Research on Economic Cost Analysis of Innovative Insulation Treatment Technology for Distribution Lines

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Abstract: The power industry is an important basic energy industry in the development of the national economy. With the advancement of modern technology, intelligent equipment is widely used in the power industry. With the continuous expansion of China's power grid, traditional manual inspection and operation methods are no longer able to meet the needs of the power system, and the research and application of power operation robots have become inevitable. In response to the current development goals of cost lean management in State Grid Anhui Electric Power Co., Ltd., this paper compares and analyzes the economic costs and application effects of traditional manual insulation repair and intelligent equipment insulation repair in distribution lines, and discusses the role of intelligent technology progress and innovation in lean management of power grid costs. Research has confirmed that technological innovation can effectively improve power operation efficiency, reduce economic costs, achieve lean cost management, and significantly enhance the safety, reliability, and stability of power grid operation.

Keywords: Distribution Lines; Insulation Treatment; Technological Innovation; Economic Cost

1. Introduction

With the continued deepening of power system reforms, there are increasing demands for effective cost management among power supply companies. This necessitates the implementation of lean analysis and thorough inspections when addressing cost control challenges [1].The primary components of lean cost management encompass reducing material and labor expenses, enhancing processes and technological innovation, and reinforcing the utilization of intelligent equipment [2].The application of intelligent technology in the smart maintenance of power grids can significantly enhance the stability and safety of power grid operations [3]. This article analyzes the economic costs and effectiveness of traditional manual insulation repair compared to intelligent equipment insulation repair through comparative analysis, examining the role of technological advancements and innovations in the refined management of power grid costs.

Traditional manual insulation repair work usually requires applying for a power outage on the line beforehand. Workers then utilize an electric lift or specialized tools to ascend the pole and complete the task. This method is only suitable for flat and open coastal areas, as well as rapidly developing inland cities, which presents significant limitations. In many complex working environments, such as slower-developing rural areas and rugged terrains, access for vehicles to the construction site is often challenging. This results in high labor intensity, low work efficiency, and inconsistent work quality. Furthermore, there are serious personal safety hazards, rendering this approach increasingly inadequate for the demands of modern power grids and the rapid advancement of the economy and society. Therefore, highly automated insulation wrapping devices will gradually replace traditional manual wrapping methods, achieving a dual improvement in safety and work efficiency, and enhancing the development of the country's smart grid [4].

This article introduces the insulation wrapping device developed for 10KV overhead lines and compares the application effects of traditional manual operations with those of intelligent equipment. Additionally, the article compares and analyzes the effectiveness of traditional manual operations against those utilizing intelligent equipment. In response to the evolving trends of refined financial management in enterprises, this paper further emphasizes the significance of technological innovation by comparing the economic costs of traditional manual insulation repair with that of intelligent equipment insulation repair[5].

2. Current Situation of Overhead Power Line Maintenance

Currently, the Huainan Power Supply Company, a subsidiary of Anhui Electric Power Company, primarily relies on traditional manual power outages for maintenance work on the insulation wrapping of overhead bare conductors. Before commencing maintenance, a power outage is typically requested for the line. Workers utilize electric lifts or specialized tools to ascend the poles. However, these traditional methods present several drawbacks during maintenance operations. Firstly, due to the optimization of the line network design, the space available for live work is limited, necessitating power outages for most repairs, which disrupts the continuity of the power supply. Secondly, maintenance personnel must climb poles in high-voltage environments, which increases the risk of electric shock, particularly under challenging conditions such as high temperatures, rain, and fog. Lastly, the identification of faults relies heavily on manual experience for segmented troubleshooting, resulting in inefficiencies.

In recent years, the rapid advancement of information technology and artificial intelligence has led to the emergence of intelligent maintenance strategies as a new trend in the maintenance of electrical equipment [6]. Traditional manual insulation repair methods are primarily effective in flat, open coastal areas and rapidly developing inland cities, but have significant limitations. In more complex environments, such as slowly developing rural areas and rugged terrains, access to construction sites can be challenging for vehicles. These conditions also result in high labor intensity, low work efficiency, and inconsistent work quality. Furthermore, there are serious personal safety hazards, rendering traditional methods increasingly inadequate for the demands of modern power grids and the swift progression of the economy and society.

3. Intelligent Device Operation

3.1 Insulation Wrapping Device

In response to the current need for insulation repair on the 10 kV distribution lines of the Fengtai Power Supply Company’s rural power network, a series of miniaturized devices for insulating wraps has been developed, as shown in Figures 1 and 2. The device features lifting and walking mechanisms, a conveying mechanism, a clamping mechanism, and a buttoning mechanism. It is equipped with dual control methods, allowing operation either through buttons on the device or via wireless terminal devices such as smartphones and tablets through a Wi-Fi network. This device can replace manual high-altitude work by automatically wrapping insulation sleeves around power lines, thereby achieving automatic insulation repair for distribution lines.

