

Development of Power Supply Technology in Power Inspection and Monitoring System

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Abstract

In the process of power system inspection and monitoring, how to ensure the continuous and stable supply of power is the key to the efficient operation of power equipment. This paper focuses on the power supply mode of substation inspection robot, transmission line inspection robot and monitoring system, analyzes the advantages and disadvantages of power supply technology, and further discusses the future development trend of power supply technology application of power inspection and monitoring system.

Keywords

Power Inspection; Transmission Line Monitoring System; Inspection Robots; Power Supply Technology.

1. Introduction

The sustainable and stable operation of modern power grid system depends on the support of advanced equipment. Therefore, many experts and scholars at home and abroad focus on power equipment to ensure its smooth operation. Such as transmission line monitoring equipment[1][2][3], inspection robot[4] and substation inspection robot[5], to monitor the transmission line state and parameter changes, to ensure the safety of substation, and has made many brilliant achievements. However, the research on how to supply power with power equipment is not exhaustive. Due to the particularity of the working environment of power equipment, how to supply power at the power system terminal is an urgent problem to be solved.

First, considering the safety of high-voltage transmission lines and substation power equipment, direct connection with the power supply terminal may cause equipment damage and it is difficult for the terminal circuit to be exposed outdoors to get daily maintenance, which will have great security risks. Therefore, it is necessary to maintain the power supply mode with a long maintenance cycle and not easily affected by the environment. Second, many devices need to transmit the condition of high voltage transmission lines to the ground, and the increasing voltage level of the power grid will affect the communication equipment by electromagnetic field, which puts forward higher requirements for the anti-interference ability of the equipment. The research on power supply mode of power equipment is very valuable. This paper summarizes and compares the power supply technology from the perspective of transmission line monitoring equipment, inspection robot and substation inspection robot, and expounds its shortcomings, and analyzes the future development trend of power supply technology for power equipment.

2. Classification of Power Supply Technology for Power Equipment

There are many kinds of power equipment in modern power grid. Transmission line monitoring equipment, line inspection robot and substation inspection robot are the most studied power

equipment by experts and scholars at home and abroad. This paper will classify the power supply technology applied to power equipment, as shown in Figure 1.

