Research on Simulation Ideas of Relay Protection Device on Load Test Based on Virtual Reality Technology

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Abstract. Various problems may occur in the design and installation of transformer, busbar and line differential protection. Therefore, it is particularly important to carry out a load test when the corresponding protection is put into operation. This article introduces the research status of virtual reality technology and the necessity of load test, puts forward the load test methods and precautions, and proposes a simulation plan combining virtual reality technology and load test.

1. Introduction
Relay protection is an important measure to detect the fault or abnormal situation in the power system, so as to send alarm signal, or directly isolate and remove the fault part. This paper studies the power system faults and abnormal conditions endangering the safe operation, in order to explore the Countermeasures of anti accident automation measures. In the process of its development, relay with contacts was mainly used to protect power system and its components (generator, transformer, transmission line, etc.) from damage, so it is also called relay protection. The basic task is: when the power system has a fault or abnormal working conditions, in the shortest possible time and minimum area, automatically remove the fault equipment from the system, or send a signal to the personnel on duty to eliminate the source of abnormal working conditions, so as to reduce or avoid the damage of equipment and the impact on the power supply of adjacent areas. The relay protection device must have the function of correctly distinguishing whether the protected component is in normal operation or in fault, and whether it is in the protection area or out of the protection area. In order to achieve this function, the protection device should be based on the characteristics of electrical physical quantity changes before and after the power system failure.

Relay protection is of great significance to the safe and reliable operation of power equipment and substations. In the network of the entire power system, transformers, busbars, and lines as the main primary equipment need to be equipped with protection devices to be reliable disconnect the fault equipment in the event of a failure, so that the entire power grid can operate safely and stably. For 220kV voltage level transformers, busbars and line protection, double sets of protection are required, including main protection and backup protection. Among them, the main protection is differential protection, and the distance protection of the line protection configuration is directional. Therefore, it is necessary to verify the correctness of the secondary wiring with load before the corresponding protection device is put into operation[1-3]. This article introduces the necessity, methods and precautions of the on-load test of the protection device before it is put into operation, analyzes the current research status of virtual reality technology at home and abroad, and puts forward the overall technical scheme of applying virtual reality technology to the simulation system of relay protection on-load test training.
2. The necessity of load test

Load test is the work that must be performed when the protection device is put into operation. Only when the load test is correct, can it be determined that the protection device will be put into operation after the completion of the construction, to ensure that it is in a normal working state, and to ensure the stable operation of the power system. At present, the process of replacing protection devices in conventional substations or the replacement of the current transformer requires the construction of the secondary circuit. In this operation, the wiring of the current and voltage circuits was changed, and the implementation methods of the differential protection of various wiring methods are also different in details[4-7]. Many small differences can easily neglect and confuse the design and installation personnel, which can cause serious consequences. In order to avoid this situation, it is necessary to carry out a load test before the differential protection is put into operation. Only after carrying out the load test, can the wiring mode and protection device design scheme in the power system be effectively checked, in order to find out the wrong wiring method, improve the protection device design scheme, and ensure the smooth operation of the protection device.

The load factor is determined by laboratory measurement. Under the condition of the same value of breaking voltage and current, the duration of radiated electromagnetic wave in the breaking process of pure resistive load, pure capacitive load and pure inductive load is measured respectively. Taking the duration of electromagnetic wave radiated by resistive load as the reference, the duration of electromagnetic wave radiated by pure capacitive load and pure inductive load during breaking process is divided by the reference as the corresponding load factor.

3. Load test method

After the newly installed transformer, busbar and directional line protection or the secondary circuit of the corresponding protection device are changed, carefully check that the actual wiring is consistent with the principle wiring diagram. Before the corresponding protection device is put into operation, the correctness of the current and voltage circuit wiring must be confirmed through a load test. The specific method of load test is as follows.

Grasp the method of using the clamp-on phase meter and make it clear whether the measured load current phase angle is lagging or leading the reference voltage angle. Find out the load situation, including the magnitude and direction of active and reactive power. When the load current phase is measured, the reference for active and reactive loads is shown in Figure 1.

It can be concluded from Figure 1 that the transmission of electric energy is divided into two situations: power transmission and power reception. The following is a detailed analysis of the various situations of active and reactive power in the two cases.

Assume that the fixed quantity is the voltage U and the change quantity is the current I. You can get.

