difficult to ensure the high-quality implementation of the work.

At the same time, the support from the policy level for building electrical green化 is also relatively weak, and there are obvious loopholes in the incentive mechanism. Compared with traditional building electrical systems, green building electrical systems do not enjoy sufficient tax reduction and exemption in tax preferential policies; in terms of financial subsidies, the amount of financial support is limited; in the electricity price policy, there is a lack of attractive preferential measures or subsidy mechanisms. As a result, construction units will have concerns when weighing costs and benefits, and equipment manufacturers also lack the motivation for innovation and promotion due to limited market demand. It is difficult to fully stimulate the enthusiasm of all parties to participate in the process of building electrical greening, which seriously hinders the rapid development of this green cause.

4.4. Increased Complexity of Operation and Maintenance Management

The structure of green building electrical systems is complex, involving a variety of new types of equipment and technologies, which brings huge challenges to operation and maintenance management. Operation and maintenance personnel not only need to master the maintenance knowledge of traditional electrical equipment but also need to be familiar with the operating principles and maintenance requirements of renewable energy power generation equipment and intelligent control systems. For example, the blade maintenance of wind turbines, the cleaning and fault detection of photovoltaic panels, etc. all require professional skills and equipment. Moreover, software upgrades and data security management of intelligent electrical systems are also new topics in operation and maintenance. Once the operation and maintenance management is not proper, it is easy to cause frequent equipment failures and a reduction in system operation efficiency, affecting the overall benefits of building electrical greening.

4.5. Obstacles in User Cognition and Behavioral Habits

At present, many users have cognitive deficiencies in building electrical greening. On the one hand, they know very little about the correct operation methods of energy-saving equipment and intelligent control systems. Take the intelligent lighting system as an example. Its dimming function can flexibly adjust the brightness according to the ambient light and personnel activities to achieve energy-saving optimization. However, many users leave this function unused due to unfamiliarity, resulting in high lighting energy consumption. Similarly, for air conditioners, ignoring their energy-saving settings, such as reasonable temperature settings and the use of sleep mode, causes unnecessary energy consumption. On the one side, the traditional electricity consumption behavioral habits formed by users over a long period are deeply ingrained. Phenomena such as leaving electrical appliances in standby mode for a long time and frequently using high-power electrical appliances when unnecessary are common. These behaviors are completely contrary to the goal of high-efficiency energy utilization pursued by building electrical greening. Although green electrical technologies have been applied, it is difficult to fully release their energy-saving effects, which greatly hinders the wider

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promotion of the concept of building electrical greening and delays the pace of electrical green transformation of the entire building industry.

5. Digital Empowerment for the Greening of Building Electrical Systems

5.1. Overcoming Difficulties in Technological Innovation and Integration

In the wave of digitalization, to address the challenges of technological innovation and integration, it is necessary to fully utilize digital means. Establish a digital R & D collaborative platform to integrate the R & D resources of green building electrical technologies on a global scale. Utilize big data to analyze the power generation data and fluctuation patterns of renewable energies such as solar and wind power in different regions, providing a basis for the R & D of high-efficiency power generation technologies adapted to local resource characteristics. For example, by analyzing massive meteorological data and power generation data, optimize the tracking algorithm of solar photovoltaic panels so that they can track the sun's trajectory more accurately and improve power generation efficiency. In terms of energy storage technology R & D, apply computer simulation and digital modeling technologies to accelerate the screening of new energy storage materials and the optimization of battery structure design, reducing R & D costs and cycles. For the docking of smart grids and distributed energy systems, develop a digital control strategy and a standard library of communication protocols, and use simulation software for virtual docking tests to detect and solve compatibility problems in advance, promoting the digital integration and innovative application of multiple green electrical technologies and constructing an intelligent, efficient, and stable ecological system of building electrical green technologies. The automation control technology of electrical engineering also needs to be continuously improved and innovated, which is the foundation for achieving the goals of green buildings and intelligent buildings and can effectively promote the sustainable development of China's construction industry. [5]

5.2. Alleviating the Pressure of Initial Investment Costs

To relieve the pressure of initial investment costs, digital finance and cost management tools can play a crucial role. Build a digital green finance service platform and utilize blockchain technology to ensure the authenticity and transparency of project information, reducing the risk assessment costs of financial institutions. Thus, more convenient and low-cost financing channels can be provided for building electrical greening projects, such as precisely matching the issuance of green bonds with the needs of investors or offering personalized green loan schemes based on the digital assessment of projects. In terms of cost structure optimization, with the help of a digital supply chain management system, seamless docking between green electrical equipment manufacturing enterprises, raw material suppliers, and logistics enterprises can be achieved, reducing procurement and logistics costs. Meanwhile, by using a digital cost prediction model, the full life cycle costs such as equipment leasing, operation, and maintenance can be accurately analyzed and simulated during the project planning stage, helping construction parties formulate the optimal investment decisions. In this way, the economic feasibility and attractiveness of building electrical greening projects can be enhanced by digital means.

