Operation and Maintenance Technology of Relay Protection Equipment Based on Digital Twin Technology

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Operation and Maintenance Technology of Relay Protection Equipment Based on Digital Twin Technology

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Abstract: With the scale of the power grid is becoming larger and larger. The corresponding operation and maintenance work of the distribution network is becoming increasingly intelligent, which also puts forward corresponding requirements for the reliability of safe and stable operation of the power grid. The condition assessment of relay protection applies the scientific concept of condition-based maintenance to the actual work site, which is of great significance. To judge the operation status of the equipment and provide a scientific basis for maintenance, in this paper, based on the application of digital twin technology in microgrid operation and maintenance, the method of calculating reliability probability density by function is applied to solve the problems of fuzziness, gray, and randomness of the relay protection status index. The invention can evaluate the state of the relay protection of the power system and can timely and accurately put forward the corresponding relay protection inspection and maintenance scheme, thereby improving the maintenance efficiency of the relay protection and further strengthening the power supply reliability of the power system. It can ensure the security and stability of the power system and reduce the reliable power consumption of the majority of power users.

1. Introduction

As an important means for the future smart grid to absorb large-scale renewable energy, such as wind power and photovoltaic power, the microgrid can operate independently and support each other with the external grid by organically combining distributed generation, energy storage system and load [1]. AC/DC microgrid has the advantages of both AC microgrid and DC microgrid and can supply power to AC and DC loads at the same time. Thus, it is an ideal microgrid structure. As an important part of the smart grid, AC/DC microgrid has important value and advantages in developing and applying digital twins in the power field through AC/DC microgrid [2].

With the development of research on relay protection state evaluation and the application of new generation substations in power systems, Literature [3] optimizes the monitoring and data collection and integration system of the operation status of the equipment on the grid site, including the equipment of the relay protection system, and pays full attention to the monitoring of the operation status of the relay protection equipment. The state evaluation of relay protection is optimized, the application of sensors and other equipment is added, and the sensing technology and monitoring technology are organically combined. The Literature [4], through the evaluation of the relay protection system state field, contains a large degree of subjective evaluation by the expert group, and the evaluation process is prone to bias. From an objective perspective, the current advanced intelligent algorithms, such as fault tree, state space, Go, Markov, and other algorithms, can play a better auxiliary role. The intelligent algorithms have accumulated some operating experience in the state evaluation of the strong current equipment of the power system, which is conducive to the scientific state evaluation of the relay protection equipment of the power system [5]

Digital twin technology is one of the ideal ways to describe, diagnose, predict and make decisions, or to achieve safe, stable, and economic operation of complex power grids in the future. It is one of the important ways to achieve safe, stable, and optimal operation of the future power system to build a smart grid digital twin system as a preview of the design, construction, operation, and maintenance of the actual power grid and to guide smart grid decision-making. Therefore, it is of great practical significance to study the digital twin of the smart grid. Reference [6] develops and constructs a digital twin model based on a physical transmission information system through the integration of virtual reality mapping, digital twin interaction technology, big data-driven virtualization, and cloud services. Reference [7] proposes substation moving object extraction based on monitoring video and describes in detail the method of linking and projecting real monitoring video in the three-dimensional virtual scene of the substation. At the same time, the improved Gaussian mixture background model is adopted for the input video information to realize the real-time extraction of moving objects. Meanwhile, it is compared with the inter-frame difference method. The accuracy and robustness of the improved Gaussian mixture background model in moving object extraction are confirmed. The research of this method has important application value for the safe operation and maintenance of substations.

Improving the power supply reliability of the power system can also avoid the waste of the maintenance cost of manpower and material resources caused by regular maintenance. It can also save the maintenance cost of relay protection, improve the maintenance efficiency of relay protection equipment of the power grid to a greater extent, and improve the reliability of power system operation. In this paper, the inner product method is taken to solve the norm of the grey fuzzy evaluation matrix's vector. After obtaining the corresponding norm of each vector, the evaluation result, which is most suitable for the relay protection state, is chosen according to the maximum membership principle. The accuracy and robustness of the proposed model in target extraction are confirmed by the comparative analysis of different schemes. The research of this method has important application value for the safe operation and maintenance of substations.

2. Digital twin model

The digital twin model is displayed in Figure 1.

