The Development of a Device for GIS Line Phase Checking

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Abstract: In view of the requirements for the development of smart grid and the advantages of GIS, GIS mode is often the first choice in the construction of substation in power system. However, there is no simple and convenient method for direct phase checking of GIS lines. Because the traditional method is not applicable to the structure of GIS and the existing method is immature, it is necessary to design a special phase checking device for GIS line by transmitting and receiving electromagnetic wave in the circuit. In this paper, the differences of power frequency, radio frequency and high frequency electromagnetic field sources in frequency range, anti-interference and economic applicability are mainly discussed. Thus, the purpose of accurate phase checking of the line without changing any connector is realized. The feasibility of the RF phase checking device is proved by the simulated phase checking test of three-core cable. The device not only improves the efficiency of phase checking test, but also ensures the personal safety of staff. This has achieved good results in the field application, and solved the practical problem of not being able to direct phase checking GIS lines.

1. Introduction

With the development of smart grid technology, the coverage rate of GIS substation in Dandong area has been increasing in recent years. Compared with open substation, it has the advantages of small area, flexible configuration, strong adaptability to environment, high operational reliability, low maintenance workload and no electromagnetic interference. However, due to its special structure, a lot of inconvenience to the line nuclear phase test work has been brought.

Line phase checking test is an important test to determine whether the phase of the line is correct or not. Because the unbalanced voltage of high voltage transmission lines needs to be eliminated by interleaving, the new, rebuilt and expanded substations and transmission lines need to be checked to ensure that the transmission line is in accordance with the phase sequence required by the substation and the main equipment. If the power supply with different phase sequence is juxtaposed or closed, huge current will be generated, which will lead to generator or electrical equipment damage, electric main equipment will be burned down, and even lead to electrical fire and other accidents.

For open substation, the traditional insulation megger method can be used for direct phase checking. The method is to ground one phase of the substation on the power side of the line and measure the insulation resistance of the grounding and non-grounding phases of the substation on the other side of the line to confirm whether the phase sequence of the buses connected to the substation is consistent. However, this method cannot be used for phase checking of transmission lines between substations with GIS. The main reason is that GIS electrical equipment is directly or indirectly sealed in the pipe tree composed of metal pipes and bushings. No circuit breakers, lines and line terminals can be seen from the outside. Therefore, the traditional insulation megger method cannot be tested. The existing immature method is to dismantle lead of high pressure bushing and the terminal of ground end of PT, and then to check the phase in segments with megger. This method has some drawbacks. Because of the phenomenon of high induction voltage and high induction current in the same tower, persons will be threatened by electric shock when using

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conventional manual insulation resistance measurement methods. In addition, the average time of dismantling and installing connection terminals for maintenance personnel is longer, and the technical support from the manufacturer is needed on the spot. Not only is it inefficient and costly, but also it is possible for SF6 gas leakage from internal equipment and external water infiltration when operating carelessly. It has laid a hidden danger for the stable operation of power grid.

In order to ensure the personal safety of the experimenters and solve the difficult problem of phase checking of GIS lines, it will be of great significance to develop a special phase checking device for GIS lines. In this paper, the method of receiving electromagnetic wave is used to accurately check the phase of the line on the side of GIS substation, aiming at the characteristics of three-phase linkage of grounding switch and without changing any connector.