Figure 1. Controller Interface

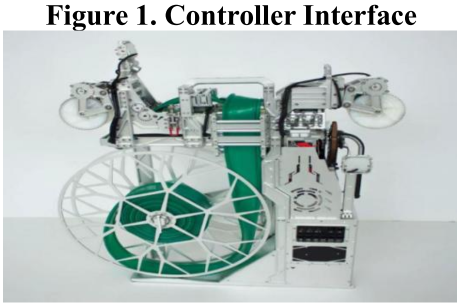

Figure 2. Insulation Wrapping Device for Distribution Lines

After trial application, the device can replace manual work to carry out insulation wrapping and repair of distribution lines, improving the efficiency of insulation transformation operations for distribution lines. It enables insulation wrapping work to be done without power outages, saving a significant amount of manpower and resources, and enhancing the company's economic benefits.

3.2 Insulation Wrapping Device Operation Process

Figure 3. Package for Homework Preparation

Figure 4. Insulation Wrapping Operation

The operation of the insulation wrapping device is illustrated in Figures 3 and 4. The operation requires staff to utilize wireless terminal devices to complete the tasks, and the process is as follows: First, the robot must be suspended from the overhead bare wire. Next, activate the lifting motor to elevate the robot to a walking state, at which point the walking motor will immediately propel the robot along the line to the target area. Once the robot reaches the packaging area, the lifting motor will raise the body to the appropriate working height using the scissor lift mechanism. At this time, the driving motor propels the entire machine forward along the cable while initiating the insulation wrapping program. During this movement, the insulating protective sleeve in the material tray is released and transported by the conveying unit to the clamping unit via the guide wheel. The pressing wheel compresses the protective sleeve onto the overhead bare wire, ensuring that the sleeve is securely fastened, thereby completing the insulation wrapping process. Finally, the finished insulating protective sleeve is secured with nails through the nailing unit to ensure a tight fit.

4 Comparative Analysis of the Economic Costs and Effects of Intelligent Device Applications

In order to evaluate the economic feasibility of the operational methods for intelligent devices, this article conducts a comparative analysis of the specific economic costs and application outcomes associated with these two operational methods for intelligent devices and traditional operational methods.

4.1 Comparative Analysis of Economic Costs

4.1.1 Comparative analysis of economic costs for overhead line maintenance calculation

Based on the annual maintenance history of overhead lines, this article calculates the yearly maintenance requirements, conducts application tests under consistent maintenance standards, and combines the experimental results of two operational methods to estimate the annual economic costs associated with traditional manual maintenance and intelligent equipment maintenance. The findings are presented in Tables 1 and 2.

From the calculation results presented in Tables 1 and 2, it is evident that the traditional manual maintenance method requires a team of 11 members, which includes one team leader, four technicians, and six assistants. In contrast, the intelligent equipment maintenance method, which employs live working techniques, necessitates only three personnel, thereby reducing the workforce by eight. Based on the average annual salary of 100,000 yuan per person at Fengtai Power Supply Company, the traditional manual maintenance method incurs an annual cost of 1.1 million yuan for 11 personnel, whereas the intelligent equipment maintenance method costs only 300,000 yuan for three personnel. This results in an annual savings of 800,000 yuan in personnel costs.

Table 1. Economic Cost Estimation of Traditional Manual Maintenance

classification of economic costs	unit price	annual usage of traditional manual maintenance	annual cost of traditional manual maintenance
personnel staff	100,000 yuan per person	11 people	1,100,000yuan
aerial bare conductor	40 yuan per meter	30km	120,000yuan

power outage during work	0.5653yuan/kw·h	614400kw	347,300 yuan
power outage due to a malfunction.	0.5653yuan/kw·h	200000kw	113,060 yuan
equipment depreciation	/	/	150,000 yuan
total			3,010,360 yuan

Table 2. Economic Cost Estimation for Intelligent Equipment Maintenance

classification of economic costs	unit price	annual usage of intelligent equipment maintenance	annual maintenance costs of intelligent devices
personnel staff	100,000 yuan per person	3 people	300,000 yuan
aerial bare conductor	40 yuan per meter	-	0
power outage during work	0.5653yuan/kw·h	-	0
power outage due to a malfunction.	0.5653yuan/kw·h	-	0
equipment depreciation	/	/	660,000 yuan
total			960,000 yuan

