Simulation Application and Research of Relay Protection Project under Virtual Reality Technology

Xianqi Li, Junwei Zhang, Qiang Luo, Chong Wang
Guizhou Power Grid Co., Ltd. Training and Evaluation Center, Guizhou 550000, China

Abstract. The accurate and fast action of relay protection devices is an important guarantee for the safe and stable operation of power systems. In order to overcome the limitations of traditional training, this paper builds a simulation system of relay protection for substations based on virtual reality technology, so that trainees cannot only pass the man-machine Interactive operation to understand the appearance and basic operation of the equipment intuitively, and to check the action of the relay protection equipment under different faults through fault settings. Practical application shows that the system is of great significance to improve the quality of staff and ensure the safe and stable operation of the power system.

1. Introduction
The substation is an important part of the power system. The safe and reliable operation of the substation is of great significance for maintaining the stable operation of the power system. A high-quality substation operation operator is an important guarantee for the normal and stable operation of the substation, and a high-quality substation simulation trainer is a prerequisite for this guarantee.

In recent years, with the rapid development of immersive virtual reality simulation technology, a large number of consumer-grade virtual reality hardware devices have been continuously introduced, such as the Oculus Rift virtual reality helmet of the American Facebook company, HTC VIVE virtual of HTC Company Reality headsets and Microsoft introduced the Kinect somatosensory device in 2010. Immersive virtual reality simulation technology mainly uses a variety of hardware, such as stereo projection, head-mounted display and other devices, to seal vision, hearing and other sensations, to provide a new, virtual sensation space, using spatial position trackers, motion capture Or input devices such as data gloves, allowing participants to fully immerse themselves in a more realistic, interactive virtual environment. The substation simulation training system studied in this article is based on immersive virtual reality technology and cooperates with interactive equipment such as virtual reality helmets, position trackers, motion capture devices, etc. to build more realistic substation operators from the aspects of vision, hearing, and interaction. Immersive substation virtual environment [1].

2. Analysis of relay protection simulation requirements
The relay protection simulation system not only needs to simulate the appearance of the equipment and the substation scene, but also needs to be able to simulate the basic operation of the equipment and various relay protection functions, such as the main protection, backup protection, and auto-reclosing of various equipment. And should try to realistically simulate the actual operation of the real power system. This article designs the functions of this simulation system based on the relay protection
settings of the substation. This relay protection simulation system mainly implements the protection simulation of three types of equipment: line protection (including 35kV, 110kV lines), transformer main protection, and transformer backup protection. The overall functional block diagram is shown in Figure 1.

![Functional block diagram of the relay protection simulation system](image)

**Figure 1.** Functional block diagram of the relay protection simulation system

As a part of the substation simulation system, the relay protection simulation system and the other three parts of the substation simulation system are integrated with an automated background monitoring simulation system, a virtual switch field simulation system, and an electrical simulation computing system. Site conditions.

3. **Relay protection principle of generator-transformer**  
The safe operation of the power generation and transformation group plays a decisive role in ensuring the normal operation of the power system and the power quality of the power supply system. Therefore, it is necessary to install a comprehensive protection relay device for various faults and abnormal operating conditions of the power generation and transformation group.

3.1. **Transformer bank longitudinal differential protection and incomplete longitudinal differential protection**  
For large generating and transforming units with a capacity of 200 MW and above, in addition to the common longitudinal differential protection for the entire group, the generator should also be equipped with a separate longitudinal differential protection. Large-capacity generators have large rated currents, and each phase of the stator winding is often composed of two or more branches connected in parallel. In this case, incomplete longitudinal differential protection can be formed.

3.2. **Single-phase grounding protection of transformer group and zero-sequence protection of grounding short circuit on the high voltage side**  
The neutral point of the generator is generally not grounded or grounded through the arc suppression coil. The grounding capacitor current (or compensated grounding current) when the single-phase grounding occurs is usually less than the allowable value in Table 1. The grounding protection can use the zero-sequence voltage protection function.
Table 1. Allowable value of single-phase grounding current of generator and transformer group

| Generator rated voltage / kV | Generator rated capacitance / MW | Allowable ground current / A |
|-----------------------------|---------------------------------|-----------------------------|
| 6.3                         | ≤50                             | 4                           |
| 10.5                        | 50-100                          | 3                           |
| 13.8-15.75                  | 125-200                         | 2                           |
| 18-20                       | 300                             | 1                           |

The transformer neutral point should also be installed with over-voltage protection and zero-sequence current protection with a discharge gap to protect the transformer that is not directly grounded when the transformer that is directly grounded at the neutral point is tripped.