5.3. Improving Standards and Regulations and Strengthening Policy Support

During the process of improving standards and regulations and strengthening policy support, digital technologies can provide powerful assistance. Establish a national digital standard library for building electrical greening, integrate various standard and regulation documents, and utilize artificial intelligence technology to analyze electrical greening cases of different regions and different types of buildings, extract common and differentiated indicators, and provide references for formulating more targeted and scientific design, installation, and

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acceptance standards. In terms of policy support, build a digital policy supervision and incentive platform, use big data to monitor the greening process and energy-saving effects of building electrical projects, and achieve precise supervision of policy implementation. For example, through the comparative analysis of smart meter data and building energy consumption models, evaluate whether the project meets the requirements of energy-saving standards, and based on this, grant corresponding tax preferences, financial subsidies, or electricity price adjustments to ensure the fairness and effectiveness of policy incentives and promote the orderly development and technological innovation of the building electrical greening market.

5.4. Coping with the Increased Complexity of Operation and Maintenance Management

To address the challenge of the increased complexity of operation and maintenance management, it is necessary to construct a digital operation and maintenance management system. Firstly, utilize the Internet of Things technology to assign digital identities to the electrical equipment in green buildings, enabling the real-time collection and uploading of equipment operation data. Based on these data, establish a digital operation and maintenance knowledge base. Employ machine learning algorithms to study the equipment fault data, generate fault prediction models, issue early warnings for potential equipment faults, and automatically dispatch maintenance tasks and repair suggestions to operation and maintenance personnel through the intelligent operation and maintenance platform. For example, by analyzing the vibration data of wind turbine blades, predict possible cracks or damages on the blades. Meanwhile, develop digital remote operation and maintenance tools, such as operation and maintenance operation manuals assisted by virtual reality (VR) or augmented reality (AR) technologies, allowing operation and maintenance personnel to conduct equipment inspections, fault diagnoses, and repair instructions remotely, reducing the difficulty and cost of operation and maintenance. In addition, utilize a digital security management system to ensure the software upgrade and data security of the intelligent electrical system, prevent the risks of cyberattacks and data leakage, and ensure the stable and efficient operation of the building electrical greening system.

5.5. Breaking Down the Barriers of User Cognition and Behavioral Habits

In terms of breaking down the barriers of user cognition and behavioral habits, digital publicity and interactive design are of crucial importance. Create a digital green building electrical publicity platform, such as developing dedicated mobile applications or WeChat mini-programs. Disseminate knowledge about building electrical greening and energy-saving techniques in the form of short videos, animations, and interactive games to enhance user participation and learning interest. Utilize digital devices such as smart meters and smart sockets to collect user electricity consumption data, analyze user electricity consumption behavioral habits, and provide users with personalized energy-saving suggestions and electricity consumption reports through the platform. For example, notify users that the energy consumption of their air conditioners is too high during specific time periods and suggest adjusting the temperature settings. In terms of equipment interactive design, adopt digital human-machine interaction interfaces (HMI), such as voice control of intelligent lighting systems, remote control via mobile APPs, and automated scene settings, making the operations more convenient and intuitive. Let users develop good electricity consumption habits in a relaxed and pleasant experience, promoting the concept of building electrical greening to penetrate into users' lives and achieving the goal of nationwide participation in the practice of building electrical greening.

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6. Conclusion

In the context of digitalization, the greening of building electrical systems has enormous potential and broad development prospects. Through the promotion of multi-dimensional and comprehensive innovation paths, such as the in-depth application of intelligent lighting systems, which can automatically and precisely adjust the lighting brightness and mode according to the ambient light and personnel activities; the wide promotion of high-efficiency and energy-saving equipment, with advanced energy-saving technologies adopted from transformers to motors; the comprehensive upgrade of energy management systems, realizing refined energy management and control with the help of digital platforms; and the ingenious integration of renewable energy, making solar, wind and other energies perfectly integrated with building electrical systems. These measures work together to remarkably improve the energy utilization efficiency of building electrical systems, significantly reduce the dependence on traditional energy, and further enhance the environmental friendliness of the entire system. Admittedly, currently there are indeed many challenges in terms of the complexity of technology integration and the severity of data security. However, with the continuous iterative innovation of digital technologies and the gradual improvement and perfection of relevant standards and regulations, the greening of building electrical systems will surely play a crucial role in the grand journey of the sustainable development of the construction industry, become an important source of strength for promoting the achievement of global energy conservation and emission reduction goals, and create a greener, lower-carbon and more livable building environment for mankind.

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