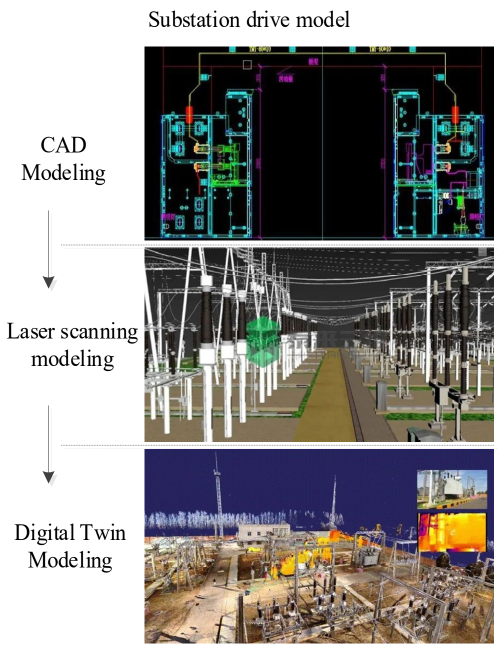

Figure 1 Substation modeling for the digital twin technology

A virtual model is constructed for a physical object in a digital way to reflect the real motion and behavior characteristics of the physical object. Real-time rendering of digital twin models and real-time and dynamic generation of customized space, models, and scenes are the key links in the construction of twin systems. Therefore, the model rendering speed and efficiency have a great impact on the performance of the digital twin system [8]. In addition, the digital twin system has higher requirements for the real-time performance and interactivity of data transmission. The real-time performance and fidelity of data interaction are important indicators to determine the performance of the digital twin system. How to quickly construct digital twin systems and ensure the fidelity and real-time performance of the twin relationship have become one of the key technologies for the development of digital twin applications in the power field [9].

3. Equipment operation and maintenance indicators

When a system fails due to the failure of a component, the failure is permanent and cannot change from the failure state to the normal state. The commonly used reliability indicators include reliability and mean time to failure [10]. When the system fails, the faulty component can be repaired for a repairable system, which is to restore the system to a normal state. This paper applies reliability, mean time to repair, availability, and other reliability parameters. Combined with the conditional probability method, it is to conduct qualitative and quantitative analysis of the relay protection system's reliability [11].

3.1 Reliability

Reliability refers to the probability that the component or system does not fail in the time interval (i, j) under the normal condition at the initial moment. In addition, unreliability ηf refers to the probability that the component or system fails for the first time in the interval (i, j) under the normal condition at the initial moment, which is expressed as:

$$\begin{cases} \lambda f = \theta(\mu > t) \\ \eta f = \theta(\mu < t) \end{cases} \tag{1}$$

Where, μ refers to the time from the initial normal state of the component to the moment of failure, and θ refers to a certain moment in the life cycle of the component. From the perspective of probability theory, reliability is the integral of the reliability probability density, which is expressed as follows:

$$\lambda f = \sqrt[t]{\frac{1}{f_{(i,j)}\phi}} \tag{2}$$

Where, ϕ is the probability density function of failure.

It is assumed that the component is repairable, and the failure of each component in the system is an independent event. The reliability of the component α is expressed as $\lambda_\alpha f$. The failure rate of the component in the protection system is a constant. The reliability obeys the exponential distribution with a constant parameter ϖ ; that is, the reliability function of the component α is:

$$\lambda_\alpha f = \sum_{i=1}^{n} \varpi_\alpha^{-t},\ i = 1, 2, \cdots, n \tag{3}$$

3.2 The mean failure time

The average time from normal operation to the next failure is the mathematical expectation of the unreliability (failure rate), that is:

$$\rho = \sqrt[-1]{\lambda f_{(t)} \kappa_i^n} \tag{4}$$

When $\rho \in 0$, it is shown in Equation 5.

$$\rho = \int_t^0 \lambda f_{(t)} \kappa \tag{5}$$

4. Operation and maintenance examples of relay protection

Line protection consists of main protection and backup protection. Longitudinal current differential and zero sequence current differential functions are equipped; the power frequency variation distance protection is used as fast section I protection to provide fast protection function in case of channel failure or abnormality. Three-section distance protection and zero sequence overcurrent protection are used as backup protection. In case of a line fault, the merging unit receives and processes the electrical quantity information from the transformer, and transmits the information to the local protection device and the process layer network, respectively. The action signal of the local protection device is directly transmitted to the intelligent terminal, and the station protection device transmits the action signal through the GOOSE network. The reliability of the protection principle is not considered; that is, it is assumed that when a fault occurs, the protection algorithm can identify the fault and get the correct judgment result. The line protection logic is shown in Figure 2 and Figure 3.

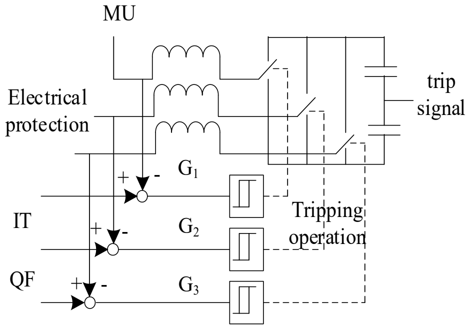

Figure 2 Line Protection Trip Logic

Line protection tripping logic: MU and IT in the figure refer to the equipment in the interval where the fault line is located, and QF refers to the tripping coil of the circuit breaker.

