Electromagnetic Transient Simulation Analysis of Single-Phase Earth Fault

Xingjun Tian¹, Yuntao Lei¹*, Jiu Li¹, Yang Liu², Zhijie Xing¹, and Qi Yao¹

¹Department of Electrical and Electronic Engineering, Shijiazhuang Tiedao University, Shijiazhuang, Hebei,050043, China
²Shuohuang Railway Development Co., Ltd., Cangzhou, Hebei, 062350, China
*Corresponding author’s e-mail: 641324300@qq.com

Abstract. In order to study the influence of different fault conditions on the initial traveling wave amplitude, initial traveling wave arrival time and duration of fault line transient voltage, a fault electromagnetic transient analysis method based on MATLAB/Simulink modeling is proposed. This method uses MATLAB software to build a 10kV railway automatic blocking and continuous power transmission lines system simulation model with a total length of 60km. The system model includes three parts: power system module, transmission line module, data acquisition and processing module. Taking the single-phase ground fault as an example, the sampling frequency is set to 2MHz, and the simulation analysis of different initial phase angles, different transition resistances, different fault distances and different branches before fault points are performed. The single phase voltage traveling wave diagrams in different fault conditions are analyzed, which shows that the analysis method has certain feasibility.

1. Introduction
Due to the power supply at the end of the railway automatic blocking and continuous power transmission lines, a spare double-end power supply mode; the power supply loads are small and evenly distributed; the power supply arms are long; the overhead lines cable are used alternately, the branches are short and few, so the railway automatic blocking and continuous power transmission lines are different from the general distribution network. It is not easy to use the impedance method. Only the traveling wave method can be used. In addition, the current traveling wave is susceptible to interference signals, so the voltage traveling wave can only be used for fault location. In addition, because of the short branches of the lines, the fault occurred on the branch line, the traveling wave method can be located at the junction of the branch and the main branch, which this article did not consider. Taking the single-phase ground fault as an example, the transient voltage waveform detected by the faulty line measurement end and the modulus waveform after phase-mode transformation are analyzed under different fault conditions.

2. Simulations of different transition resistances
When a ground fault occurs at a certain point in the transmission lines, the grounding resistances generated are generally small, about 2Ω to 20Ω. However, when the lines are discharged or the single-phase grounding occurs, the grounding resistances generated will be large. Dozens or even hundreds of ohms[8], different transition resistances will produce different transient voltage traveling waves. Therefore, it is necessary to simulate the fault of different transition resistors.
In order to study the influence of different grounding resistance on the traveling wave of fault voltage, in the simulation model of railway automatic blocking and continuous power transmission lines system, a single-phase short-circuit ground fault occurs at a distance of 5km from the beginning of a single overhead line, and the initial phase angle of the power supply is 0°. The initial angle of the fault voltage is 30° and the fault time is 0.02 s. The electromagnetic transient simulations of the transition resistances of 10Ω, 100Ω, 200Ω and 400Ω are respectively performed, and the fault waveforms at different starting resistances at the beginning of the line are shown in Fig. 1.

Figure 1(a) shows the A-phase voltage traveling wave under different transition resistances. Before the fault, the system runs and the normal state is steady state. When the system fails, the voltage waveform begins to change irregularly. After a transient process, the waveform tends to be stable, the voltage amplitude will no longer change, and the system enters a new steady state. Therefore, it can be said that the process of the power system from transient to a steady state, and then from the steady state to a transient state is the wave process of the traveling wave. In this process, the severity of the waveform of the traveling wave, the duration of the irregular waveform and the duration of the state process are related to the magnitude of the transition resistance. The smaller the transition resistance, the more severe the sudden change of the voltage traveling wave, the more obvious the amplitude drop, and the longer the transient process lasts. When the transition resistance is 400 Ω, the voltage abrupt change is very small, and finally the steady-state voltage amplitude is close to the voltage amplitude in normal operating conditions before the fault.

Figure 1(b) and Figure 1(c) show the α-mode and zero-mode voltage traveling wave with different transition resistances. Before the fault, the system operation is symmetric with three-phase voltage in normal state, the zero-mode voltage traveling wave is 0, and the α-mode voltage traveling wave changes periodically. After the fault, the various modular traveling waves begin to change significantly. The severity of the change is related to the size of the transition resistances. The smaller the transition resistance is, the larger the asymmetry is, the more severe the waveform changes, the more time to spend to the steady state; the more the transition resistance larger, the smaller the asymmetry, the...
smoother the waveform changes and the shorter the time to reach steady state. Therefore, the transition resistance has a great influence on the transient and steady-state processes of the voltage waveform.

3. Simulations of different Initial faults phase angles
Since the moment of the fault has great uncertainty, the initial angle of the signal corresponding to the fault occurrence time also has great uncertainty, which also causes the uncertainty of the initial traveling wave signal of the fault [8]. The initial angle of the voltage at the time of the fault may have a large influence on the amplitude of the fault traveling wave. By setting different initial angles of three-phase voltage source and different faults initial phase angles to study the influence of different initial angles of fault on the traveling wave of fault voltage.

In the simulation model of the railway 10kV automatic blocking and continuous power transmission lines system, a single-phase short-circuit ground fault is set at a distance of 5km from the beginning of a single overhead line, the transition resistance is 10Ω, and the fault time is 0.02s. The initial phase angles of the power supplies are -15°, 15°, 45°, and 60°, respectively, corresponding to the initial phase angles of the fault voltages of 15°, 45°, 75°, and 90°.