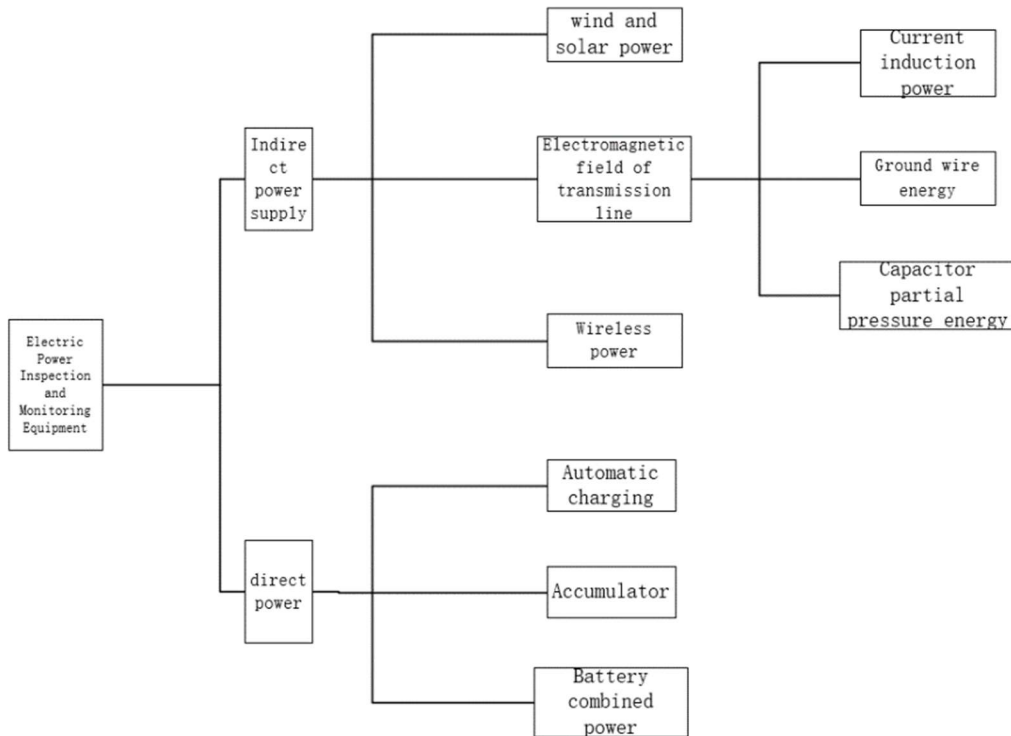


Figure 1. Classification chart of power supply technology

3. Indirect Power Supply

3.1 Wind and Solar Power Supply

Wind power supply mainly uses wind turbines to convert natural wind into electricity. Guizhou Power Grid has developed a wind powered high voltage transmission line patrol robot, as shown in Figure 2[6]. The whole power supply system is installed in the box of the robot, and the blade is connected with the generator by the transmission shaft, so as to convert wind energy into electrical energy.

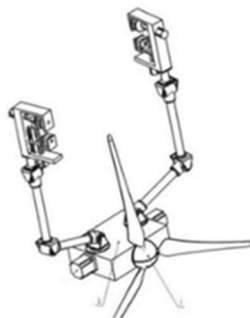


Figure 2. Wind power patrol robot

Wind energy as a natural energy inexhaustible is its huge advantage. However, this power supply mode has great limitations. (1) In order to better ensure the normal operation of the transmission line, the transmission line inspection robot will carry many equipment to inspect. If the wind is added again, the weight of the robot will increase, which is not conducive to the service life of the inspection robot. (2) There are no abundant wind resources in many transmission line environments, which need

to be applied in open and windy areas, and sufficient wind speed needs to be ensured, which is not universal.

The utilization of solar energy in China and abroad has many years of research foundation and practical experience, and the technology is relatively mature. When sunlight is sufficient, photovoltaic panels are used to convert solar energy into electricity. Yu Dengke et al designed a solar power supply system to solve the problem of independent power supply of monitoring equipment installed on transmission line towers, and carried out an example calculation and verification. In the peak sunshine of 3.9 h, four consecutive rainy days can supply 179 Ah of battery and 138 W of power[7]. Yu Yansheng et al invented and designed a new type of charging device for patrol robot. The device uses solar cells to convert solar energy into electrical energy and store it into batteries to power the patrol robot[8].

Solar energy as a clean energy has a unique advantage. But solar power supply also has the following problems. (1) The output is vulnerable to light intensity, environmental temperature changes, seasonal changes and other factors. Therefore, for the equipment powered by light energy, in order to ensure the reliable operation of the equipment in cloudy, rainy and snowy weather and night, it is necessary to install large-capacity rechargeable batteries. The battery life is short, which can only be used 600 – 1000 times. After 2 – 3 years, the new battery must be replaced, which is in conflict with the long-term stable operation performance required by outdoor power equipment. (2) The large volume of solar cell square plate increases the weight of power equipment and affects the service life.

3.2 Electromagnetic Field of Transmission Line

The power supply modes for inspection robot and monitoring system by using electromagnetic field of transmission line mainly include current induction power supply, ground wire energy supply and capacitor partial pressure energy supply.

3.2.1 Current Induction Power Supply

Current induction power supply is also called induction current power supply or CT power supply. As is known to all, the high-voltage transmission line itself is a large channel for energy transmission, and it is a good scheme to use its own energy for energy supply. However, China's high-voltage transmission lines are mainly divided into AC and DC, and most of them are AC transmission lines. Therefore, many scholars in China have studied more on the current-inductive energy harvesting, and its principle is similar to that of the current transformer. The basic idea of power harvesting design is that the alternating magnetic field will be generated around the AC transmission line. When the current changes, the induction coil is used to generate the induced voltage on the secondary side of the AC transmission line. After rectification, filtering and voltage stabilization, the load is supplied by the DC-DC power supply module or energy storage component.