2. Theoretical Basis of GIS Line Phase Checking Device

Typical power frequency, radio frequency or high frequency analog signals are usually used. The frequency range of power frequency signal is from 50 Hz to 60 Hz. Because the frequency of electromagnetic wave will be absorbed by the surface when it is less than 100kHz, the power frequency cannot form long-distance effective transmission. In addition, since the working environment of the device is usually inside the substation, there will be strong power frequency interference sources. However, the anti-interference ability of power frequency signal is poor, so the interference signal in the field may lead to the misjudgment of the measurement signal of the receiving device. The frequency range of radio frequency signal is between 300kHz and 30GHz, and its electromagnetic wave can propagate in the air. It is reflected by the ionosphere at the outer edge of the atmosphere to form long-distance transmission capability. And the anti-jamming ability of radio frequency signal is strong, which makes the decoding and identification of the received signal of the receiver more correct. In addition, for the same size of received signal, power setting of power frequency signal and high frequency signal transmitter should be larger than that of radio frequency signal to meet the requirements. In this way, the total cost will be increased, resulting in unnecessary waste. In order to ensure the purity of the signal in the injection line and avoid the misjudgment of the nuclear phase, as well as the reasons for reducing the cost output. The radio frequency signal with strong anti-jamming ability and long transmission distance is chosen as the transmitting signal of signal transmitter by us. The advantages of radio frequency signal include the following aspects: (1)Strong anti-interference ability to ensure the accuracy of phase checking; (2)The signal attenuation is small, the signal penetration ability is strong, and the transmission distance is long; (3)The power setting of the signal source is small and the cost is reduced; (4) The high frequency of the injected line signal (resonance frequency greater than inductive circuit) makes the line's inductance (mainly refers to the line PT reactance) small and the received signal strong, which is conducive to the processing of the received signal. The device transmits the radio frequency signal of the pulse through the period set by the internal software. It is proved that the encoding of the transmitted signal of the signal transmitter can be achieved by transmitting power of 50W. Therefore, the frequency value of radio frequency signal used in this device is set to 100MHz.

3. Overall Design of GIS Line Phase Checking Device

A device for checking phase of GIS line is developed. The device consists of a signal transmitter, a signal receiver and a flexible current clamp. The receiver is connected with the flexible current clamp lock through the lead of the flexible current clamp. The signal transmitter is a high frequency signal generator with three switching frequency bands: The first frequency band is 30 MHz±1%, the second frequency band is 80 MHz±1%, and the third frequency band is 100 MHz±1%. The working principle of the device is as follows: The transmitter injects periodic radio frequency signals into the circuit under test so that the radio frequency current signals are generated in the circuit. Then, the RF signal on the unknown line is induced by the flexible current clamp. Finally, after the received signal is amplified, decoded and identified by the receiver, it can be determined whether it is the circuit of the added signal. The flexible current clamp couples the high frequency signal to the receiver based on the principle of electromagnetic induction. In this way, the non-contact measurement without changing any terminal can be realized, and the operation is safe and reliable.

