Research and Application of a New Electric Coupling Device

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Abstract. With the increase in the size of the distribution network, as the overhead cable that accounts for the largest proportion in the urban power grid, the importance of electricity inspection and phase detection is also increasing. In order to avoid the shortcomings of traditional electroscope and the possible serious consequences caused by incorrect phase-detecting, this paper proposes a new type of electric coupling device, introduces the structure and performance of the device, and analyzes its advantages and practical applications. This electric coupling device can measure, calculate, analyze and report the real-time status of transmission line operation, and it can fully meet the requirements of engineering that is economical and practical, safe and reliable, and intuitive judgment.

1 Preface

With the rapid development of China's national economy, the grid capacity and power load are increasing, the grid operation mode and grid structure are becoming more and more complex, and the stability requirements of the grid are also increasing. During the overhaul of power lines or substation equipment, the problem of the traditional electroscope's presence of a blind spot on the induced voltage directly affects the safety of the operator, and it may also reduce the insulation of the wire and damage the line [¹]. In addition, the incorrect phase-detecting may cause damage to electrical equipment, damage to the original stability and balance of the power grid system, etc [²], and the phase detection of substations and lines is also more complicated. In this paper, at the same time of electrical inspection and measurement, voltage phase information is obtained, and the working efficiency of the nuclear phase is improved.

2 Structure of a new type of electric coupling device

In this paper, a new electric coupling device is designed according to the principle of space capacitance partial voltage [³]. Place a parallel plate under the test line, the capacitance between the plates, the distributed capacitance between the upper plate and the test line, and the distributed capacitance of the lower plate box to ground together constitute a space capacitor voltage divider, it can achieve non-contact measurement [⁴]. If the electroscope is designed to be an integral structure that is not conducive to observation and inconvenient to use, the electroscope shall be lifted for measurement and the electric field distribution under
the circuit shall be changed. Therefore, the electrical inspection coupling device is designed as a split structure composed of a receiver and a transmitter. The structure distribution of the electric coupling device is shown in Figure 1.

![Figure 1. Structure distribution diagram of the electric coupling device.](image)

The power system applicable to the new type of electric quantity coupling device developed in this paper is: rated frequency 50Hz, rated voltage 10kV, working current 0~500A, applicable wire diameter 9 ~ 26.8mm (35 ~ 240mm²), and the neutral grounding mode is various grounding modes; The communication index of the device are: working frequency 880~915MHz, transmitting power 23dBm ± 2dB, receiving sensitivity ≥-129dBm, communication rate 200kbps; power supply: battery capacity 3.6V, 9Ah, self-powered operation line current >3A; power supply: battery capacity 3.6V, 9Ah, self-powered operation line current >3A; mechanical characteristics of the device: size (WxHxD) 115mm × 115mm × 178mm, weight <1.0kg, protection grade IP67. The device dimensions are shown in Figure 2.

![Figure 2. Dimensions of the electric coupling devices.](image)

3 Performance of the new electric coupling device

The signal acquisition and processing is the most important part in the design of the new electric coupling device. The device can collect all electrical indicators at any time and at any point in the distribution network and upload them to the cloud. The data formed by it has the following characteristics:

(1) abundant information
1) Collect all the characteristic data of power on the distribution network, including:
three-phase current, three-phase voltage, voltage fluctuation rate, power, electricity consumption, power factor, voltage harmonic component, current harmonic component, three-phase unbalance, Line Loss.

2) All the data in the distribution network were collected, including trunk, branches and leaf nodes.

3) In addition to reporting characteristic data, the device can also collect and upload real-time waveforms from the distribution network. The collection methods include cloud instruction wave recording, fault triggered wave recording, and periodic wave recording.

2) Strong competence of collecting information
1) 6600 samples per second, real-time calculation, real-time analysis.
2) Report characteristic data every minute.

3) High data synchronization
1) Three-phase synchronous acquisition, support GPS time synchronization, error <30ns.
2) All devices on the whole line are collected simultaneously, and the error is less than 0.01 milliseconds. The collected data has a strong causal relationship and a high analyzable value.

3) The waveform of the recorded wave is the same period waveform, and the running status on the line can be analyzed in real time.

This equipment is equivalent to moving the oscilloscope in the laboratory to the line, and real-time analysis of the waveform through the edge computing chip, so as to extract the characteristic data and upload it. For the three-phase imbalance of distribution network lines, voltage harmonics, current harmonics, and energy supply quality also provide direct data. Therefore, the distribution network failure model, dynamic load model, ring network scheduling model, power flow model, and line loss model in the laboratory can all be used as data processing methods, adding power system analysis methods.