At present, the current induction power supply technology is more applied to the patrol robot. Many experts and scholars mainly study the structure design, magnetic core material, output power, voltage influence factors and power circuit design of this power supply mode. Li Weifeng et al have designed a claw-type inductive power supply structure and successfully applied to the patrol robot. At the same time, the size of the magnetic core, the number of turns of the coil and the output power are studied. The prototype experiment proves that the maximum output power of this scheme is close to 40 W when the transmission line current is 200 A[9]. Valenta Pavel et al used the split core current transformer to solve the power supply problem for the patrol robot, and then carried out the actual test on the 110 kV power line. Under the transmission line current of 200 A, the maximum power can be obtained over 90 W[10]. Sarbajit Paul et al designed power-taking mechanisms with dual-core materials to provide sufficient power for de-icing patrol robots[11]. Mingbo Yang et al proposed the dynamic control of air gap length and coil turns to deal with the problem of unstable output caused by large variation of transmission line current[12]. The simulation results show that the output power of current induction mechanism can be more stable. The circuit structure of the power supply is designed in detail. The experimental results show that the current induction device can charge 24V12Ah lithium battery continuously at 6A current[13].

Although the current induction charging structure is simple, it is widely used. However, there are still the following problems : (1) The current fluctuation of AC transmission line is large, which leads to the unstable output power of induction power extraction device and the output dead zone. (2) When the power current of the transmission line is too large, the power supply device is short-circuited and the structure is damaged. How to effectively protect the power supply is also a problem to be considered. (3) How to supply power at any time without interfering with the normal operation of the patrol robot.

3.2.2 Ground Wire Energy Supply

The principle of ground wire energy supply is that AC transmission lines generate alternating magnetic field to excite vortex electric field. The induced electric field will form a closed loop with the ground wire. If the load is connected to the wire, the induced electromotive force and induced current will be generated. The principle is shown in Figure 3.

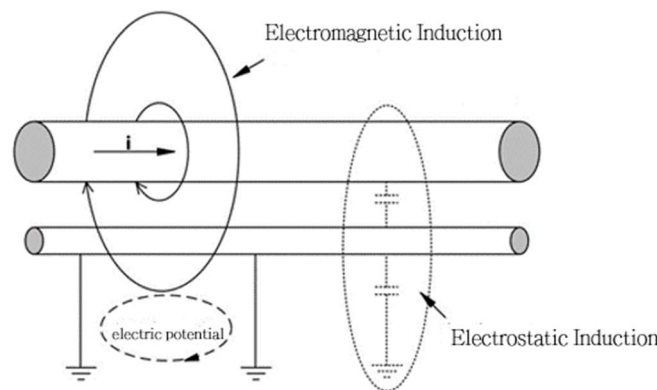


Figure 3. The principle diagram of ground line energy extraction

Ground wire energy supply is more for low voltage side transmission line monitoring equipment to collect electrical energy. Vasquez-Arnez et al. found that there were two kinds of induction effects in the transmission line, namely electromagnetic induction and electrostatic induction. The simulation analysis showed that the induced current generated by the double ground wire was twice that generated by the single ground wire. In order to prove this theory, experiments were carried out on the overhead line at 525 V, indicating that for the current of the phase conductor 200 A, the induced power was sufficient to supply power for small load[14]. Jiang Xingliang analyzed the equivalent circuit of ground wire energy harvesting, calculated the maximum power, and measured the data error on 220 kv transmission line, which provided a theoretical calculation method for domestic ground wire energy harvesting[15]. Based on the original ground wire energy harvesting, Fan et al. proposed a new energy harvesting method for tower-by-tower grounding optical fiber composite overhead ground wire (OPGW). OPGW was connected with the earth to form a closed circuit to supply power to the load[16]. Xie Yanbin et al put forward the theory of piecewise insulated ground wire, that is, ground wire and ground wire constitute a closed loop, and proved that the output power can meet the demand of online power supply in 500 kv line[17].