In the Fengtai Company area, there are nearly 30 kilometers of bare overhead conductors. The average price of overhead insulated wire is 40 yuan per meter, and the annual cost associated with traditional manual maintenance methods totals 1.2 million yuan. Maintenance of intelligent devices is typically carried out by workers using live working boom lifts, which transport the insulated wrapping device for the distribution lines to the construction site, thereby eliminating the need to replace bare conductors. As a result, this approach can save 1.2 million yuan per year. The traditional manual maintenance method necessitates a power outage to replace insulation wires. In recent years, Fengtai Power Supply Company has conducted an average of 80 maintenance operations annually, with each operation lasting 6 hours. During these outages, approximately 1,600 households are affected, each consuming 0.8 kW of electricity per hour. The charging standard for residential electricity in the rural network of Fengtai Power Supply Company is 0.5653 yuan per kilowatt-hour. Consequently, the annual loss incurred due to power outages for maintenance operations amounts to 347,300 yuan.

According to the investigation, Fengtai Company experiences nearly 20 instances of grounding trips each year due to bare wire faults. The implementation of intelligent maintenance equipment can significantly reduce the frequency of line fault trips, potentially decreasing the number of households affected by power outages by 10,000 and providing an additional power supply of nearly 200,000 kilowatt-hours. This improvement could lead to a reduction in fault loss costs amounting to 113,060 yuan per year.

Table 3. Economic Cost Comparison

classification of economic costs	annual cost of traditional manual maintenance	annual maintenance costs of intelligent devices
personnel staff	1,100,000yuan	300,000 yuan
aerial bare conductor	120,000yuan	0
power outage during work	347,300 yuan	0
power outage due to a malfunction.	113,060 yuan	0
equipment depreciation	150,000 yuan	660,000 yuan
total	3,010,360 yuan	960,000 yuan

According to the economic cost comparison presented in Table 3, employing intelligent equipment to replace manual labor for the insulation wrapping and repair of distribution lines can reduce costs by 2.05036 million yuan annually. This method not only enhances the efficiency of insulation transformation work on distribution lines and enables insulated wrapping operations without power outages, but it also conserves significant manpower and resources for the company, thereby improving overall economic benefits.

4.2 Comparison and Analysis of Application

Effects

4.2.1 Labor force

Through the implementation of intelligent collaborative robots, enterprises can achieve a transformative upgrade of their maintenance equipment. This transformation encompasses continuous enhancements in several areas, including workforce management, equipment durability, maintenance expenses, and production efficiency. It not only lightens the workload for operators but also lowers production costs for businesses [7].

The traditional manual maintenance method necessitates a significant amount of manpower, with a team of 11 people, resulting in high labor costs. In contrast, the use of intelligent equipment for maintenance only requires 3 people to complete the operation. Compared to manual maintenance, this approach can greatly reduce labor costs. Additionally, intelligent equipment can minimize losses caused by human errors, effectively avoiding secondary costs and significantly improving operational efficiency.

4.2.2 Work efficiency

Under the premise of achieving the same operational effect, using traditional manual maintenance methods requires power outages for the work. Power outages for routine maintenance and repairs are the safest and most reliable method, but power outages have a significant impact on industrial production, severely reducing maintenance efficiency. During the maintenance process, staff use electric lift vehicles or specialized tools to access the poles. This practice is only suitable for flat and open coastal areas and rapidly developing inland cities, which has significant limitations. In many complex working conditions, such as slower-developing rural areas and regions with rugged terrain, not only is it difficult for vehicles to reach the construction site, but it also results in high labor intensity, low work efficiency, unstable work quality, and serious personal safety hazards. On the contrary, using highly automated insulation wrapping devices for maintenance work is not affected by power outages or environmental constraints. At the same time, intelligent equipment has the capability for rapid adjustments, making it highly adaptable and able to flexibly adjust according to different needs, which can significantly improve work efficiency and save manpower and resources. In comparison, manual operations may require more time and effort to adapt to different maintenance requirements.

The technology of intelligent devices has significantly enhanced the operational efficiency of enterprises through precise control and optimized processes [8].In the future, maintenance methods for intelligent devices will gradually replace traditional manual packaging techniques, which have many drawbacks, achieving a dual improvements in safety and work efficiency, and enhancing the country's smart grid infrastructure.

