

Energy-Saving Design Strategies in Electrical Engineering Automation Systems: Towards an Environmentally Friendly Society

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Abstract: With the advancement of science and technology in China, electrical engineering has seen significant development, encompassing areas such as photonics and electronics. Currently, there is a societal focus on the automation systems within electrical engineering, with a particular emphasis on researching energy-saving designs to foster an environmentally friendly society. This paper analyzes the structure of electrical engineering automation systems, the characteristics of these systems, and the principles followed in energy-saving designs within electrical engineering automation. It explores the application strategies for energy-saving design in these systems, aiming to improve efficiency and sustainability.

Keywords: Electrical Engineering; Automation Systems; Energy-Saving Design; Application.

1. Introduction

Electrical Engineering, as a cornerstone discipline within the modern technological domain, not only signifies the pinnacle of human technological civilization but also plays an indispensable role in driving societal progress and economic growth. It encompasses the scientific and technological knowledge necessary for the creation and management of electronic and electrical systems, aiming to address engineering challenges and foster innovation. With the rapid advancement of technology, the concept of Electrical Engineering has vastly exceeded its traditional scope, incorporating not just the design and maintenance of power systems and electronic devices but also extending to smart systems, renewable energy, and integration with computer information technology [1].

As a significant academic course, Electrical Engineering is offered under various names and specializations in higher education institutions worldwide, reflecting its broad applicability and continually expanding research fields [2]. The close connection between Electrical Engineering and Computer Science, particularly in the interdisciplinary applications of automation, information processing, and communication technology, has not only greatly propelled technological innovation but also transformed how people work and live [3].

Against the backdrop of rapid socio-economic development in our country, the application of Electrical Engineering is crucial for liberating and developing productive forces. Especially in the widespread application of automation technology [4], it has facilitated energy-efficient designs in industry and daily life, reduced energy consumption, and provided robust support for the development of electronic information technology. Through these innovative applications, Electrical Engineering is helping to build a more efficient, environmentally friendly, and intelligent future.

2. The Automation System Structure of Electrical Engineering

The structure of automation systems in electrical engineering is a key component of technological advancement today, particularly in the application of intelligent devices and online monitoring of primary equipment. This automation integrates knowledge of electrical engineering and information technology and requires technicians to have a thorough understanding of the complex structure and operating principles of electrical systems to ensure the efficient operation of automation systems.

- **Fiber Optic Communication:** As the main carrier in electrical engineering automation, fiber optics, due to its high transmission efficiency, greatly improves the efficiency of information transmission. This is beneficial for reducing the cost of control information transmission. The use of fiber optics promotes the innovation of all-weather automation online monitoring technology, leading to the development of various devices towards greater intelligence.

- **The Role of Collection Stations:** As the core part of the online monitoring system, collection stations process and collect various types of information. In the complex environment of all-weather monitoring, collection stations control and manage various parameters through advanced computer networks, ensuring the accuracy and effectiveness of data collection.

- **Improvement and Development of Technology:** Against the backdrop of the digital age, electrical engineering utilizes computer networks to improve and develop automation technology. This requires the investment of more resources, such as new facilities, materials, technologies, and products, to support the continuous progress of electrical automation.

- **Development towards Openness:** Leveraging network technology, electrical engineering automation is developing in an open direction. By quickly connecting with the outside world and spreading information through online platforms, electrical engineering automation not only improves the

facilities of the power system but also comprehensively enhances and perfects electrical engineering technology.

3. Characteristics of Electrical Engineering Automation System

The widespread application of electrical engineering automation systems in industry and enterprise is attributed to a series of unique characteristics. These characteristics not only enhance the efficiency of system design and application but also promote the continuous progress and development of electrical engineering automation technology.

(1) Integration of Various Technologies

A significant characteristic of electrical engineering automation systems is their integration of multiple technologies into a single system. This integration encompasses several fields, including power electronics, computer technology, and mechanical automation technology, which significantly enhances the system's performance and application scope through mutual complementation and optimization. For example, the application of power

electronics technology can improve energy efficiency, computer technology provides intelligent control and data processing capabilities, and mechanical automation technology directly affects the automation level of production lines.

