Exploring the Application of Energy-Saving Technologies in Building Electrical Design

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Abstract: Energy conservation and environmental protection have become the mainstream development trend at present. By incorporating this idea into contemporary structure electricity design, the assimilation can drastically lower diverse unnecessary resource usage. This article starts with the energy-saving development requirements of building electrical design. It first examines the significance of energy-saving technologies for the sustainable use of energy resources, reducing the total life-cycle operational costs of buildings, and supporting macro environmentally protected targets. Then, it explains the functional adaptation and energy efficiency synergy, whole-cycle economic balance and technological iteration and system upgrading principles. Finally, it describes the dynamic optimization allocation of power supply and distribution, scenario-based lighting energy conservation and the integrated application of renewable energy, in order to provide reference for the practical work of related practitioners.

1. Introduction

As the core link of energy transmission, distribution and terminal consumption in the building system, the operation of an electrical system generates a material scale of energy consumption. This is not only directly connected to the general energy efficiency of the building, but in fact even determining for consistent energy supply control during the entire life cycle of the subject building. It is precisely for this reason that actively exploring and adopting new electrical energy-saving technologies have become the vital core path for the construction sector to break through the traditional high-energy-consumption mode of development, realize the industry transition from green and low-carbon direction and thus it will lay a solid foundation to help achieve the sustainable development goal widely advocated globally.

2. The Importance of Energy-Saving Technologies in Building Electrical Design

2.1 Ensuring Sustainable Utilization of Energy Resources

The building electrical system is the main part of the overall energy consumption of the building, and its long-term stable operation is inseparable from continuous energy input [1]. Through practical applications of energy-saving technologies, the computer technology can be used to enhance equipment efficiency and establish intelligent energy distribution systems in electrical design to reduce the dependence on and consumption of traditional non-renewable energy sources. This not only saves a lot of energy resources, which is much higher than the utilization efficiency per unit of energy used at any time, but also extends the overall supply cycle of energy resources and reserves potential space for the future development of society's demand for energy. From a design source it is aligned with the main demand of "ensuring sustainable resource utilization" in sustainable development.

2.2 Reducing Whole-Life-Cycle Operational Costs of Buildings

Energy consumption by the electrical system accounts for a very high proportion of the entire life cycle cost of the building from commissioning to decommissioning. By carrying the concept of "on-demand energy supply" to the electrical design stage [2], such as mastering time-based

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open-close for lighting and power equipment through intelligent control systems, using energy-saving electrical components, etc., to minimize standby energy consumption at the source, creating more spaces for electricity efficiency savings during construction work operations. Meanwhile, low-energy operation can decrease the damage to electrical equipment in high-load operation and prolong the service life of equipment and lower subsequent maintenance costs and replacement costs, at relieve long-term pressure on building operators' economy, which can enhance overall benefits of buildings.

2.3 Contributing to the Achievement of Macro Environmental Goals

Reducing greenhouse gas emissions is one of them listed under the United Nations Sustainable Development Goals. Among them, the building energy consumption, represented by electrical system energy consumption, is one of the main sources of carbon emissions in the construction industry [3]. Make use of energy-saving may directly decrease the carbon dioxide as well as other greenhouse gaseous substance for being exhaust from vitality burning, and lower building electrical power utilization rates, so that their own construction area is hop over-oriented towards low-carbon. In fact, this does not only turn buildings from an environmental burden into an important tool to achieve carbon reduction goals, but also requires the construction industry to adapt to macro ecological requirements and help promote the entire society moving towards sustainable ecological development goals.

3. Principles of Energy Saving in Building Electrical Design

3.1 Principle of Functional Adaptation and Energy Efficiency Synergy

The energy-saving electrical design of buildings should be based on functional requirements, wherein energy efficiency optimization is accurately adapted to specific application scenarios. The designer should scientifically configure electrical systems according to building type, usage function and regional climate characteristic, so that the basic function and energy-saving goal can meet synergetic progress. At the same time, according to the "Electrical Design Standards for Civil Buildings," 1) The power supply and distribution system should meet the power quality specifications; 2) The lighting system should meet the illumination standards. Moreover, designers should also carry out resource analysis of solar energy and reasonably configure the supplemental photovoltaic energy source to prevent functional defects caused by pursuing energy saving blindly [4]. For instance, campus buildings could implement Building-Integrated Photovoltaics (BIPV) technology to focus on supplying their electricity demand first; office buildings can install AI tidal lighting systems that automatically adjust the brightness according to fluctuations in human traffic. Not only covering the demand of basic needs like teaching and office work, but also preventing unreasonable energy waste such as “always-on lights”, converting static equilibrium in normal conditions to dynamic equilibrium between function and energy saving