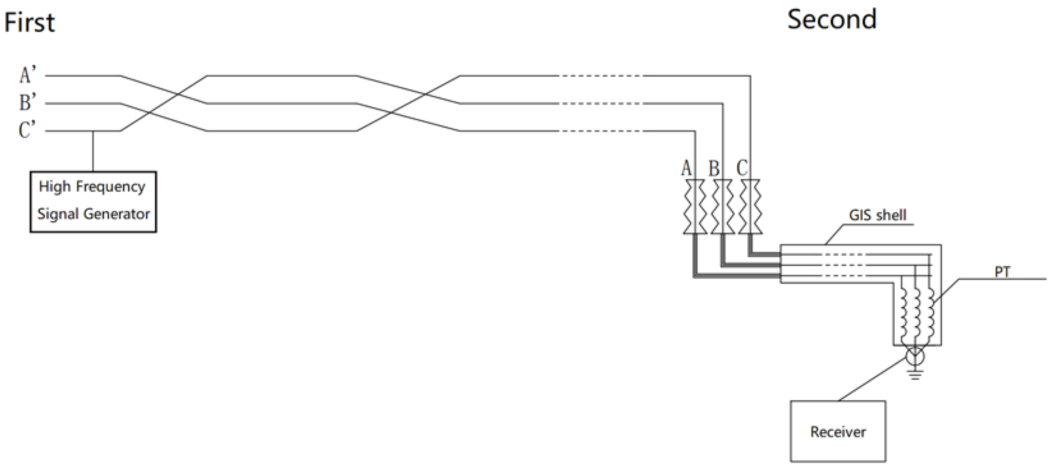

Fig.1 Field Application Design of GIS Line Phase Checking Device

3.1 Design of Signal Transmitter

The exterior of transmitter is provided with a display screen, a control button, an output interface and a charging interface. And internally it includes power amplifier, transmitter, rectifier, high frequency oscillator, control device, power supply device and display device. Its working principle is to inject high frequency pulse coded current signal into the circuit by using pulse current. The electromagnetic field generated by the current around the target line is detected, decoded and phase checked by the signal receiver and the flexible coil. The appearance of the transmitter is designed with an integrated special toolbox. Polypropylene plastic is used as raw material and a new type of composite filler is added for injection moulding. In this way, the density, strength, stiffness, hardness, wear resistance, heat resistance and insulation performance are better. The box can withstand about 200 kg of pressure. The super large LCD of mainframe shows the remaining battery power in real time. The white backlight and the dynamic indication of the emission signal are clear at a glance.

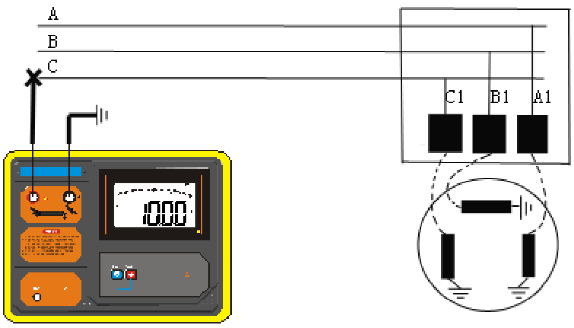

Fig.2 Outward appearance of signal transmitter

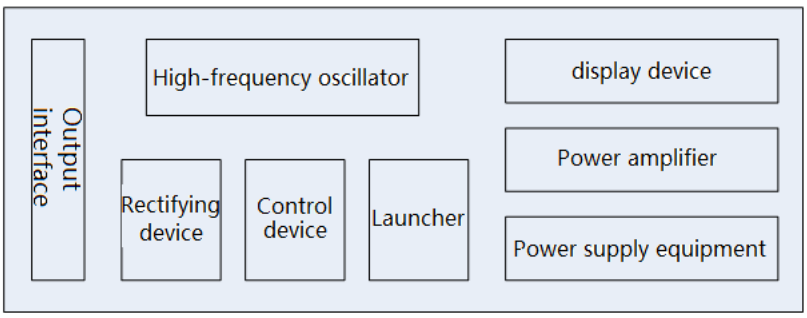

Fig.3 Block diagram of signal transmitter

3.2 Design of Signal Receiver

The outside of the receiver is provided with a display screen, a control button, a voltage input jack, a charging interface and a coil access port. The inner part is provided frequency selective filter, display device, signal acquisition processor, control device, anti-interference device and power supply device. Its working principle is to receive the pulse coded current signal from the transmitter from the flexible coil. After enlarging, filtering, recognizing and decoding by the signal receiver, the data is displayed on the display screen. The receiver's appearance is set as handheld device, 3.5 inch color LCD screen, built-in high-speed microprocessor, electronic dial indicating signal strength, color grating dynamic display, all of which are exquisite and intuitive. It can perform fast automatic phase checking.