4 Advantages of the new power coupling device

The new electric coupling device can measure current, power factor and harmonic of the line with high precision, and can periodically send on-line recordings to monitor the working status of the line in real time. In the extreme case of network failure, the equipment status and waveform data can also be transmitted via Bluetooth, which is convenient for maintenance personnel to understand the site conditions. The specific advantages are as follows:

1) Achieve comprehensive high-precision measurement

With the help of accurate current measurement and voltage measurement detection technology, the measurement accuracy can be less than 0.5% in the range of line current 10~500A; An error of less than 0.5% can be obtained in the line voltage range of 8-12kV; the power factor measurement error is less than 0.5%; the accurate measurement of the accumulated power on the line is achieved, and the measurement error is less than 1%; the proportion of the 2-30th harmonic component on the line is accurately analyzed, and the measurement error of the voltage harmonic distortion rate and current harmonic distortion rate is less than 1%; online temperature measurement ±0.1°C.

2) Support remote recording waveform

1) Support regular wave recording and analyze line working conditions through waveform. The period of regular wave recording can be configured in the background.

2) Support fault recording waveform and zero sequence synthesis. When a fault occurs on the line, send 4 cycles of waveform before failure and 8 cycles of waveform after failure to the cloud. It also supports handheld device on-site Bluetooth recorder.
(3) Provide abundant operation information
It can provide the main station system with line current, line voltage, power factor, average power consumption, voltage harmonic distortion rate, current harmonic distortion rate and other working condition information, as well as auxiliary information such as air temperature and humidity, equipment battery voltage and so on, so as to help the operators master the line operation status comprehensively.

(4) Multiple modes of communication
Using low-power Bluetooth and NB-IoT communication technology. NB-IoT (Narrow Band Internet of Things (NB-IoT) remotely reports online data information; by means of Bluetooth communication, field investigation and detection can be carried out.

(5) Real-time monitoring, the state of the line can be controlled at any time
24 hours of uninterrupted collection of signals, the sampling rate of 6600, the use of excellent software algorithm, in the collection at the same time to calculate the data in the sampling period, without missing a data. Real-time analysis of the voltage, current, power factor, and harmonic components of each cycle; accumulate power per minute and analyze whether the line is faulty; form a set of data every minute, including accumulated power, average power factor, and average voltage harmonic distortion rate, average current harmonic distortion rate, instantaneous voltage, instantaneous current; report once every 3 minutes (including 3 sets of data). When the network fails, the device can save 8 hours of data to ensure the reliability of the device.

(6) High-efficiency online energy acquisition circuit without battery
Built-in large-capacity supercapacitor, through the application of efficient energy acquisition circuit, the line current is greater than 3A to meet the minimum requirements for self-powered operation. When the battery is fully charged, the device can continue to work at low power consumption for 45 days when there is no current on the line.

(7) Maintenance-free design, remote wireless upgrade
It can run autonomously after hanging up, completely maintenance-free design. When necessary, the operating parameters can be maintained remotely and wirelessly to update the fault criterion or upgrade the software program, which is convenient and flexible and improves work efficiency.

8) Electric loading and unloading, safe and convenient
It is safe and convenient to install and disassemble the device live with the insulating operating rod.

(9) High-level safety protection, not afraid of wind and rain
Adopt reliable industrial design, with high-grade electromagnetic compatibility protection capability, extremely strong wide pressure and wide temperature working characteristics, shell protection grade reaches IP67, can resist 8-level typhoon and heavy rain; structural parts adopt anti-corrosion and anti-rust treatment, which can resist salt spray corrosion and ensure steady operation and stable in harsh environments in the long run.

5 Practical application of the new type electric coupling device
The actual application scenarios of the new electric coupling device are as follows:

(1) Contribute to grid planning
The analysis of the current status of the power grid is the basic work of power grid planning. It can be clarified whether the power supply capacity of the current power grid can meet the needs of the existing load and whether it can adapt to the increase of the load, thereby providing a basis for the construction of the target power grid. After the local economy develops, the originally planned load of the power grid is often insufficient to meet the demand, so expansion of the line is imperative. But how to comprehensively and most cost-effectively expand capacity is inseparable from the daily monitoring of online
loads. The device can count the current of each branch of the distribution network by minute, so it can know the situation of line overload at any time, count the size and time of overload, so as to find out the lines with insufficient capacity and need to be replaced.