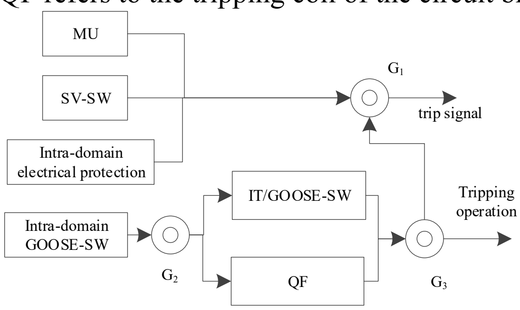

Figure 3 Protection logic of devices in the domain

When the merging unit and the line local protection device are normal, the local protection system can send the local tripping signal, which is connected to the GOOSE network as the starting signal of the breaker failure protection. When the merging unit, line local protection device, intelligent terminal, and circuit breaker are normal, the local protection can trip the outlet circuit breaker of the fault line

5. Experimental results and analysis

5.1. Experimental scheme

The invention relates to a twin system oriented to circuit breaker digital power, and the twin data comprises process data, equipment action logic data, action data, equipment state data, and the like. It is used for driving the movement and control of a twin relay protection model on the one hand and is also applied for monitoring the action state of equipment in real-time at the same time. It quickly and dynamically responds to and makes decisions on abnormal actions, adjustments, and other events in real time, so as to optimize system resources [12]. On the basis of the developed twin system, the proposed dynamic control method and its effect are verified according to the index of model motion stability. The speed and acceleration curves of the circuit breaker model collision are compared respectively when the control is not applied (scheme 1) and when the dynamic control is applied based on action constraints (Scheme 2).

5.2. Analysis of experimental results

After the driving force is applied to the circuit breaker model, the circuit breaker model can quickly complete the acceleration process until the uniform motion is realized. The experimental results are presented in Figure 4.

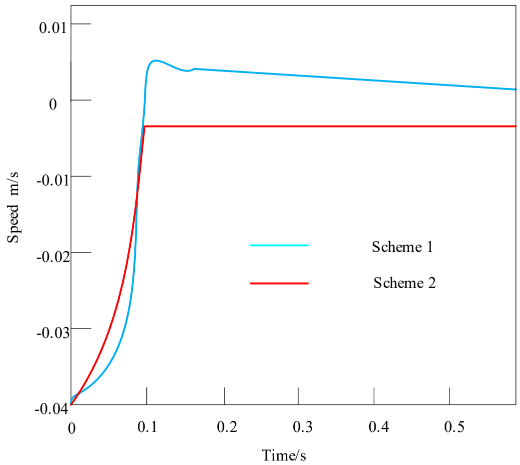

Figure 4 Comparison of velocity curves

It can be seen from the comparison results that when the control constraint is not applied, the model jitter is obvious. The speed curve oscillates for a long time due to the continuous impact of the subsequent circuit breaker on the detection line. Similar phenomena can also be observed in the acceleration curve displayed in Figure 5.

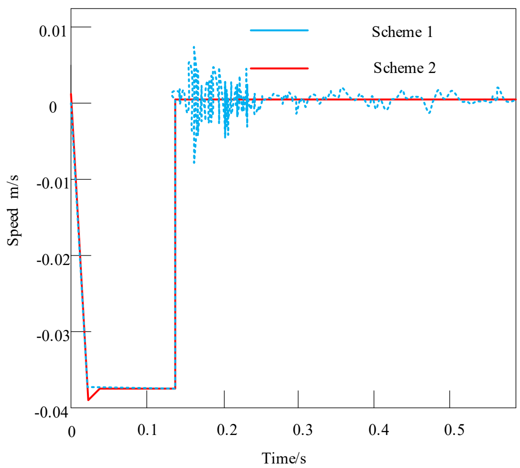

Figure 5 Comparison of acceleration curves

Dynamic control is carried out on the basis of action constraints. From the speed curve, it can be seen that compared with scheme 1, scheme 2 has less model oscillation. The circuit breaker model can quickly enter the static state, thus improving the operation stability and real-time performance of the twin system. Digital twin technology is an important research direction in the current smart power industry. An important prerequisite for the realization of the digital twin is that the twin should faithfully reflect the state and law of motion of physical entities in real time. The specific problems and difficulties of realizing this mapping relationship are different for different application scenarios.

6. Conclusion
According to the circuit breaker action layout and action requirements of microgrid relay, this paper proposes a dynamic control method of the twin model considering action constraints, which is helpful to guide the construction and control of the digital twin model with microgrid as the main protection mechanism. Through the model dynamics control considering the action constraints, the chattering phenomenon in the collision process of the circuit breaker twin model is reduced, and the stability and reliability of the twin system operation are improved. The status of the relay protection system can be evaluated more accurately, and the corresponding relay protection inspection and maintenance plan can be timely and accurately put forward to improve the maintenance efficiency of the relay protection.

Digital twin substation inspection system requires high real-time and stability. The existing technical level can not guarantee a perfect stable state. The next step can be further explored in the stability of data transmission. In future work, the two algorithms will be combined to break through their own limitations. With the emergence of new and efficient algorithms, we can also compare the results and advantages and disadvantages of different algorithms.

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