There are two grounding wires of typical overhead transmission lines, namely OPGW and segmented insulated ground wire. The location of the load is the difference between the two theories. Both theoretical analysis and experimental methods of experts can supply power for small power monitoring equipment. However, there are still some problems: (1) For tower-by-tower grounding, the load can only be placed in the continuous optical fiber. (2) For sectional insulated ground wire, although the power is larger than the former and the position is not restricted, the ground wire is vulnerable to lightning shocks and has a great test on the protection of the energy harvesting device.

3.2.3 Capacitor Partial Pressure Energy Supply

The capacitor voltage divider is mainly used to convert the electric field generated by the high voltage transmission line into electrical energy. As shown in Figure 4, it is the principle diagram of the capacitor voltage divider. The high capacitance of C_1 and the low capacitance of C_2 are in series. The voltage U_0 obtained by the parallel connection of the low capacitance and the load is the input voltage of the power supply device, and then the obtained electrical energy is output to the supply side equipment through the rectifier and filter circuit. Capacitance partial pressure energy supply technology is more applied to transmission line monitoring equipment.

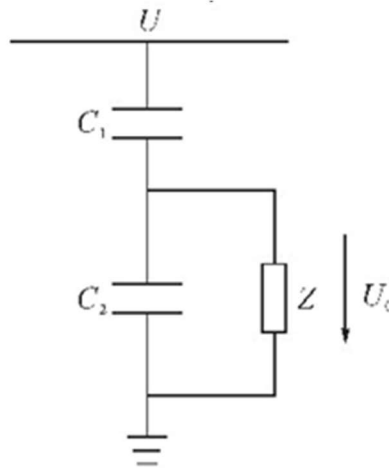


Figure 4. Capacitor partial pressure energy supply

In order to make the output voltage of capacitor voltage more stable, Wu ke et al improved the capacitor material. The high-voltage capacitor used ceramic material, and the low-voltage capacitor used metallized polypropylene film[18]. The loss caused by the decrease of capacitance with temperature is ensured. Zhao Dongsheng et al carried out numerical analysis on AC double-circuit 500 kv dry-type transmission tower, and then used capacitive collector to collect the potential energy around it. The experiment proved that the output power of the potential energy collector meets the minimum power of the wireless sensor[19]. Dong Yuting et al in the experimental process of high voltage capacitor charging technology, replaced the aluminum plate capacitor, and output stable current at 110 kv, 220 kv and 500 kv high voltage[20].

There are several problems in capacitor voltage divider technology : (1) When collecting electric energy, the load needs to meet the great impedance to achieve the desired output power due to the high impedance characteristics of the material itself. (2) The capacitance is sensitive to the change of ambient temperature, and it is easy to produce large output error. (3) In many literature studies, the output power of capacitor voltage sharing technology is limited, which cannot meet the work of large power monitoring system.

3.3 Wireless Power Supply

Wireless transmission power supply (WPT), according to the principle of WPT can be roughly divided into three categories, magnetic induction coupling, microwave radiation and magnetic coupling resonance. Magnetic induction coupling power supply uses the principle of separable transformer to transmit electric energy, which can only be transmitted in close range. Microwave radiation is mainly composed of two parts, microwave power source and transmitting antenna. The microwave power source converts electric energy into microwave energy, and the transmitting antenna receives the microwave to realize power transmission, which can realize long-distance transmission. Magnetic coupling resonance uses two same resonant coils, when the resonant frequency is the same and the distance is a certain distance, it will produce electromagnetic coupling

phenomenon. The electric energy is transmitted by coupling resonance, which is suitable for medium and longer distance transmission. Figure 5 is the schematic diagram of magnetic coupling resonance[21]. Therefore, many experts and scholars have found that the energy supply principle, transmission structure and transmission distance of magnetic coupling resonant technology are more suitable for power supply of power equipment, especially for substation inspection robots and transmission line monitoring equipment. Therefore, this paper will focus on this method.