(2) Strong Practicality

Another key feature is the strong practicality of electrical engineering automation systems. In enterprise production activities, these systems offer precise control and efficient operation, solving various problems encountered in the production process. For example, an isolated DC-DC converter called an auxiliary power module (APM) is an essential component in the E/E architecture of electric vehicles, as shown in Figure 1. They can monitor and debug technological equipment in real-time, ensuring the efficient operation of equipment, thus aiding enterprises in achieving automated production, improving production efficiency, and economic benefits. By reducing manual operations and lowering production costs, electrical engineering automation systems become a key tool in enhancing enterprise competitiveness.

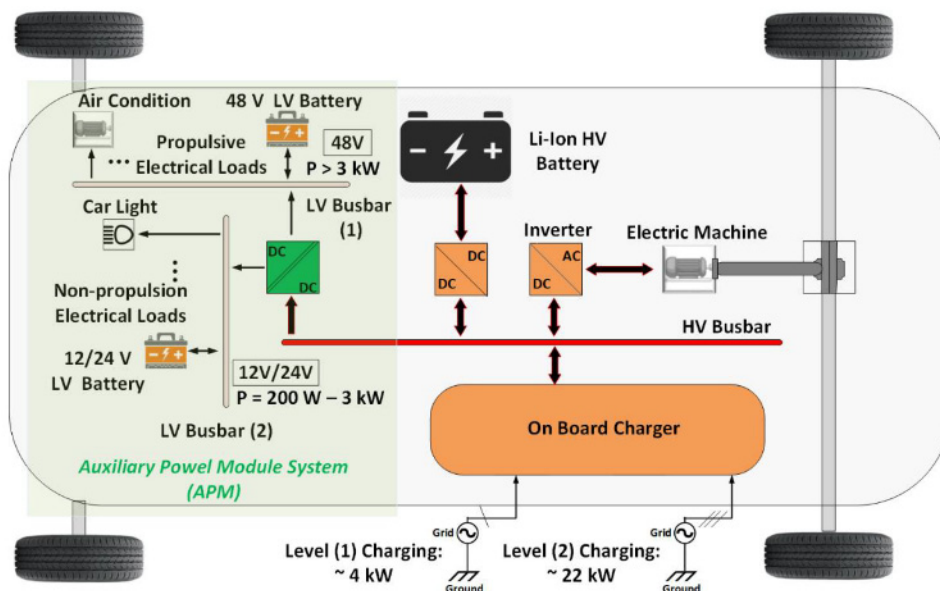


Figure 1. Application of auxiliary power module in automobile industry

4. The Principle of Energy Saving Design in Electrical Engineering Automation System

In the context of promoting energy conservation, emission reduction, and sustainable development, the energy-saving design of electrical engineering automation systems has become an important research area. Effective energy-saving designs can not only improve the efficiency of power systems but also reduce environmental impacts, promoting the sustainable development of society and economy. Here are the three fundamental principles to follow:

(1) Adherence to Safety Principles

Firstly, the principle of safety is the foremost consideration in the design of electrical engineering automation. When designing energy-saving solutions, it is essential to ensure the safe operation of electrical equipment and systems to prevent accidents caused by energy-saving measures. This includes conducting strict safety assessments for electrical equipment and power resources and ensuring all electrical loads comply with national and industry-specific safety standards.

Additionally, extra safety measures should be taken for electrical wires and other key components to avoid potential risks such as overload and short circuits.

(2) Adherence to Environmental Protection Principles

Secondly, the principle of environmental protection requires minimizing energy consumption and environmental pollution in the design and operation of electrical engineering automation systems. This means considering energy efficiency from the system design stage, choosing low-energy consumption equipment and materials, and optimizing system operation procedures to reduce unnecessary energy waste. At the same time, by adopting clean energy and improving energy recycling rates, the burden on the environment is lessened, ensuring the system's environmental performance.

(3) Adherence to Advancement Principles

Lastly, the principle of advancement emphasizes the application of the latest technologies and methods in electrical engineering automation design. With rapid technological development, new energy-saving technologies and materials emerge continuously, offering effective solutions to improve energy utilization and reduce resource waste. Therefore,

energy-saving design needs to keep pace with technological advancements, employing the latest technologies and materials while also considering the long-term environmental and economic benefits, bringing sustained benefits to enterprises and society.