(2) Comprehensive anti-theft of electricity
Combating electricity theft is an urgent requirement for ensuring the safety of the power grid, improving the reliability of power supply, maintaining the order of the power market, and ensuring the benefits of power supply enterprises [6]. By monitoring the total power consumption of each branch, the power situation of each branch of the line can be monitored. If unexpected power loss occurs on the line, the system can locate the segment where the power is lost within 5 minutes, which is especially suitable for long-distance power transmission. At the same time, the device is equivalent to a meter on the high-pressure side. Comparing the reading of the device with that of the low-voltage side can prevent the low-voltage side from stealing power, which is realized by changing the turn ratio of the current transformer coil.

(3) Digital patrol line
The patrol of overhead lines by grid companies has always been a problem that has plagued the industry. Untimely and inaccurate line inspection will lead to serious consequences [7]. For example, the forest fire caused by the disconnection of the power grid of the US Grid Company has affected several states and caused huge losses to the grid company. At present, some places in our country have begun to try line patrol robots, or drone patrol lines. These methods are not mature enough but costly.

From the point of view of what the line patrol is responsible for, it is necessary to solve the problems of operation monitoring and condition monitoring. The monitoring of the line state has different levels of importance, and some of the more important content, once there are problems, its changes can also be reflected by the actual waveforms of voltage and current. For example: the branches touch the wire for a short time, the joint is loose, the cable is broken, the wire is loose and close to the ground to form an arc discharge, etc. Once we can analyze these problems through digital methods, the requirements and frequency of line patrol can be greatly reduced.

(4) Follow up the production status of the enterprise
The device can accurately observe the production of enterprises on the high-pressure side, which is very important for banks, insurance, securities and other companies. The device can detect the harmonic generated in the production process of the enterprise, which is the fingerprint of the enterprise production. We can analyze the production line operated by the enterprise, the enabled machinery and equipment, and the running time of various equipment through big data. Such data is of greater value to financial institutions. In addition, the data analysis can also be used for environmental protection monitoring, to avoid the case where the user only starts the production equipment and does not start the environmental protection equipment. Data is also very important for the government to build energy big data.

(5) Warning of transformer failure
Through the new electric coupling device, combined with the data of the low-voltage side monitoring equipment, the conversion efficiency of the transformer can be checked in time. Once the conversion efficiency of the transformer becomes low, an alarm is immediately reported. At the same time, it can also track the duration of transformer overloading for a long time, predict the life of the transformer, and warn the transformer of the fault [8].

(6) Timely discover, report and locate line faults
The non-contact device has the advantages of small volume of magnetic field coil and low cost, which is suitable for dense layout along the line [9], and can solve the following problems:
1) Solve the problem of the overhead line passing through the mountain forest contacting the tree, which once caused a forest fire.

2) Solve the problem of electrocution in humans and animals when the wire ends are grounded.

3) Directly report the location of the grounding point, and troubleshoot problems more quickly, the system will not report false alarms.

4) When the circuit breaker tripping, the device can directly report which circuit breaker tripping, which is beneficial to the faster restoration of power supply of the line.

7) Find out the quality problems of line power supply and identify their sources

Qualified power quality is the basic requirement of power system operation, and the continuous monitoring, analysis and evaluation of power quality information is the prerequisite for discovering power quality problems and improving power quality level [10].

1) The device can timely find the time distribution with low power factor and high three-phase imbalance of the line, and also describe the harmonic components and harmonic proportion of the line in each period.

2) The device can also find the source of the line that causes the poor power supply quality, which is helpful for maintenance personnel to solve the problem effectively. For example, if a section of a line has a low power factor for a long period of time, the device can identify which parts of the load are causing the problem and timely send signals to notify the maintenance personnel to solve the problem.

8) Verify various theoretical models applied in power grid

The predicted value of the load forecasting model used in the power grid can be compared with the measured data of the device, so as to improve the model and improve the accuracy of the forecast; at the same time, the measured data of the device can also be incorporated into the model to improve the computing speed. Today's simulation reclosing model of power grid can predict the current situation of all parts of the line after switching on, including the overload situation that we pay attention to. The device can not only improve the model, but also reduce the complexity of the operation model of simulated reclosing. In the case of ring network power supply, the operation time of the model can be reduced from 0.5 days to 1-2 seconds.

6 Conclusion

This paper proposes a new type of electric coupling device, which can measure, calculate, analyze and report the current, voltage, power, power factor, harmonic components and other real-time conditions of transmission line operation. At the same time, it also has the function of recording wave and fault indicator, which can transmit the device status and waveform data through Bluetooth when the network fails in extreme situations, which is convenient for maintenance personnel to survey anytime and anywhere. If used in the actual system, it can have a positive effect on the personal safety of the staff and the intelligence of the power system distribution network.

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