4.2.3 Safety

The outer layer of the metal core of overhead distribution lines is coated with insulating rubber for protection. However, strong winds, exposure to sunlight, corrosion from rain, and falling or scraping from foreign objects like trees can lead to damage of the insulation layer. During maintenance, variable obstacles such as trees, are often encountered, which may result in grounding of the line, tripping of the circuit, or electric shock incidents. The traditional manual maintenance method necessitates a power outage to operate, which poses issues such as high labor intensity, elevated risk factors, extended construction periods, and considerable power loss. According to a survey, a 600 km distribution line experiences an average of approximately 100 emergency repairs per year, resulting in substantial power outage losses due to these repair operations. Additionally, in the power industry, accidents involving personal injuries during high-altitude emergency repairs occur frequently. Using intelligent equipment for maintenance allows for the completion of maintenance work on overhead lines while energized, effectively addressing the aforementioned issues. This approach reduces harm to workers, lowers the risk of occupational injuries, achieves a dual improvement in safety and work efficiency, and ensures the safe and orderly operation of the distribution network.

4.2.4 Financial management

As the electricity reform deepens, the operating and maintenance costs of power grid companies will be influenced by various factors. It is anticipated that the growth of new operation and maintenance repair costs will gradually decelerate in the coming years, and companies need to pay attention to optimizing operation and maintenance repair costs [9].The intelligent detection and automatic data analysis functions of smart device maintenance methods assist enterprises manage costs more accurately and optimizing financial management. Specifically, the company can analyze data from the maintenance process to understand the cost composition and influencing factors during maintenance. This helps the enterprise formulate scientific and reasonable cost control strategies, reduce cost expenditures, and significantly enhance the company's profitability. The maintenance methods for intelligent devices provide enterprises with more accurate data information, allowing them to adjust resource allocation in a timely manner based on actual conditions, thereby avoiding resource waste and uneven distribution. This effectively enhances operational efficiency and economic benefits [10].

4.2.5 Social benefits

The Chinese power industry is undergoing an accelerated transformation towards digitalization, intelligence, and greening. With the advancement of the "dual carbon" goals, the installed capacity of renewable energy continues to expand, and the construction of smart grids is being implemented more deeply, and the complexity and safety requirements of the power system have significantly increased. The inspection of electrical equipment, a core aspect of ensuring the reliable operation of the power grid, is becoming increasingly important. The investment in and utilization of intelligent devices can further promote deep cooperation between industry, academia, and research, improve the input-output efficiency of scientific and technological research and development, provide assistance in enhancing the efficiency of enterprise innovation systems, and optimize the overall development framework of businesses. The commissioning of the insulation wrapping device for distribution lines has significantly improved the efficiency of the insulation wrapping repair work for the power supply company in Fengtai County. It has further enhanced the stability and safety of the operation and maintenance of distribution lines, laying a solid foundation for the automation and intelligent development of the company's transmission line operation and maintenance. At the same time, the workload for replacing insulated wires during power outages has been greatly reduced, and the risk of personal injury and fatalities in the power grid has been significantly lowered, fully implementing the requirements and directives regarding safety production work. At the same time, it can promote the development of the specialized insulation sheath industry for insulated wrapping. As of now, there are no products similar to the 10kV distribution line insulation wrapping devices in the world. With the deepening of the insulation of bare conductors, it can significantly advance the development of related industries, address employment issues, and improve the local economic level.

5. Conclusion

After an in-depth study of insulation wrapping devices for distribution lines, as well as a thorough comparative analysis of their economic costs and application effects, the annual primary economic costs and application results of different operating methods have been revealed. The conclusions are as follows:

The analysis of economic cost comparison shows that under the same workload and performance requirements, using intelligent equipment for operations can reduce economic costs by an average of 65%. Furthermore, the initial research and development investment can be recouped in a relatively short period, indicating a promising market outlook.

Through a comparative analysis of application effects, it has been concluded that the implementation of insulation wrapping devices for distribution lines has significantly improved the efficiency of insulation wrapping repair work for the distribution lines of the Fengtai County Power Supply Company. This advancement has further enhanced the stability and safety of the operation and maintenance of distribution lines, and the economic cost is relatively low. It helps enterprises to achieve cost reduction and efficiency improvement, realizing lean financial management and has good economic and social benefits.

With the advancement of the Internet of Things, big data, and artificial intelligence technologies, intelligent maintenance systems will facilitate real-time monitoring of conditions, predict failures, and enable preventive maintenance. This approach will reduce the downtime and maintenance costs caused by unexpected failures while enhancing the stability and safety of distribution line operations and maintenance. At the same time, by conducting in-depth analyses of maintenance data, we can develop scientific and effective maintenance plans and strategies, reduce maintenance costs, and optimizing maintenance solutions. This cost-effective development strategy will support the company's lean cost management initiatives and promote the integration of finance and operations within power enterprises.

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