Fault simulation in ultrahigh voltage substation

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Abstract: Ultrahigh voltage(UHV) and extra-high voltage (EHV) have been widely used in power system, so the requirement for technology of operation management, as well as the accident analysis and disposal are more pressing. Based on the theory of Newton-Laphson power flow method, this simulation system imitates the primary device and secondary circuit, together with the normal, the abnormal and accidents in operation. Through simulation in various situations, it validates that this design is capable of simulating the complicated faults in UHV and EHV accurately and in real time. In addition, it can analyse and dispose them efficiently.

Key words: ultrahigh voltage (UHV); extra-high voltage (EHV); fault simulation

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In recent years, a plan to build 750 kV super grids massively has been established, and some projects have been completed or under construction. In a few years, a backbone network covering provinces Shanxi, Gansu, Qinghai, Ningxia and Xinjiang will emerge, which acts as the bond between hydroelectricity base in Yellow River upstream and coal power in northern Shanxi, eastern Ningxia and Kumul, and enhances the power transmission to North China, Central China and East China. Optimal allocation of the resources is approaching toward a wider scope and more aggressive force. Meanwhile, ultrahigh voltage grids above 1 000 kV are about to emerge, which will absolutely produce significant economic profits and promote the rapid, sustainable and healthy development of national economy[1]. Based on China Southern Power Grid and State Grid, about RMB 600 billion will be invested into the development of UHV grids till 2020, and the funding will be up to RMB 400 billion, so the market space is vast[2].

Transmission line possesses the highest fault rate in all components of power system, so it is vital to ensure the normal operation of power line in order to improve circuits[3]. In UHV or EHV system, one single fault will affect not only the corresponding line, but also others, then the whole system refuses to work. When short circuit fault occurs, a great force and high temperature, which do harm to the elements, will appear. For the single-phase ground fault, a highly inhomogeneous magnetic field caused by current will interfere with the communication line, signal system and equipments nearby, even mislead them. During 2002 – 2004, short circuit fault accounted for the bulk of ground faults in the level of 220 kV and above[4]. However, inter-phase short circuit is the worst accident if happens. This article provides relevant simulations and analyses in view of the typical faults mentioned previously.

The design follows the open principle both in software and hardware. The operating system qualifies portable operating system interface for UNIX (POSIX) and open software foundation (OSF), as well as transmission control protocol (TCP) or internet protocol (IP). Using the distributed structure, the hardware has a flexible and reasonable allocation and a high cost performance. Owing to the easiness to extend, port and upgrade, the users' investment in software and hardware can get sufficient protection.

1 Basic principles

1.1 Mathematical model of the faults

Two kinds of those faults are illustrated in Fig. 1 and Fig. 3 below, where a, b and c stand for three-phase power. And the relevant voltages and currents are marked clearly. When single-phase earth short-circuit happens, the value of U_a will be forced to zero. While inter-phase short-circuit occurs, it is obvious that I_a and I_b are equal in magnitude and opposite in direction[5-7].

Three boundary conditions are defined as

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$$U_a = 0,\ I_b = 0,\ I_c = 0. \tag{1}$$

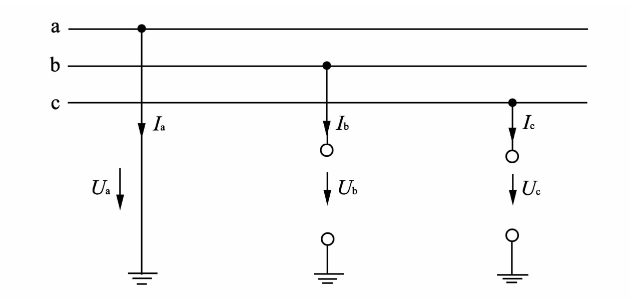

Fig.1 Single-phase earth short-circuit

The compound sequence network based on the functions above is shown in Fig.2.