Figure 2 (a), Figure 2 (b) and Figure 2 (c) are the A-phase, α-mode and zero-mode voltage traveling waves at different initial phase angles. It can be seen from the figure that when the transition resistance and the fault distance are fixed, the initial phase angle of the fault increases, and the severity of the three waveform changes also increases. The changes of the amplitude of the initial traveling wave are more obvious, but the amplitude of the traveling wave when it reaches the steady state is basically unaffected. Therefore, the initial phase angle of the fault affects the transient process of the fault voltage waveform, and has little effect on the steady-state waveform.

4. Simulations of different fault distance
Traveling waves will produce attenuation and loss during the propagation process. Faults that occur at different fault distances will also have different effects on the traveling wave. In order to detect the influence of the fault distance on the fault waveform in different fault distances conditions, in the railway 10kV automatic blocking and continuous power transmission lines simulation model, the simulation of electromagnetic transient is carried out at the beginning of the single overhead lines at
5km, 25km and 45km. the transition resistance is 100Ω, the initial phase angle of the power supply is 0°, the corresponding initial phase angle of the fault voltage is 30°, and the fault occurrence time is 0.02 s. The waveform at the beginning of the lines at different fault distances is shown in Figure 3.

![Waveform at different fault distances](image)

(a). A-Phase voltage traveling wave

(b). α-mode voltage traveling wave

(c). zero-mode voltage traveling wave

Figure 3. A-phase, α-mode and zero-mode voltage traveling wave at different fault distances

Figure 3 (a), Figure 3 (b) and Figure 3 (c) are the A-phase, α-mode and zero-mode voltage traveling waves at different fault distances. It can be seen from the figure that when the transition resistance and the initial phase angle of the fault are fixed, the various voltage traveling waves are relatively stable before fault, and the waveforms are basically coincident. After the fault occurs, the waveform suddenly changes suddenly and the amplitude and phase angle are different when finally reaching the steady state. Because the attenuation and loss of the traveling wave of different fault points when they reach the measuring end are different. The farther the distance is, the more serious the attenuation and loss are, and the later the traveling wave arrives. Therefore, the fault distance has a great influence on the amplitude and arrival time of the transient traveling wave.

5. Simulations of different fault distances

The wave impedance changes at the connection point of the line branch, and the traveling wave will refract and reflect, so the traveling wave arriving at the measuring end may be different through different number of branches connecting points. In order to detect the influence of the number of different branches before the fault point on the fault waveform, in the simulation model, the electromagnetic transient simulations are carried out at the beginning of the single overhead lines at 5km, 25km and 45km. The branches connection point of the fault traveling wave are Set 4, 2 and 0. The transition resistance is 100Ω, the initial phase angle of the power supply is 0°, the corresponding initial phase angle of the fault voltage is 30°, and the fault occurrence time is 0.02s. The waveform when the number of branches is measured at the beginning of the line is shown in Figure 4.

It can be seen from Figure 4(a) that the number of branches before the fault point has a significant influence on the transient fault traveling wave, and has little effect on the final steady state. It can be seen from Figure 4 (b) and Figure 4 (c) that, when other conditions are fixed, although the number of branches before the fault point has no influence on the initial traveling wave arrival time of the fault, the fewer the number of branches before the fault point, the each modulus fault traveling wave amplitude changes of reaching the measuring end are more obvious, the easier it is to identify the wave head.
Figure 4. A-phase, α-mode and zero-mode voltage traveling wave with different number of branches before the fault point.

Because the more connection points of the same fault traveling wave, the more folds and reflections occur, and the greater the loss of the traveling wave amplitude. Therefore, the number of different branches before the fault point has a great influence on the transient traveling wave, and has no effect on the steady-state waveform.

In summary, if the influence of the fault transition resistances, the initial phase angles of the fault, the fault distances and the number of branches before the fault point on the voltage traveling wave are divided into important and unimportant conditions. Different influences on the voltage traveling wave are shown in Table 1.

Table 1. Influence of different fault conditions on voltage traveling wave

| Fault conditions       | Initial traveling wave arrival time | Initial traveling wave amplitudes | Duration | Steady state amplitudes |
|------------------------|-------------------------------------|----------------------------------|----------|-------------------------|
| Transition resistances  | unimportant                         | important                        | important| important               |
| initial phase angle     | unimportant                         | important                        | important| unimportant             |
| distances              | important                           | important                        | unimportant| unimportant             |
| branches               | unimportant                         | important                        | unimportant| unimportant             |

6. Conclusion

The simulation results of single-phase ground fault show that the traveling wave is greatly affected by the transition resistance, the initial phase angles of the fault, the fault distances, and the number of branches before the fault point. With the numerical value of transition resistance increased, the process of transient traveling wave becomes more severe, and the duration continues longer. The waveform is close to the normal voltage when the steady state is reached. The fault angle of the initial phase becomes larger, which leads to more intense transient traveling wave process and longer duration. But the final steady-state waveform has little effect; the fault distance mainly affects the amplitude and arrival time of the transient traveling wave, and has little effect on the steady-state waveform. The
number of branches before the fault point has a great influence on the amplitude of the initial traveling wave of the fault, and has no effect on the arrival time and the steady-state waveform.

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