5. The Application Strategy of Energy Saving Design in Electrical Engineering Automation System

The development and application of electrical engineering automation technology span multiple disciplinary fields, and its energy-saving design is crucial for the efficient operation of power systems and plays a significant role in promoting enterprise development and economic construction. Here are some key application strategies for energy-saving design in electrical engineering automation systems.

(1) Optimize Distribution System Design

Optimizing the design of the distribution system is one of the key steps to achieve energy savings. By scientifically planning the distribution system, it can ensure the effective control and safe operation of electrical equipment while meeting the needs of electrical loads. The optimization design of the distribution system requires the following:

Ensure System Applicability and Safety: Consider the stability, efficiency, controllability, and flexibility of the power system in the design, ensuring the safety of the electrical system's operation.

Reasonably Select Conductors and Insulation Materials: Choose suitable conductor materials and insulation properties to reduce energy consumption, ensuring an appropriate distance between wires and meeting the requirements for load capacity, thermal stability, and dynamic stability.

Prevent Overload of Electrical Load: By strictly controlling the load of electrical equipment, ensure the reliability and safety of the supply equipment, avoiding energy waste.

(2) Scientific Selection of Transformers

The choice of transformers is crucial for energy-saving design due to their significant energy consumption in the power system.

Choose Energy-saving Transformers: Consider the transformer's material, capacity, and configuration comprehensively, choosing energy-efficient transformers to reduce energy consumption.

Optimize Transformer Configuration: Based on the demand for electricity and equipment expansion, reasonably determine the number and capacity of transformers to ensure their optimal operation and reduce energy waste.

(3) Application of Active Filters

Active filters have emerged as a sophisticated solution for mitigating the adverse effects of harmonics in electrical systems. Harmonics, which are distortions in the electrical waveform, can lead to a myriad of issues including increased heat generation, reduced lifespan of equipment, and inefficiencies in energy usage. The application of active filters, however, provides a dynamic and effective method to counteract these disturbances, thereby enhancing the system's operational efficiency and reliability.

An active filter works by dynamically injecting compensating currents into the power system. These currents are precisely opposite in phase to the unwanted harmonics, effectively canceling them out. This process can be represented mathematically by the equation:

$$I_{comp} = -I_{harmonic}$$

Where (I_{comp}) is the compensating current provided by the active filter, and ($I_{harmonic}$) represents the harmonic current in the system. By applying this principle, active filters can significantly reduce the total harmonic distortion (THD) in the electrical system.

The implementation of active filters not only improves the power quality by reducing harmonic distortion but also contributes to the reduction of energy waste. Improved power quality means that electrical equipment operates more efficiently, suffers less wear and tear, and consumes less energy, leading to reduced operational costs and extended equipment lifespan.

Moreover, active filters are capable of adapting to changing network conditions, offering real-time harmonic compensation. This adaptability makes them particularly suitable for modern electrical systems, which may experience variable loads and diverse types of electronic equipment. By ensuring that the electrical system operates closer to its ideal state, active filters play a critical role in optimizing the distribution and use of electrical power.

In addition to their direct benefits, the use of active filters in electrical systems aligns with broader environmental goals by promoting more efficient energy use and reducing the carbon footprint of electrical operations. As such, their application is a key strategy in the transition towards more sustainable and reliable electrical infrastructure.

(4) Application of Reactive Power Compensation Technology

Reactive power compensation technology plays a crucial role in enhancing the operational efficiency of power systems. It primarily targets the improvement of the power factor, which is a key metric reflecting the efficiency with which the electrical power is converted into useful work output. The power factor (PF) is defined as the ratio of real power (P), measured in watts (W), to apparent power (S), measured in volt-amperes (VA), mathematically represented as:

$$PF = \frac{P}{S} = \frac{\text{Real Power (W)}}{\text{Apparent Power (VA)}}$$

An optimal power factor is close to unity, or one, indicating that the electrical power is utilized effectively. In practical terms, reactive power compensation involves the deployment of devices such as capacitors or inductors, which can either absorb or generate reactive power (Q), thereby balancing the reactive power in the system. This balance is crucial for minimizing the phase difference between voltage and current, ultimately leading to a higher power factor.

