Remote acquisition of insulator icing flashover signal based on frequency optimization of ring-shaped intelligent current sensor

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Abstract—In order to improve the safety of power grid operation and avoid the hidden danger in the process of power supply, a remote acquisition method of insulator ice-covered flashover signal based on the frequency optimization of ring intelligent current sensor was proposed. According to principle of take electricity by capacitance, transmission line, current sensor, current sensor B and double rectifier circuit composed of parallel resonant magnetic circuit for electric model. By monitoring the current sensor and current sensor B the secondary side of induction electromotive force, magnetic core KaiQi gap equivalent permeability values, such as through the calculation of current sensor parameters of iron core and coil number of turns. In this paper, the current sensor is optimized to improve the power monitoring effect, and the remote acquisition of the flashover signal of insulator icing is realized. The experimental results show that. This monitoring method can effectively monitor the maximum load power, load resistance and load voltage of the model when the current value is different. In the face of impedance branch resonant, resonant and open air gap and other circumstances, can effectively monitor the power taking situation, a wide range of applications.

1. Introduction
The development of the power grid system has become increasingly mature and complete, and the power consumption in various fields has greatly increased [1]. With the continuous improvement of the voltage level of the transmission line, the demand for the safety of the power grid has also increased rapidly [2]. At present, the more commonly used methods of taking power mainly include battery power supply, laser power supply, capacitor voltage division power supply, current sensor induction power supply, etc. [3]. There are certain technical shortcomings and difficulties in the above-mentioned methods of obtaining electricity, in order to improve the reliability and safety of the transmission line to obtain electricity, and to ensure the safe operation of the transmission line [4,5]. Liu and others proposed a non-intrusive load monitoring method based on improved chicken flock algorithm. This method uses an improved chicken flock algorithm to monitor power grid load. Due to the influence of steady-state harmonic current and power, this method has low load identification and the monitoring data is not accurate enough[6]. Zhao and others proposed a four-way four-state modulation-based fiber optic gyroscope optical path power monitoring method. This method uses four-way four-state square wave modulation and software independent monitoring to achieve power monitoring, but the method has poor stability and performance. Broadband has a high degree of impact and cannot meet most power demand [7].
In order to solve the problems of the above methods, a method for remote acquisition of ice-covered flashover signal of insulator based on frequency optimization of annular smart current sensor is presented. The method achieves remote acquisition of ice-covered flashover signal of insulator by means of frequency optimization of shunt resonance dual magnetic circuit and monitoring principle.

2. Remote acquisition method for insulator icing flashover signal under frequency optimization of ring-shaped intelligent current sensor

2.1. Remote signal extraction for insulator icing flashover

The peak value, effective value and frequency are extracted from the remote signal of the insulator icing flashover. The characteristic quantity information such as the accumulated charge amount, the maximum pulse amplitude, the average value of the peak value in a certain time, the average value of the effective value and the number of pulses are extracted from the current signal. The software can display and store the voltage and current waveforms and characteristic quantities, and can call out the observation data for analysis afterwards. The calculation formula of signal extraction induced electromotive force is as follows:

\[ K_2 = \frac{2\pi fV_0\mu S\lambda i_1}{l} \]  \hspace{1cm} (1)

In equation (1), the induced electromotive force on the secondary side of the current sensor A and the relative permeability of the magnetic core material are represented by \( K_2 \) and \( \mu \), respectively. Power frequency 50Hz is represented by \( f \). The cross-sectional area of the core, the core lamination coefficient, the number of turns on the secondary side of the core, the average magnetic path length, and the vacuum permeability are represented by \( S \), \( \lambda \), \( V \), \( l \), and \( \mu_0 \) respectively [10]. In addition, due to the addition of the climbing skirt, the ice coating state is effectively improved, so that most of the ice is not bridged, and more air gaps are formed. At the same time, due to the installation of the climbing skirt, the overall climbing distance of the insulator is increased. In the case of the umbrella skirt without bridge, it also has a certain effect on the improvement of ice flash voltage.