![Fig. 1. Load current phase measurement.](image)
\[ P = U\cos\phi \quad Q = U\sin\phi \]

Among them, \( \phi \) is the phase angle between \( U \) and \( I \), and when \( U \) leads \( I \) (inductive), \( \phi \) is positive, and when \( U \) lags \( I \) (capacitive), \( U \) is negative.

When \( 0^\circ < U < 90^\circ \) (the first quadrant), \( U \) is ahead of \( I \), at this time, \( P > 0, Q > 0 \), the line is sending active and reactive power.

When \( 90^\circ < U < 180^\circ \) (the second quadrant), \( I \) is ahead of \( U \), at this time, \( P > 0, Q < 0 \), the line is sending active power and receiving reactive power.

When \( 180^\circ < U < 270^\circ \) (the third quadrant), \( I \) is ahead of \( U \), at this time, \( P < 0, Q < 0 \), the line is receiving active power and receiving reactive power.

When \( 270^\circ < U < 360^\circ \) (the fourth quadrant), \( U \) is ahead of \( I \), at this time, \( P < 0, Q > 0 \), the line is receiving active power and sending reactive power.

Therefore, the following conclusions can be drawn:

**Power transmission side:** Active power must be positive, while reactive power is not necessarily positive or negative. When \( U \) leads \( I \) (inductive), the reactive power is positive, and when \( U \) lags \( I \) (capacitive), the reactive power is negative.

**Power receiving side:** Active power must be negative, while reactive power is not necessarily positive or negative. When \( U \) leads \( I \) (inductive), the reactive power is positive, when \( U \) lags \( I \) (capacitive), the reactive power is negative.

4. **Precautions for load test**

When the power equipment of the substation is in normal operation, it is necessary to put the transformer protection, busbar differential protection and directional line protection into operation. However, when the protection device is replaced or the wiring of the secondary circuit is changed, the polarity of the current circuit must be checked with the load before the corresponding protection is put into operation. Pay attention to the following aspects when carrying out the load test.

1. To determine the power flow of the equipment under test, the magnitude and direction of the active power and reactive power on the background machine or monitoring display are mainly used to determine the corresponding quadrant. That is, the operator needs to clarify whether the measured phase angle of the load current is lagging or leading the angle of the reference voltage before carrying out the load test.

2. Due to the limitations of the actual equipment wiring, transformation ratio and accuracy of the tester, if the load is small, the measured data cannot normally judge the accuracy of the wiring. In addition, the larger the load current, the more fully the various errors are reflected in the load test. Therefore, in order to ensure the correctness of the test results, the load current should not be too small, otherwise the test results will be unclear, and the test needs to be performed after the load current is stable.

3. When verifying the polarity of the current loop, in addition to determining the A, B, and C three-phase current loop, the current amplitude of the N loop should also be determined to ensure the integrity and correctness of the loop. Since the current of the N loop is very small under normal operation, it is not easy to find even the loop wiring error. Therefore, when doing this work, pay special attention to the current amplitude displayed by the tester. In addition, before loading, you can also use the protection tester to add three-phase unbalanced current to verify.

4. In addition to using the phase meter to determine the current polarity and the correctness of the circuit wiring, you should also check whether the differential current of the device meets the specified requirements.

Common problems and analysis of load test mainly include the following aspects[9].

1. Look at the three-phase current phase sequence

Under normal circumstances, if the wiring is correct, the currents on each side are in the positive phase sequence. If the phase sequence is different from this, there may be the following possibilities.
(a) When wiring the outdoor terminal box, that the current loop on the secondary side of the CT and the current loop on the secondary side of the terminal box are connected incorrectly. That is, when the CT secondary wiring terminal is introduced into the terminal box, the A phase is mistakenly used as phase C for wiring. In actual engineering, such problems often occur due to the confusion of the primary side.

(b) When wiring in the protection screen cabinet, the current loop of the outdoor terminal box and the current loop of the corresponding protection screen in the main control room are connected in reverse order. That is, one core of the cable is connected to the phase B current loop at the terminal box, Connect the cable core to the phase A current loop at the protective screen cabinet by mistake. In actual engineering, it is often caused by the wrong number of cable core wires or wrong terminals during wiring.