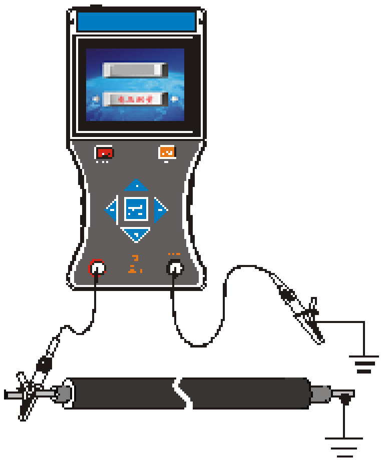

Fig.4 Outward appearance of signal receiver

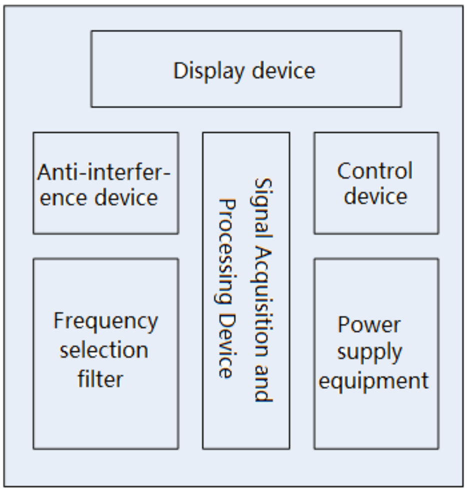

Fig.5 Block diagram of signal receiver

3.3 Design of Signal Receiver

Flexible current clamp is made of flexible material, which is suitable for irregular conductors or thick cables. The caliber of the clamp is about 200 mm, and the line below 200 mm can be clamped. A gap is arranged at the end and a lock is arranged at the gap. The working principle of the flexible current clamp is as follows: The transmission line is jammed by closing the lock hole at the high voltage grounding terminal of GIS voltage transformer end of the gap. By inserting the coil lead into the coil access port, the pulse coded current signal on the transmission line is received directly. Thus, the high frequency pulse coded current generated by the signal transmitter can be quickly identified without changing any terminal. It has excellent transient tracking ability.

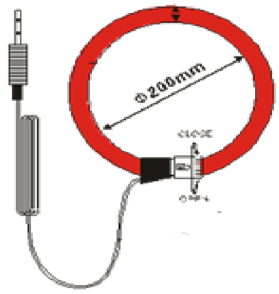

Fig.6 Appearance of flexible current clamp

3.4 Design of Signal Receiver

In order to improve the design level of products and find better product accessories, it is particularly important to select the parameters of each component of GIS line phase checking instrument. The main parameters of the instrument include: Wien bridge oscillator circuit, MCU micro-control circuit, OCL power amplifier, FMC6416P/PA acquisition and processing module, active bandpass filter, LED display and Rogowski coil. The orthogonal experimental design method is used to determine the parameters.

The main selection parameters are: Factor A: Frequency of Wien bridge oscillator circuit (1000Hz, 900Hz), Factor B: Time interval of MCU micro-control circuit (1s, 2s), Factor C: Signal amplification of OCL power amplifier (60W, 80W), Factor D: Interrupt response time of FMC6416P/PA acquisition and processing module (1us, 2us), Factor E: Other band contents of active bandpass filters (0.2%, 0.3%), Factor F: Reflective light condition of LED display (110lm, 100lm), Factor G: Coupling coefficient of Rogowski coil (97%, 98%), shown in Table 1.

Table 1 Orthogonal experimental design table

Test number / Factor	A Wien bridge oscillator circuit	B MCU micro-control circuit	C OCL power amplifier	D FMC6416P /PA acquisition and processing module	E Active Bandpass Filter	F LED display	G Rogowski coil	test result	
								strength of received signal	Whether the coupling is up to standard
1	1 (1000)	1 (1)	1 (60)	2 (2)	2 (0.3)	1 (110)	1 (97)	878	yes
2	2 (900)	1	2 (80)	2	1 (0.2)	1	2 (98)	956	yes
3	1	2 (2)	2	2	2	2 (100)	1	858	no
4	2	2	1	2	1	2	2	738	no
5	1	1	2	1 (1)	1	2	2	748	yes
6	2	1	1	1	2	2	1	918	yes
7	1	2	1	1	1	1	2	998	no
8	2	2	2	1	2	1	1	738	no
I(Sum of received signal strength)	3482	3512	3532	3402	3452	3582	3392	T=I+II =47896	
II(Sum of received signal strength)	3362	3332	3312	3442	3392	3262	3440		
Absolute value of range R	120	180	220	40	60	320	48		

"Take a look": The received signal strength of the seventh test is 998dB, which is the best, but the coupling is not up to standard, so it does not meet the requirements. In the second experiment, the received signal strength is 956dB, and the coupling is up to the standard, so the best scheme is chosen for the second experiment. That is, selection factors A2, B1, C2, D2, E1, F1, G2.

"Calculate": For factor A, the sum of level I is 3482, the sum of level II is 3362, R = 120, so A1 meets the requirements. Similarly, B1, C1, D2, E1, F1, G2 were selected.