3.2 Principle of Whole-Cycle Economic Balance

Energy-saving is required for energy-saving design to form a dynamic balance mechanism between the amount of capital investment and energy saving, so as not to lead to another cost burden owing to overly pursuing energy saving. Designers must make material economic and technical comparisons during design to choose the most economical solutions, so as to effectively utilize resources in sectors including equipment selection, circuit layout, etc. For example, in the design of industrial plants, rational layout planning shortens line length to minimize energy loss, high-efficiency transformer and LED lamp selection reduces long-term energy consumption; Prepaid metering systems cultivate user energy-saving consciousness and systematically convert short-term investment into long-term returns/benefits. Designers also must consult energy efficiency grading standard, optimize the application of equipment meeting energy-saving levels and exploit policy means like subsidies and trade-in to cut down equipment updating cost, as well achieve the optimization on operation and maintenance costs via data from efficiency monitoring systems so that technical energy savings will go coincident with financial savings.

3.3 Principle of Technological Iteration and System Upgrading

Only by relying on the progress of science and technology to enhance energy-saving design's scientific and forward-looking characteristics can designers further promote the advancement of electrical systems toward intelligence, integration, etc. According to data, designers should be able to include a threefold energy-saving system from power supply and distribution, lighting, and renewable energy during the design stage process. Attaining full-link monitoring and regulation through an energy efficiency management platform [5]. In campus buildings, for example, intelligent energy efficiency management systems integrate functions such as photovoltaic monitoring, load control and water consumption supervision; by a data mining method to optimize energy use patterns; office buildings employ air conditioning AI-based energy saving technology from environmental sensors will make the "reach temperature automatic start-stop" and "unoccupied automatic shut down" imperceptible energy-saving rating. At the same time, it is necessary to reserve interfaces for technological transformations of the whole system in electrical design, monitor and update energy efficiency standards dynamically at real-time status, vigorously carry out advanced energy-saving equipment promotion work, so that the electrics total system can maintain a high-level technology and energy saving effect throughout its lifetime.

4. Application of Energy-Saving Technologies in Building Electrical Design

4.1 Dynamic Energy Efficiency Optimization of Power Supply and Distribution Systems

The distribution system of building power supply is the core link of all energy transmission. To utilize these energy-saving technologies, designers need to jump out of the traditional fixed thinking mode of design and begin to optimize dynamic energy efficiency.

At the first loading matching level, designers can consider setting "on-demand adjustment" of the transformer operation mode according to real-time load changes in each functional area of the building [6]. The data collected can then be used along with control technology to automatically determine the operating transformers by the intelligent monitoring system. If a commercial building only has 'low loads' (security and emergency lighting) at night, most of them can switch to run with a single small-capacity transformer without 'no-load energy consumption' from multiple transformers; during peak load hours in the daytime, enough transformers have been inter-connected and put into operation to achieve precise matching between load and power supply capacity.

Second, regarding reactive power compensation, designers have to replace traditional local compensation methods with AI-enhanced dynamic compensation systems. By using this system, the reactive power changes of all electrical equipment can be monitored synchronously in real-time, and it is possible to control the input capacity and duration of compensation capacitor banks according to this data automatically without causing power loss due to excessive compensation or insufficient compensation. At the same time, in response to long power supply and distribution lines in high-rise buildings, low impedance new cable materials with small resistance loss and satisfying the requirements of current carrying capacity and thermal stability are applied. In conjunction with the architecture, building substations and distribution rooms closer to load density areas shortens the power supply radius and reduces cross-regional energy transmission loss.

Finally, designers are reaching fine energy allocation by smart area management and regulation of power supply and distribution system. An example would be segmenting the building into several stand-alone power supply areas, all with smart energy meter and load controller enabled. The system possesses the ability to monitor energy usage, detect overconsumption within specific zones, issue real-time alerts, and autonomously restrict excessive energy use if it exceeds acceptable levels in whatever sector it was in — this can help ensure localized unusual power demands do not disrupt overall generation and distribution systems. From multiple dimensional aspects of the power supply and distribution system think transmission, compensation, and management control this achieves energy-saving upgrades.