The relative permeability \( \mu \) and the transmission line current \( i_1 \) are the main parameters of the induced electromotive force on the secondary side of the current sensor A. And the induced electromotive force of the secondary side of the current sensor A, the relative permeability and the current of the transmission line are all proportional. The current sensor A uses an open air gap, and the equivalent permeability calculation equation for the open air gap of the magnetic core is as follows:

\[ \mu_{eq} = \frac{\mu}{\delta} = \frac{1}{l + \frac{1}{\mu}} \approx \frac{l}{\delta} \]  \hspace{1cm} (2)

It can be seen from equation (2) that the equivalent permeability of the magnetic core drops rapidly after the magnetic core has an air gap, which reduces the induced electromotive force \( E_2 \) of the secondary side of the current sensor A. Therefore, the conventional current sensor takes less power [11].

In order to avoid the problem of small electric power of conventional current sensors, the new electric circuit topology is introduced into the electric circuit [12]. Using the principle of circuit shunting, suppose \( \mu' \) represents the relative permeability in parallel. Connect a non-open air-gap magnetic core with a relative permeability of \( \mu' \) to the branch of current sensor A, and the current expression equation input to current sensor B is as follows:

\[ i_2 = I - i_1 \]  \hspace{1cm} (3)
In equation (3), \( I \) represents the current of the high-voltage transmission line.

Assume that the magnetic core magnetizing impedance is represented by \( \omega L_{mt} + R_{mt} \). The capacitance is represented by \( C \). Parallel the capacitor on the secondary side of the current sensor A. When the magnetic core excitation impedance and the capacitor generate parallel resonance, it means that the total impedance of the branch circuit of the current sensor A is higher than the total impedance of the current sensor B. Affected by the current shunt, most of the high-voltage transmission current \( I \) flows into the power-taking branch \( i_2 \), so the calculation equation of the induced electromotive force \( K'_2 \) on the secondary side of the current sensor B is as follows:

\[
K'_2 = \frac{2\pi fV \mu_0 \mu'_l S l i_2}{l} \quad (4)
\]

It can be seen from equation (4) that the induced electromotive force \( K'_2 \) of current sensor B is higher than the magnetic induced electromotive force \( K_2 \) of current sensor A, and the power obtained by the load is relatively high\(^{[13]}\). The reason is that the relative permeability of the core without air gap is higher, and the current \( \mu' \) input to the current sensor B is higher than the current \( \mu \) input to the current sensor A.

2.2. Current sensor parameter optimization

In order to obtain accurate monitoring results of integrated power supply, the current sensor core parameters and coil turns are calculated and optimized\(^{[14]}\). At the moment of current start, the load voltage has a certain limit, and the maximum power obtained by the load is the most reasonable power.

Assuming \( U_d \) is the lowest operating voltage of the device, the load resistance can be obtained by the ratio of the lowest operating voltage of the device to the operating load current of the device\(^{[15]}\).

Let the primary side current of the current sensor be \( I_q \), according to the principle of the transformer, there are:

\[
I_s = \frac{I_q}{V} \quad (5)
\]

In equation (5), the number of turns on the secondary side of the electric current sensor is represented by \( V \). When the value \( I_s \) is not extremely small, then:

\[
Y_m = R_L \quad (6)
\]

In equation (6), the excitation reactance is represented by \( Y_m \). It can be seen from equation (6) that the power can be maximized when most of the currents have different values. When the difference between the electric power and the load power when the maximum power condition is met is low, there are:

\[
Y_{m, min} = R_L \quad (7)
\]

When the circuit satisfies the condition of equation (7), the value of the secondary turns \( V \) of the current sensor can be obtained through equation (5).