By implementing reactive power compensation, power systems can significantly reduce energy waste associated with non-productive power, thereby enhancing the overall efficiency and quality of electrical energy transmission. This not only contributes to a reduction in energy consumption but also leads to substantial economic savings and a decrease in greenhouse gas emissions, aligning with the global push towards more sustainable energy solutions.

The application of reactive power compensation technology encompasses various strategies, including static VAR compensators (SVCs) and dynamic voltage restorers (DVRs), each tailored to specific requirements of the power distribution network. These technologies ensure that the power system operates at an optimal power factor, thereby

reducing the need for excess generation capacity and enhancing the reliability of the electrical supply.

Through careful planning and the strategic deployment of reactive power compensation devices, electrical engineers can effectively tackle the challenges posed by inefficient power use. This not only results in a more stable and efficient power system but also significantly contributes to the broader goals of energy conservation and environmental protection, marking a pivotal step towards the creation of an environmentally friendly society.

(5) Reduce Electricity Consumption

Reducing electricity consumption is a pivotal goal in the design and operation of modern electrical systems. Through strategic optimization of electrical equipment and the distribution network, significant reductions in energy waste can be achieved, thereby lowering electricity costs and contributing to environmental sustainability. One effective strategy involves minimizing the resistance in electrical wiring and mitigating the losses incurred during electrical energy transmission.

The relationship between the resistance of electrical wiring, the current flowing through it, and the power loss can be expressed by the equation:

$$P_{loss} = I^2 \times R$$

where (P_{loss}) represents the power loss in watts (W), (I) is the current in amperes (A), and (R) is the resistance of the wire in ohms (Ω). This equation highlights the direct impact of wire resistance on power loss: as resistance increases, so does the power loss for a given current. Therefore, reducing wire resistance is a key factor in decreasing energy losses and, by extension, electricity consumption.

Several approaches can be employed to achieve this reduction in resistance and subsequent power loss:

- **Utilizing materials with lower resistivity:** Choosing wiring materials with inherently lower resistivity, such as copper or aluminum alloys optimized for electrical applications, can significantly decrease the resistance of electrical pathways.

- **Increasing wire diameter:** A larger cross-sectional area of the wire reduces its resistance, according to the formula:

$$R = \rho \times \frac{L}{A}$$

where (ρ) is the material's resistivity, (L) is the length of the wire, and (A) is its cross-sectional area. Implementing wires with greater diameters can, therefore, reduce energy losses.

- **Optimizing the distribution network design:** Carefully planning the layout of the electrical distribution network to minimize distances electricity must travel reduces overall transmission losses. This includes the strategic placement of transformers and substations to ensure shorter and more efficient pathways for electrical flow.

Additionally, incorporating advanced technologies such as smart grid systems can further enhance the efficiency of electricity use. Smart grids enable real-time monitoring and adaptive control of the distribution network, allowing for dynamic adjustments that minimize waste and balance loads more effectively.

By addressing the resistance in wires and optimizing the design of the distribution system, not only can electricity consumption be significantly reduced, but operational reliability and system longevity can also be improved. These

measures contribute to a cycle of savings that extends beyond mere cost reduction, fostering a more sustainable and environmentally friendly approach to electrical energy usage.

(6) Scientific Selection of Power Cables

The strategic selection of power cables is a critical aspect of designing energy-efficient electrical systems. The material composition and cross-sectional size of cables directly impact the overall efficiency and performance of power transmission. By choosing the most appropriate power cables for specific application scenarios, whether copper or aluminum, and determining the optimal size of the cable cross-section, it is possible to significantly enhance energy conservation within the system.

Copper and aluminum are the most commonly used materials for power cables, each with its distinct advantages. Copper has a lower resistivity compared to aluminum, which means it can carry the same amount of current with a smaller cross-sectional area or less resistance, leading to lower energy losses. This can be represented by the formula:

$$R = \rho \times \frac{L}{A}$$

where (R) is resistance, (ρ) is the material resistivity, (L) is the length of the cable, and (A) is the cross-sectional area. Therefore, for applications requiring high efficiency and minimal energy loss, copper cables are often the preferred choice.

On the other hand, aluminum cables, while having higher resistivity, offer advantages in terms of cost, weight, and ease of handling. For applications where these factors are prioritized, and the larger cross-sectional area required by aluminum to achieve comparable conductivity to copper is not a constraint, aluminum cables can be an effective choice.