4.2 Scenario-Based Intelligent Energy Saving for Lighting Systems

One is that energy saving in building lighting systems must step out of the singular thinking mode of simply "reducing power" and transform to a scenario-based intelligent regulation, which maximizes energy savings on the premise that the quality of lighting meets requirements. Indeed, custom energy-saving solutions can be developed according to the different lighting requirements of various functional areas. As an example, the office areas are suggested to select a mode that prioritizes natural light and dynamically adjusts auxiliary lighting. The previous work also installed light sensors to measure indoor natural illuminance in real-time so that when the office standards are reached by the natural illuminance, only local auxiliary lighting of corridors and workstations is retained while all ceiling main lighting near windows is automatically turned off. Meeting room type three-stage control (reservation, in-use, standby), basic lighting will automatically turn on during the reservation period for people to count adjusted during use of both light brightness and no meeting end all non-emergency class lights will be automatically cut off can avoid "always-on light" phenomenon.

At the same time, designers in commercial environments have to balance display effects with energy consumption control. For example, the spectrum is adaptive energy-saving light source of shopping mall exhibition hall can adjust according to the type exhibit adjusts the light source spectrum. The clothing area can choose LED light source with high Color Rendering Index ($Ra \geqslant 90$) to truly restore the colors of clothing, and use intelligent dimming systems in the non-key exhibition area to reduce lighting brightness during period of low customer flow. In the exhibition area of jewelry, directional spotlighting LED lamps can also be used to shine on the exhibits while avoiding waste of ambient light. Additionally, some designers must integrate the lighting system with the mall's customer flow monitoring system. In certain exhibition area, when the customer flow is too low to reach a critical threshold value, part of redundant lighting will automatically turn off functions; When customer flow increases and exceeds the critical number of people in demand, can be restored gradually does not need to carry out dynamic energy saving characterized by "just arrived lights brightened, leave began to adjust".

Moreover, sound-activated or light-activated switches in public spaces can also be upgraded to intelligent control modules that integrate human presence detection and delayed power-off [7]. Example: when the micro radar sensors installed in underground garages, when car or someone within the monitoring range, only on all Illuminating lights in the current area and forward 30 meters of road lighting appliances, after they leave stop automatic delay 30 seconds. In a high-rise building, floor location-based optimization of sensor sensitivity in stairwells can help to minimize the impact of environmental factors creating wind noise or echoes which cause frequent triggering of potentially unnecessary lighting and leads to savings in invalid light energy consumption. This enables the lighting system not only to meet the demand of usage but also to utilize energy more accurately.

4.3 Integrated Application of Renewable Energy and Building Electrical Systems

Integrating renewable energy generation deeply into building electrical systems is a vital way to develop from the traditional dependency on grid supply way of energy consumption and to realize energy self-sufficiency. Designers, on the one hand, can design integral photovoltaic (PV), energy storage and power distribution for solar energy utilization [8]. PV modules can be installed on building roof tops and curtain walls to provide power first for loads like lighting, air conditioning, and office equipment. At the same time, lithium battery energy storage systems can be configured to balance excess PV power generated in the daytime and released in nighttime/cloudy day periods, reducing dependence on grid electricity. For instance, a PV module design for an office building that covers 80% of the roof area combined with a separate 100 kW·h energy storage battery can meet anywhere from 30% to 40% of its electricity needs per day at times, effectively reducing its reliance on the power grid. On the other hand, this new energy management platform is capable of real-time monitoring PV output, storage status and building load, then automatically adjusting the ratio of power supply between PV, storage and grid to maximize solar energy utilization. In contrast, designers may also explore the synergism of small-scale wind energy and building electrical systems. It is suitable to install small wind turbines on the roof tops of high-rise buildings or open area. Forecasts that when the wind speed is more than 3m/s, then the generator for power generation and supply to loads (such as emergency lighting, etc., outdoor landscape lighting, etc.) Intelligent switching devices enable the system to automatically use grid power when wind energy output is reduced, maintaining stable function of the loads. In addition, how to combine renewable energy with building electricity system can greatly reduce the dependence of buildings on traditional energy sources and effectively reduce the loss in the process of transmitting energy. It provides new ideas for building electrical energy saving.

5. Conclusion

Building electrical energy saving is a systematic project, it includes concept, principles and technologies. With energy sustainability, whole-life-cycle cost reduction, and environmental goals as the core development objectives, alongside functional adaptation, economic balance, and technological iteration as the core principles of power supply enterprises, efficient and low-carbon electrical systems are constructed through dynamic optimization of power supply and distribution management strategy scenario-based lighting regulation deep integration of renewable energy. The system effectively eliminates the energy consumption bottlenecks of traditional building electrical systems and promotes low-carbon transformation in the construction industry, which further aligns with the national "Dual Carbon" goals and sustainable development needs. Designers should continue to deepen the technological innovation and system integration in the future, take building electrical energy saving as the key link of green building development, and provide sustainable power for the coordinated advancement of ecological protection and economic development.

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