In order to make the starting current of the circuit within the set range, the core material must meet the following conditions:

\[
\frac{\mu S}{l} \geq \frac{Y_{m, min}}{2\pi fV} \quad (8)
\]

Affected by the iron consumption and heating factor of the current sensor, there are:

\[
U_d + 1.4 = 4fNB_{d, min} S \quad (8)
\]
In equation (8), when the voltage is \( U_d \), the peak value of magnetic induction is represented by \( B_{d,m} \). Therefore, the peak value of the magnetic induction intensity at \( U \) when the voltage is \( U_d \) can be calculated from the cross-sectional area of the iron core as \( B_{d,m} \). After determining the core material, the no-load experiment can be performed to obtain the magnetic permeability \( \mu \) value under the corresponding magnetic induction intensity. According to the iron core shape, calculate the average magnetic path length \( l \) value, and finally obtain the best iron core.

The selection of the wire diameter of the secondary winding of the current sensor can be calculated by the following equation:

\[
d = \frac{I_{\text{max}}}{V} \quad (9)
\]

In equation (9), the maximum allowable current effective value of the line and the copper wire radius are represented by \( I_{\text{max}} \) and \( d \) respectively.

3. Experiment and analysis

In order to verify the effectiveness of the proposed remote acquisition method of insulator icing flashover signal based on ring-shaped intelligent current sensor frequency optimization, a simulation experiment is designed. The experiment uses PSIM software to establish the power model and circuit topology, and select 0.02A and 0.04A respectively from the primary side conversion to the secondary side current value. Set two sets of current values to adjust the load size to 350 \( \Omega \).

Use the monitoring method in this paper to monitor the calculation results of the load power curve corresponding to the power model at different current values, as shown in Figure 1.

![Fig. 1 Load power curve of electric model under different current values](image)

Analyzing Figure 1(a), we can see that when the current value is 0.02A and the load resistance is 150 \( \Omega \), the load power of the electrical model reaches 0.015W. It can be seen from Figure 1(b) that when the current value is 0.04A and the load resistance is 70 \( \Omega \), the load power of the electrical model reaches 0.65W. It can be seen that the method in this paper can monitor the maximum load power of the power-taking model under different current values, and has a high monitoring capability.

Use this method to monitor the load resistance and load voltage of the electric model under different current values, and the results are shown in Figure 2.
Fig. 2 Load voltage curve of the electrification model under different current values

Analysis of Figure 2 shows that when the current value is 0.02A, the load voltage curve shows a gentle upward trend. When the load resistance is 600 Ω, the load voltage reaches the maximum value of 1.99V. When the current value is 0.04A, the load voltage curve rises first and then remains flat. When the load resistance is 250 Ω, the load voltage reaches the maximum value of 27V. It can be seen that the method in this paper can effectively monitor the load resistance and load voltage of the power model under different current values.

Test the method in this paper when there is no resonance in the impedance branch of the current sensor A, resonance occurs, and the air gap is open. The result is shown in Figure 3.

Fig. 3 This article monitors the circuit load power results under three conditions

Analyzing Figure 3(a), it can be seen that when the current sensor A does not resonate, the power of the electrification model rises rapidly from 2.8W to 7W. After a slow decline, it showed an upward
trend, and the overall load power curve appeared undulating and wavy. In Figure 3(b), after the resonance of the current sensor A, the minimum load power of the electrification model is 4.8W. As the load resistance increases, the load power also increases. When the load resistance is between 70V and 80V, the load power remains stable. In Figure 3(c), when the air gap is opened, the power of the sensor’s electrical model is inversely proportional to the load resistance. When the load resistance is between 10Ω - 30Ω, the load power drops rapidly. When the load voltage exceeds 30Ω, the load power of the electrification model will decrease gradually. Comprehensive analysis of Figure 5 can be obtained, the monitoring method in this paper can monitor the occurrence of impedance branch and the sensor's electrical power situation when resonance and open air gap are not occurred, and its application has a wide range of applications.