3.3. Back-up protection for reactive interphase faults
When setting up generator-transformer backup protection, consider the generator-transformer group, and its backup protection is used both as a backup for the generator and transformer group and as a backup for high-voltage bus-phase faults.

3.4. Transverse Differential Protection of Generator
The principle of the longitudinal differential protection of the generator determines that it cannot reflect the short-circuit fault between the turns of a phase winding. For the case where the stator winding of a large-capacity generator consists of two (or more) parallel windings in each phase, it can constitute transverse differential interterm short-circuit protection [2].

4. Research on data acquisition methods of virtual reality relay protection

4.1. Data Acquisition Module
The data acquisition module is controlled by software. The hardware part includes computer I / O ports such as serial port, parallel port, and data acquisition card. The software part is mainly the application program written in Lab VIEW. The system uses the NI PCI-6221 data acquisition card. It is a high-performance DAQmx device from National Instruments. It can collect the electrical quantities of the relay protection system individually or in multiple channels.

4.2. Data processing module
The current on the secondary side of the current transformer is collected by a data acquisition card and entered the program to run. On the protection front panel, the user can debug the transformation ratio of the transformers TA1 and TA2. The system also displays the waveform of the mutual inductor current and its frequency. And phase. The secondary current of the current transformer is collected by the data collector and entered the program for operation. On the front panel of the transformer longitudinal differential protection, the user can debug the transformation ratios of the current transformers TA3 and TA4, and the system simultaneously displays the magnitude and phase of the secondary current. The third harmonic voltage \( u_{3n} \) on the neutral side of the generator and the third harmonic voltage \( u_{3s} \) on the generator end are collected by the data collector and entered into this program to run. On the front panel of the single-phase ground protection on the generator side, the user the threshold \( \beta = (0.2-0.3) \) and the adjustment coefficient \( K_p \) can be debugged. The system simultaneously displays the waveforms of the third harmonic voltage on the neutral side and the third harmonic voltage on the machine side [3].

The secondary-side current of the generator neutral point current transformer TA0 and the secondary-side voltage of the generator-side voltage transformer TV0 are collected by the data collector and entered the program to run. The backup protection front panel on the reaction phase failure the system will display the secondary side current waveform of the current transformer TA0 and the secondary side voltage waveform of the voltage transformer TV0. The user can adjust
parameters such as the rated current of the generator, the rated voltage of the transformer, and the reliability factor according to the actual situation. The ABC three-phase current sum and another group of ABC three-phase current sum are collected by a data collector and entered the program to run. On the front panel of the zero-sequence cross-linked differential protection of the generator, the system will display the current mutual inductance. The magnitude and phase of the current on both sides of the device TA0.

5. Construction of virtual scenes

3D solid modelling is the main work of scene construction. This article uses 3DSMAX and VRML to implement the construction of virtual scenes. In the modelling process, the idea of partial first and then overall is used. First, corresponding models are established according to different types of equipment to form a model library, and then the required equipment models are adjusted, and their positions and sizes are adjusted to match the actual situation. And add the corresponding background and lighting effects. The virtual control room scene is shown in Figure 2 [4].

![Figure 2. Virtual master control room scene](image)

5.1. Simulation of incomplete longitudinal differential protection of generator

Due to the actual conditions, the secondary side currents of the transformers TA1 and TA2 of the generator cannot be collected. When verifying the feasibility of the incomplete longitudinal differential protection of the generator, the simulation signals in LabVIEW are used to simulate the transformers TA1 and TA2. Secondary current. When the ratio of the secondary side currents of the current transformers TA1 and TA2 is 1:2, and the secondary side currents of the current transformers TA1 and TA2 are in the same direction, the generator runs normally; if the current transformers TA1 and TA2 are two The ratio of the magnitude of the secondary side current is 1:2, or the secondary side current direction of the current transformers TA1 and TA2 is different, then a phase-to-phase short-circuit fault occurs in the generator, and the indicator light is on, that is, a trip action occurs. During the simulation, different values are used to simulate the transformation ratios of the current transformers TA1 and TA2, the secondary current amplitudes of the current transformers TA1 and TA2, and the secondary current phases of the current transformers TA1 and TA2. The results in Table 2 were obtained [5].
### Table 2. Related results