Determining the size of the cable cross-section is equally important. A cable that is too small for the current it is expected to carry can lead to excessive energy losses and may even pose safety risks due to overheating. Conversely, unnecessarily large cables can be more expensive and harder to install. Therefore, the cable size should be chosen based on the maximum expected current load, ensuring efficient transmission with minimal losses, while also considering installation and material costs.

The equation for calculating the ideal cable size to minimize energy losses while ensuring safe operation is:

$$A = \frac{I}{\delta}$$

where (A) is the required cross-sectional area, (I) is the current load, and (δ) represents the current density suitable for the cable material and insulation type.

Incorporating these considerations into the selection process allows for the scientific choice of power cables that align with energy-saving goals. By optimizing the material and size of cables based on the specific demands of the application scenario, it is possible to achieve significant reductions in energy consumption, thereby contributing to the overall efficiency and sustainability of electrical systems.

(7) Improve the Efficiency of Electrical Systems

Improving the efficiency of electrical systems is fundamental to reducing energy consumption and enhancing sustainability. The deployment of efficient electrical equipment, coupled with the strategic optimization of system design, can lead to significant improvements in how electrical energy is utilized, ultimately reducing wastage and

operational costs.

Efficient Electrical Equipment: The selection of high-efficiency electrical equipment is the cornerstone of enhancing system efficiency. This includes energy-efficient motors, transformers, lighting, and HVAC systems that operate at higher efficiencies than standard models. For instance, the efficiency of an electric motor can be represented by the equation:

$$\text{Efficiency}(\%) = \left(\frac{\text{Output Power}}{\text{Input Power}} \right) \times 100$$

Where the output power is the useful power provided by the motor, and the input power is the electrical power it consumes. High-efficiency motors are designed to minimize energy losses through heat and friction, thus requiring less electrical power to achieve the same output as less efficient models.

System Design Optimization: Beyond individual components, the overall design of the electrical system plays a critical role in energy efficiency. This involves:

-Load Management: Balancing the load across the system to avoid overloading and underutilization, which can lead to inefficiencies. Implementing smart grid technologies can dynamically adjust the distribution of power based on real-time demand, optimizing energy use.

-Minimizing Transmission Losses: As discussed, the resistance of cables and the distance over which power must be transmitted can lead to energy losses. By designing the system to minimize these factors—such as through the strategic placement of substations and the use of high-conductivity materials—overall efficiency is improved.

-Harmonic Reduction: Implementing solutions like active filters to mitigate harmonic distortions, which can cause additional losses and affect the performance of sensitive equipment.

Renewable Energy Integration: Incorporating renewable energy sources, such as solar or wind power, into the electrical system design can significantly reduce reliance on non-renewable energy sources and decrease overall energy consumption. Renewable energy systems can be seamlessly integrated with traditional power systems to provide clean, efficient, and sustainable energy.

Advanced Control Systems: Utilizing advanced control systems and automation can further optimize the operation of electrical systems. These systems can make intelligent decisions about power distribution, equipment operation, and maintenance schedules, based on data analysis and predictive

algorithms, ensuring the system operates at peak efficiency.

By focusing on the use of efficient electrical equipment and optimizing the design and operation of electrical systems, significant reductions in energy consumption can be achieved. This not only leads to cost savings but also contributes to environmental sustainability by reducing the carbon footprint associated with electricity generation and use.

6. Conclusion

In conclusion, based on the structure and characteristics of the electrical engineering automation system, and adhering to the relevant principles for electrical automation design, the distribution system is optimized. Selecting transformers that meet standard requirements, employing active filters and reactive power compensation technology in the system, and focusing on the rational selection of power cables, energy consumption is reduced. This prevents the operation of the electrical engineering automation system from polluting and damaging the environment, making the operation of the electrical system more effective and thereby improving the efficiency of the electrical system.

This comprehensive approach not only aligns with the goals of sustainable development and environmental protection but also ensures the reliability and safety of the electrical engineering automation system. By integrating advanced technologies and optimizing system design, it's possible to achieve significant energy savings and operational efficiency, contributing to the economic benefits of enterprises and the wider community.

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