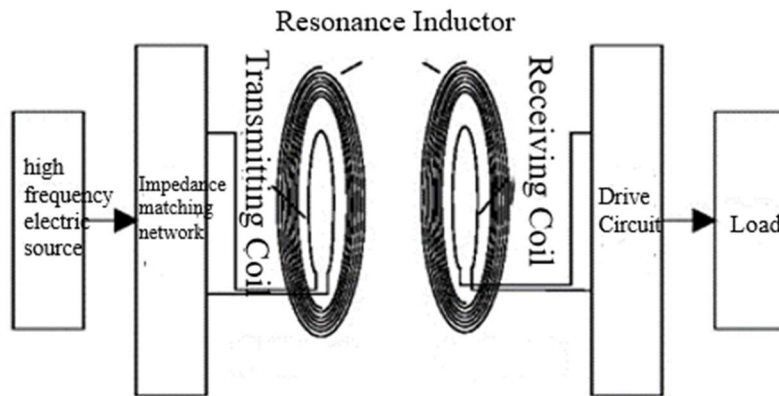


Figure 5. Principle diagram of magnetic coupling resonance

Magnetic coupling resonance system is mainly composed of transmitting coil and receiving coil. In the application of substation inspection robot, more experts focus on the structure of transmitting end and receiving end. Jiang Bingwei et al. proposed to design the component section transmitting coil rail for the receiving end of the wireless charging system of the substation inspection robot. As shown in Figure 6(a), compared with the long rail transmitting coil, the efficiency is greatly improved, and the rail soft switching is used between the coils to prevent large current shocks and protect the circuit[22]. Han Liu et al. proposed the structure of decentralized energy receiving coil based on the use of segmented rail transmitting coil, that is, an additional coil is added at the receiving end of the substation inspection robot, as shown in Fig. 6 (b), and the working performance is compared with that of a single receiving end coil. The conclusion is that the structure and performance of the decentralized energy receiving coil are better[23].

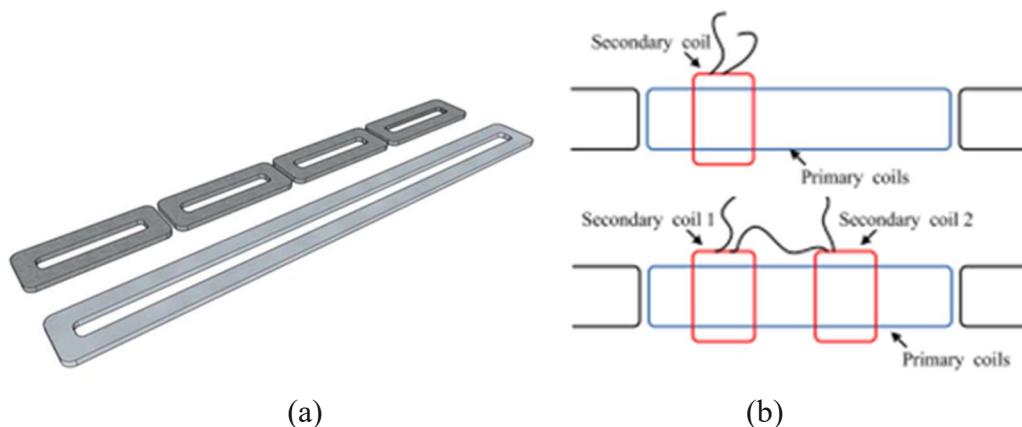


Figure 6. Coil structure of transmitter and receiver

In the application of radio energy in transmission line monitoring equipment, it is more likely to be combined with current induction, which is equivalent to high-frequency power supply. The number