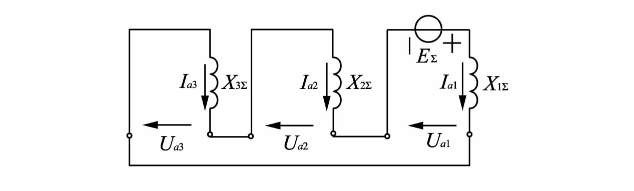

Fig.2 Compound sequence network of single-phase earth short-circuit

According to Kirchhoff's law, the corresponding calculation formulas of voltage and current are available as follows

$$I_{a1} = I_{a2} = I_{a3} = E_{\Sigma}/(X_{1\Sigma} + X_{2\Sigma} + X_{3\Sigma}), \tag{2}$$

$$U_{a1} = E_{\Sigma} - I_{a1}X_{1\Sigma}, \tag{3}$$

$$U_{a2} = - I_{a2}X_{2\Sigma}, \tag{4}$$

$$U_{a3} = - I_{a3}X_{3\Sigma}. \tag{5}$$

In the same way, the boundary conditions of inter-phase short-circuit are shown in Eq.(6) and the corresponding network is shown in Fig.4.

$$U_a = U_b,\ I_a = - I_b,\ I_c = 0. \tag{6}$$

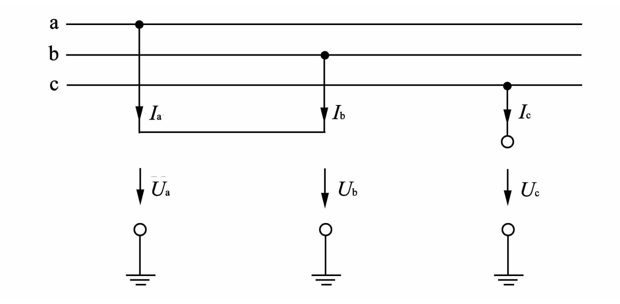

Fig.3 Inter-phase short-circuit

It is easy to calculate the required values.

$$I_{c1} = I_{c2} = E_{\Sigma}/(X_{1\Sigma} + X_{2\Sigma}), \tag{7}$$

$$U_{c1} = E_{\Sigma} - I_{c1}X_{1\Sigma}, \tag{8}$$

$$U_{c2} = - I_{c2}X_{2\Sigma}. \tag{9}$$

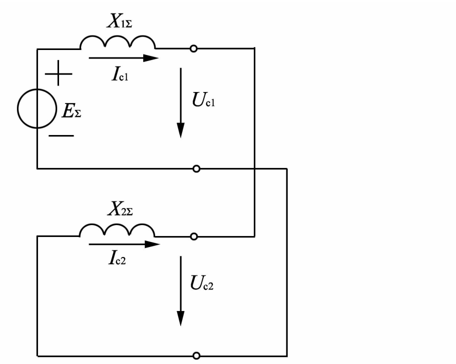

Fig.4 Compound sequence network of inter-phase short-circuit

1.2 Implementation of the function

The realization process of the function is depicted in Fig.5, which shows that when a fault occurs, the information will be transmitted automatically to the background. Meanwhile, the system is about to analyze the fault and deal with it as well.