Test the input voltage and output voltage of the current sensor in the case of different coil turns, and the results are shown in Table 1.

| Tab. 1 Current sensor voltage monitoring results under different coil turns |
|-----------------|------------------|------------------|
| Coil turns      | Current sensor input voltage/V | Current sensor output voltage/V |
| 3               | 18.92             | 5.11             |
| 6               | 22.3              | 5.13             |
| 9               | 24.2              | 5.13             |
| 12              | 27.1              | 5.13             |
| 15              | 29.9              | 5.13             |
| 18              | 31.3              | 5.13             |

Analysis of Table 1 shows that when the number of turns of the coil increases, the input voltage of the current sensor also increases. When the number of turns of the coil is 3, the output voltage of the current sensor is 5.11V. As the number of coil turns continues to increase, the output voltage of the current sensor remains at 5.13V. It can be seen that the method in this paper can monitor the input and output of the current sensor when the number of turns of the coil is different.

Take communication distance as the index of test monitoring method, set up different communication distance in PSIM software, and record the results of different communication distance monitored by three monitoring methods respectively by using method of this paper, the method of reference [6] and the method of reference [7] method, as shown in Table 2. The method of reference [6] represents a noninvasive load monitoring method based on the improved flock algorithm, and the method of reference [7] represents a fiber optic gyroscope power monitoring method based on quadrupartite four-state modulation.

| Tab. 2 Communication distance test results of three monitoring methods |
|-----------------|------------------|------------------|------------------|
| Communication distance/m | The method of this paper monitors the distance/m | Reference [6] Method of monitoring distance/m | Reference [7] Method of monitoring distance/m |
| 200             | 200              | 200              | 200              |
| 400             | 400              | 394              | 395              |
| 600             | 600              | 586              | 593              |
| 800             | 800              | 781              | 766              |
| 1000            | 999              | 957              | 980              |
| 1200            | 1198             | 1157             | 1182             |
| 1400            | 1396             | 1309             | 1350             |
| 1600            | 1592             | 1503             | 1499             |
| 1800            | 1792             | 1730             | 1785             |
| 2000            | 1981             | 1824             | 1909             |

Analysis of Table 2 shows that with the increase of communication distance, the distance monitored by the three methods gradually appears error, and the difference gradually increases. When monitoring distance is ≤800 m, the monitored distance is the same as the communication distance and there is no error. When the monitoring distance is more than 1000m, the error of this monitoring method appears gradually, and the maximum error is 19m. Reference [6] methods and Reference [7] methods both have monitoring errors at communication distances of 400m. The maximum error of the monitoring distance was 157m and 101m, respectively, and the monitoring error was higher and lower.
The results show that the monitoring stability of the method [6] and the method [7] is poor, and the method has higher monitoring stability than the method.

4. Conclusion

This paper proposes a remote acquisition method of insulator icing flashover signal based on frequency optimization of ring-shaped intelligent current sensor, and designs an integrated monitoring model of parallel resonant dual magnetic circuit for power extraction. Through the optimization of the frequency of the ring-shaped intelligent current sensor that meets the monitoring requirements, the remote acquisition of the flashover signal of insulator ice coating is realized. In order to improve the power monitoring effect, the current mutual inductance parameters of the current sensor are optimized during the monitoring process. After experimental verification, the conclusions are as follows:

1) When the current value is 0.02A and 0.04A respectively, the maximum load power is 0.015W and 0.64W, and the load resistance is 150Ω and 70Ω, respectively.

2) When the current value is 0.02A, the load voltage curve of the model rises gently, and the maximum load voltage value is 1.99V. When the current value is 0.04A, the load voltage curve first rises and then maintains a smooth state, and the maximum load voltage is 27V.

3) When resonance, resonance and open air gap occur in current sensor A, this method can effectively monitor the current load power of the model, and the monitoring ability is high.

4) In the case of different turns of current sensor coil, the input and output of current sensor can be effectively monitored.

5) When the communication distance is different, the monitoring distance is the closest to the actual communication distance, and the error value is the lowest, the monitoring stability is strong.

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