of coils and circuit structure of magnetic coupling resonance system are studied. Dai Xinwen proposed to combine inductive current (CT) with wireless power transmission, and add multiple relay coils to increase the coupling coefficient, and the transmitter coil adopts LCC compensation network[24]. Based on the multi-relay LCC magnetic coupling system, Hou et al carried out numerical simulation analysis on the three working modes of the transmitter LCC compensation network, and proved that the output power and constant voltage characteristics of the system can be improved in this mode[25]. In order to transmit the energy at the high voltage side to the transmission line monitoring equipment at the low voltage side, Qu et al proposed to embed 11 relay resonant coils into large insulators with an interval of 95 mm, as shown in Fig. 7. The actual measurement was carried out based on the 110 kV insulator prototype, which proved the feasibility of this method[26].

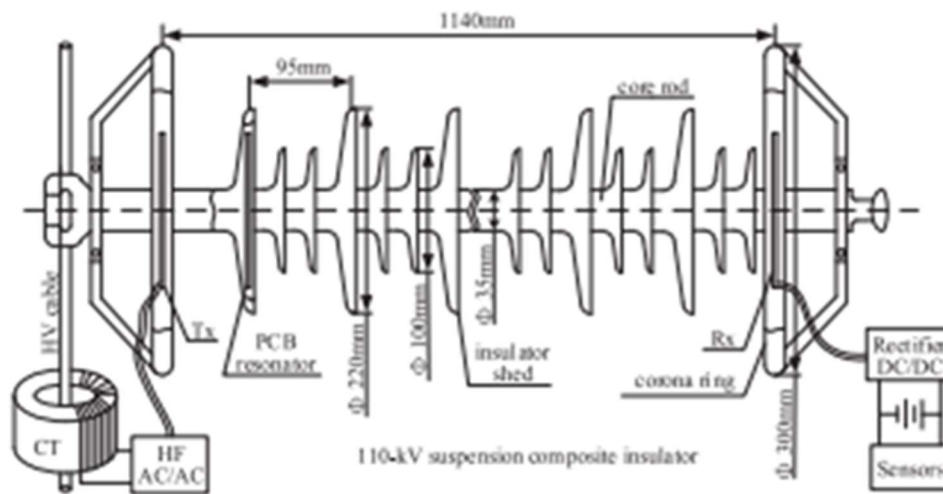


Figure 7. 110kv suspended composite insulator wireless power transmission structure

Wireless power transmission has the advantages of small electromagnetic radiation and high transmission efficiency in the application of power equipment. However, there are still problems to be solved. (1) In principle, the frequency of the transmitting coil and the receiving coil needs to be consistent. If there is an error, the transmission efficiency will be greatly reduced.(2) As substations and transmission lines are high electromagnetic fields, how to ensure electromagnetic compatibility and electromagnetic safety of transmission coils. (3) Due to the particularity of power equipment, how to optimize the structure of the transmitter and the output is still an urgent problem to be solved.

4. Direct Power

4.1 Battery Power

Energy storage and lithium battery is mainly to convert chemical energy into electrical energy, which can be stably supplied. As a traditional power supply, battery is still widely used in some low power monitoring equipment, with the advantages of low cost and high safety. However, if it is used in high power occasions, the service life of the battery is relatively short, and it is often inconvenient to replace the power supply of outdoor power equipment, and the cost will also increase.

4.2 Combined Power Supply

The combined power supply is a combination of battery as an auxiliary power supply and other power supply modes to form a combined power supply system. The storage and lithium batteries are mostly complemented by current induction, laser, solar energy and wind energy to achieve stable power supply. This combined power supply also has some problems, when using the above way to collect energy stored in the battery, in order to obtain power output, stable voltage and current circuit design, resulting in power supply structure becomes complicated.