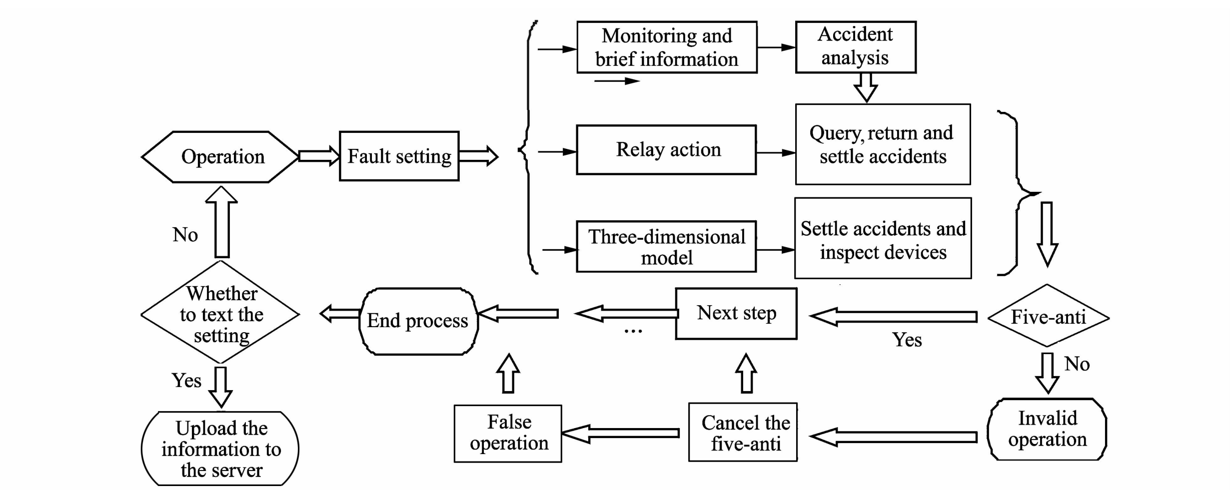

Fig.5 Block diagram of the basic function

With sparse matrix, sparse vector and other technologies, the instantaneity of dynamic simulation has been greatly improved that responds to operation and accidents veritably without any jet lag. By using the standardized calculation method, the fault current in all kinds of complex malfunctions (including the crossing fault in different lines of combined frame) is calculated. Switch current calculation uses the method which has no effect on the standardization of the trend convergence. The system can accurately simulate the movement situation of the relay protection and automatic device when the time disturbance happening or that happening later[8]. Using the fault record wave technology, the waveform can be shown instantaneously and authentically when the fault occurs.

2 Simulation and analysis

With dynamic simulation, we can get the corresponding dynamic fault wave record when any fault happens in a specific point of the system, not only the corresponding waveform and other lines, but also the whole local system will be influenced at last. Fault wave record function makes it possible to show the circumstances in real time. For instance, in the 750 kV accurate east primary line, when the inter-phase fault happens between phase A and B shown in Fig. 6, both the relevant voltages and the currents will have instant oscillations. There will be no zero-sequence current because of none earth-fault.

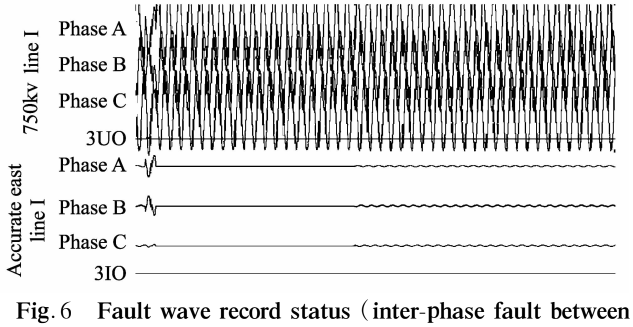

Fig. 6 Fault wave record status (inter-phase fault between phase A and B on a 750 kV line)

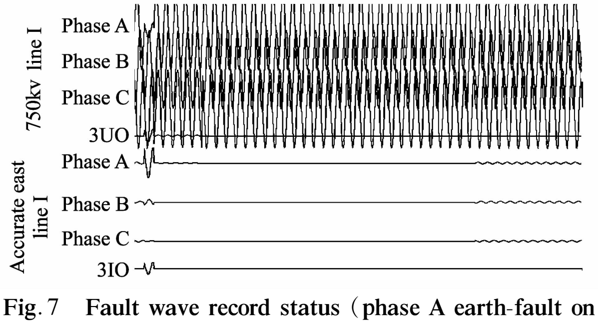

Fig. 7 Fault wave record status (phase A earth-fault on a 750 kV line)

When earth-fault occurs to phase A illustrated in Fig. 7, its voltage and current will oscillate. However, the zero-sequence current and voltage will come up in the waveform because of grounding.

3 Conclusion

1) The simulation picture is totally based on the real electric power equipments in the substation, which is very vivid. Operators can arouse the motion of elements by clicking mouse on the mock or secondary connection drawing, and the status between simulation and the reality is accordant.

2) It can not only simulate the normal or exceptional accidents, but also provide a refined quadratic diagram explanation. And this system can explain the relay protection sets separately from theory to process, shaping the breaker and respond element, and imitating the current locus through animation as well.

3) The simulation system should also provide the function of maintaining, thus users can modify it according to practice during employment, making it closer to the real substation.

4) Friendly human-machine interface, easy to operate and display intuitively, it has characteristics of reality, validity and flexibility.

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