| Serial number | Ratio (TA1, TA2) | Phase (TA1, TA2) | Current amplitude (TA1, TA2) | PB0, PB1 | Protective action |
|---------------|------------------|------------------|-------------------------------|---------|-------------------|
| 1             | 1, 1             | 120, 120         | 30, 60                        | 0, 0    | No action         |
| 2             | 1, 1             | 120, 120         | 30, 70                        | 0, 1    | action            |
| 3             | 1, 1             | 120, 119         | 30, 60                        | 0, 1    | action            |
| 4             | 1, 2             | 120, 120         | 30, 30                        | 0, 0    | No action         |

#### 5.2. Transformer Pilot Differential Protection Simulation

Due to the limitation of the actual conditions, the secondary side currents of the transformers TA3 and TA4 of the generator cannot be collected, so when verifying the feasibility of the longitudinal differential protection of the transformer, the simulation signals in LabVIEW are used to simulate the transformers TA3 and TA4. Secondary current. If the ratio of the secondary side currents of the current transformers TA3 and TA4 is $n_{TA3} : n_{TA4}$ and the secondary current phases of the current transformers TA3 and TA4 are the same, the generator operates normally; if the secondary of the current transformers TA3 and TA4 The ratio of the magnitude of the side current is not $n_{TA3} : n_{TA4}$, or the secondary side current phases of the current transformers TA3 and TA4 are different. The internal fault of the generator occurs, the indicator light is on, and that is, a trip occurs. The front panel of the transformer longitudinal differential protection is shown in Figure 3 [6].

![Differential Relay](https://via.placeholder.com/150)

**Figure 3.** Front panel of transformer longitudinal differential protection

In the simulation process, different values are used to simulate the transformation ratios of the current transformers TA3 and TA4, the secondary side current amplitudes of the current transformers TA3 and TA4, and the secondary side current phases of the current transformers TA3 and TA4. Table 3.

### Table 3. Comparison of simulation data of transformer longitudinal differential protection

| Serial number | Ratio (TA1, TA2) | Phase (TA1, TA2) | Current amplitude (TA1, TA2) | PB0, PB1 | Protective action |
|---------------|------------------|------------------|-------------------------------|---------|-------------------|
| 1             | 1, 10            | 120, 120         | 3, 30                         | 0, 0    | No action         |
| 2             | 1, 10            | 120, 120         | 3, 31                         | 0, 1    | action            |
| 3             | 1, 10            | 120, 119         | 3, 30                         | 0, 1    | action            |
| 4             | 1, 5             | 120, 120         | 3, 15                         | 0, 0    | No action         |
5.3. Simulation of generator zero sequence transverse differential protection

Due to the limitation of the actual conditions, the current on the two sides of the transformer TA0 of the generator cannot be collected. Therefore, when verifying the feasibility of the longitudinal differential protection of the transformer, the simulation signal is used to simulate the current on the two sides of the transformer TA0. If the ratio of the currents on the two sides of the current transformer TA0 is 1:1, and the current phases on the two sides of the current transformer TA0 are the same, the generator runs normally. If the ratio of the currents on the two sides of the current transformer TA0 is not 1:1, or the current phases on the two sides of the current transformer TA0 are different, an internal fault occurs in the generator, the indicator light is on, that is, a trip occurs, and the generator's zero-sequence crossbar The front panel of the differential protection is shown in Figure 4.

![Figure 4. Zero sequence transverse differential protection](image)

6. Conclusion

Virtual reality technology is an emerging technology that is being widely used in the training of simulation systems, and has attracted a lot of students for its immersion and authenticity. Practice has proved that the system not only presents the three-dimensional visual display of the relay protection device to the trainees, but also allows the trainees to perform man-machine interactive operations, which is of great significance to the improvement of trainees' relay protection operation skills.

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