(2) Look at the symmetry of the three-phase current

After the protection device is loaded, the amplitude of the three-phase current of A, B, and C is basically the same under normal conditions, and the phase difference is 120 degrees. Otherwise, there is a problem in the current loop, and further investigation is required. In addition, use a clamp-on phase meter to sequentially measure the amplitude and phase of phase A, B, and C from the terminal block of the protection screen, record and compare with the amplitude and phase of the current recorded on the LCD screen of the microcomputer protection device to ensure accuracy of data.

5. Research status of virtual reality technology at home and abroad

Some foreign research institutions have carried out more in-depth research on the level of virtual reality technology. Among them, Professor A.S. MALOWANY from the Department of Electrical Engineering of MCGIL University in Canada, and others have developed virtual reality operator training system ESOPE-VR, which is applied to power system training on graphics workstations. The system establishes a three-dimensional computer simulation environment of the power station, which can simulate various sounds of the power station operation and recognize the voice commands of the operator. It can simulate the power station environment and equipment actions through interactive multimedia interfaces such as pictures and videos. The Computer Department of the University of North Carolina (UNC) in the United States developed a personalized and portable visualization system based on the virtual reality research group. The system allows users to roam and interact with object models with complex meanings, while receiving actual visual, auditory, and tactile feedback graphics with a refresh rate of 25 frames per second. The GUV of Georgia Institute of Technology in the United States has also completed the virtual geographic information system project, which uses geographic information system (GIS) for military visualization and application integration of simulated virtual environments.

Many domestic research institutions and universities are also carrying out the research and application of virtual reality technology, including the Virtual Reality and Visualization New Technology Research Laboratory of the Department of Computer Science and Technology of Beijing University of Aeronautics and Astronautics, which can provide real-time 3D dynamic database, virtual reality demonstration environment, virtual reality system for flight training, and virtual reality application system development platform. The State Key Laboratory of CAD&CG of Zhejiang University has developed a desktop virtual building environment real-time roaming system. The Institute of Intelligent Manufacturing and Control of Wuhan University of Technology uses virtual reality technology for mechanical virtual manufacturing. However, within the scope of State Grid Corporation of China, VR virtual reality technology is still in the stage of demonstration and research. Moreover, only for theoretical research on the operation of secondary equipment for power transmission and transformation, secondary equipment simulation training and its application are still blank. Therefore, the application of virtual reality technology in the simulation technology of relay protection is in urgent need of research [10].

6. Technical solution combining virtual reality technology with load test training

Study the virtual reality scene of the secondary equipment area of the high-precision substation based on the actual substation operation specification. The relay protection device is connected by physical
wiring. The working mode is that the operators use the tester to output the analog signal to the analog input circuit of the relay protection device. The staff uses the meter to measure and view the voltage and current amplitude of the relay protection device, and phase to judge the correctness of the secondary circuit wiring. This puts forward higher-precision design requirements for the virtual reality 3D scene and the exterior and interior of the equipment, especially in the secondary loop scene screen, which needs to be more refined. For dense wiring areas, a flexible regional amplification operation mechanism can be used, which is convenient for device operations in virtual scenarios.

Realize the in-depth simulation of the load phase measurement of the relay protection of the substation. The in-depth simulation of the relay protection load phase measurement includes not only the real-time status information of the current primary equipment of the monitoring equipment, but also the simulation of the real-time changes of the equipment related signals, meters, and equipment LCD panel display content, etc. By setting the fault parameters of the secondary circuit wiring, the display of the instrument and the protection device panel can respond in real time, and the impact on the relay protection equipment is consistent with the actual situation on the scene. The simulation system simulates the dynamic process of the substation in detail, and at the same time, considers the mutual influence between the related power network and the substation, and establishes a power network mathematical model of the whole physical process.

7. Conclusion
Load test is the last guarantee for the protection device to be put into operation. Therefore, before the transformer protection, bus differential protection and directional line protection are officially put into operation, the performance and correctness of the complete protection device and its secondary circuit should be verified according to relevant requirements. The load phase measurement test plays a vital role in the correct operation of transformers, busbars and directional line protection devices. The application of virtual reality technology to the on-load test training of relay protection devices can effectively solve the problem of providing relay protection operation and maintenance personnel and new employees with a platform for intuitive understanding of the operation during the load test. In addition, it provides a visual and real sense of the scene to make up for the problems of young employees' lack of experience in the operation process of the relay protection load test. The use of VR technology to increase the interest of relay protection training is conducive to the improvement of training efficiency and has great practical significance and application value for filling the gaps in the industry.

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