The good conditions for "calculating" are the same as those for "taking a look". In summary, according to the results of orthogonal experiments: The frequency of Wien bridge oscillator circuit is 1000Hz. The time interval of MCU micro-control circuit is 1s. The signal amplification of OCL power amplifier is 60W. The interrupt response time of FMC6416P/PA acquisition and processing module is 2us. The other band content of the active bandpass filter is 0.2%. Selection of Light Reflective Conditions for LED Display 110 LM. The coupling coefficient of Rogowski coil is 98%.

4. Acceptance of GIS Line Phase Checking Device

After the equipment is assembled, the electrical tester checks and accepts the phase checking device of the GIS line in the staff innovation studio. The test personnel used 100 meters of red, yellow and green three-wire cables instead of the phase A, B and C of the same tower line to carry out simulation tests. The specific operation is as follows: The red alligator clip of the transmitter is clamped on the red core of the cable at the transmitter end of the three-wire cable, and the black alligator clip clamp is short-connected to ground. After the device is opened, the red core is injected with current signal. At the receiving end, the flexible coil is sheathed on the red core of the cable. Start the receiver and adjust the 1-6 level gain by pressing the left and right arrow keys (Level 6 is the strongest). At this time, the pointer in the color electronic dial display indicates 8. Green grating clockwise dynamic indication. At the bottom of the screen, there is a "successful line phase check" accompanied by a prompt sound. This core is the target core which is shown by the results. The transmitter remains unchanged and the flexible coil is reversed by the receiving end on the red core. At this time, the red-orange grating is dynamically indicated counterclockwise, and the "non-target phase line" is displayed below. It is proved that the pulse coded current signal is a non-positive input. Because the current is directional, so the testing is directional, so the flexible coil needs to be transposed. The flexible coil is sheathed on the green core without changing the transmitter. Start the receiver. At this time, the display screen has no grating indication and no prompt sound. The non-target core is proved by this operation process.

5. Field Application of GIS Line Phase Checking Device

In the transformation of 220kV Baoshishan GIS substation power grid on September 27, 2018, it is necessary to carry out line phase check test on Danbao I line. Firstly, the phase lines to be checked will be separated from the system by operators from the substation. Then, the high frequency pulse coded current signal will be injected into phase A of Danbao I line of Dandongbei 500kV substation by the high voltage tester through the operation signal transmitter. At the receiving end of the Baoshishan substation, the flexible current clamp will be placed in the high voltage grounding end of the GIS voltage transformer in turn by the experimenters. Finally, no terminal is changed for testing. The signal will be displayed on the screen of the receiver. The transmitter of Dandongbei substation shows the current pulse voltage is 1201V. After the receiver at the receiving end is started, the gain is adjusted. At this time, the gain intensity is 1 level, the pointer in the color electronic dial is 9, and the green grating is clockwise and dynamically indicated. At this time, the "line phase check success" is displayed below the screen, accompanied by the "beep" prompt sound. From the above test results, it is concluded that this is the A-phase line injected into the signal. Similarly, B and C phases are measured, thus completing the phase checking of the Danbao I line.

Fig.7 Overview of device field application

6. Summary

GIS line phase checking device has the advantages of safety, economy, cleanliness and strong anti-interference ability. According to the particularity of GIS structure, it can accomplish line phase checking in high induction voltage and high induction current environment and without changing any terminal. Personal safety of operators is guaranteed and the time and manpower cost of equipment maintenance test are effectively saved. The problems of Internal SF6 gas leakage and external water infiltration in the equipment are eliminated from the source. The system stability and power supply reliability are improved. At the same time, the device has the characteristics of fast response, no saturation, small angle difference, high measurement accuracy, small phase offset, wide frequency range, abundant output signal, convenient use and easy handling. It is widely used in GIS substation in Dandong area. The gaps in the field of GIS line checking phase test have been filled. Practical work problems have been solved. The safe and reliable operation of power systems is promoted. It has extensive popularization value and application prospect.

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