4.3 Auto-charging Technology

Automatic charging technology is mainly divided into two types of wired contact automatic charging and wireless charging. Wireless charging, namely wireless transmission energy supply, has been introduced in detail above. Wire contact automatic charging is the use of cable or metal wire as a transmission medium and power grid port, automatic connection through navigation power supply. In the early stage, automatic charging technology was mainly applied to the charging pile designed to meet the long-distance driving of electric vehicles. For example, the snake robot independently developed by Tesla can automatically charge the electric vehicle. With the development of automatic charging technology, it has been widely applied to substation inspection robots and other service types of robots. Song Zhifeng put forward the automatic charging scheme of substation inspection robot, which takes the automatic charging structure and charging room as the core, can accurately charge the docking, and reduce the influence of vibration on the charging position[27]. In order to ensure the safe and reliable charging of substation inspection robots without intervention, Yang et al designed an automatic charging system for the lateral docking of charging devices. The structural diagram of the contact lateral charging docking device is shown in Fig. 8. Guided by the magnetic track, the navigation accuracy is high, and the sliding groove is used to connect the charging seat and the positioning groove plate to ensure the reliability of automatic charging[28].

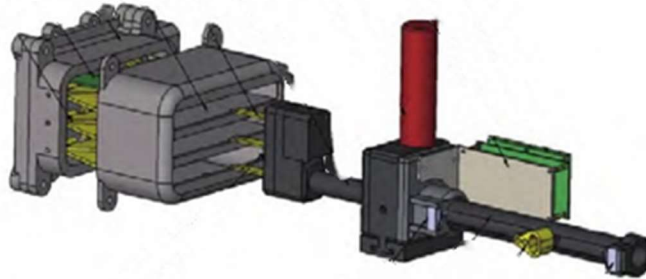


Figure 8. Structure diagram of contact lateral charging docking device

Automatic charging technology has many advantages, especially in the application of substation inspection robot is more obvious, save more human and financial costs, large charging output power, has great flexibility, more in line with the needs of China 's power grid intelligent automation development. At the same time, this technology also has the following problems. (1) The navigation accuracy and search range of the inspection robot in searching the charging pile need to be improved. (2) When the inspection robot is docked with the charging pile contact, sparks are prone to security risks. And how to accurately dock with the charging pile is a major problem faced by automatic charging technology.

5. Conclusion

The application of power supply technology in power inspection and monitoring system is summarized as shown in table 1. For the use of wind and solar energy for power supply, it is necessary to consider whether environmental natural energy is rich and applied. Current induction, ground wire power supply, capacitor voltage sharing power supply technology, such as solving the key problems it faces, has great future development prospects. Wireless transmission power supply, although some achievements but still in the initial stage, in the future wireless transmission system will have a broader application prospect. Automatic charging technology is not only applied in power system, but also mature in other fields. Battery combined power supply and other combined power supply technologies must be an important research direction in the future.

Table 1. Summary table of power supply technology

	Power supply principle	Application scenarios	Advantages	Shortcomings
Wind and solar power	Power Supply Using Fan and Solar Panel	Transmission Line Robot and Monitoring System	As natural energy inexhaustible is its huge advantage	Larger weight has limitations due to environmental impacts
Current induction power	Electromagnetic field generated by AC transmission lines	Transmission Line Robot and Monitoring System	Simple structure and high output power	Existence of output dead zone, vulnerable to transmission current
Ground wire energy			Low voltage side equipment available	Low output power, limited placement
Capacitor partial pressure energy			Simple structure	Affected by environment and material properties
Wireless power	Magnetic Coupling Resonance Power Supply Using Resonant Coil	Substation Inspection Robot and Transmission Line Monitoring System	Suitable for medium and long distance transmission with high transmission efficiency	Frequency needs to be consistent, structural optimization and other issues
Automatic charging	Automatic Power Supply by Navigation	Substation Inspection Robot	Economically low cost and unmanned manipulation	Navigation accuracy and search range need to be improved
Accumulator		Suitable for all application scenarios	Low cost and high safety	Shorter battery life and inconvenient replacement
Battery combined power	Other Power Supply Methods Storage Battery Power Supply	Transmission Line Robot and Monitoring System	Stable output power	Complex structure of power supply and heavy weight of equipment

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