GROUNDING FAULT LOCATION IN DC RAILWAY SYSTEM

X. K. Wang,
Beijing Jiaotong University–China,
11121681@bjtu.edu.cn

J. H. He,
Beijing jiaotong University–China
jhhe@bjtu.edu.cn

C.Y. Dong
Beijing jiaotong University–China
11125704@bjtu.edu.cn

X. Yang,
Alstom Grid Technology Center-China
Autoy.yang@alstom.com

Brian Kirby,
Alstom Automation–UK
Brian.kirby@alstom.com

David Writer
Alstom Automation–UK
David.writer@alstom.com

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ABSTRACT

Due to the increased strain of the urban ground traffic, the DC railway transit system has been developed rapidly to solve the traffic problems. Therefore, it is important to ensure the security and reliability of the DC traction power supply system. Low-resistance grounding fault has an extremely deadly effect against the safe operation of urban rail transit system. Furthermore, it is difficult to locate the fault position because of little available statistical information. In order to locate the fault position rapidly, a method is proposed by transforming the DC traction power supply system circuit into the Bergeron equivalent circuit and calculating the voltage distribution of the catenary. This paper the details of this algorithm.. Simulations are used to verify the accuracy of this approach.

1 INTRODUCTION

Over 90% of electrical system faults start as grounding faults[1,2,3]. In general, there are two kinds of grounding fault in DC traction power supply system, high-resistance grounding fault and low-resistance grounding fault. The high-resistance grounding fault has a potential risk to the DC traction system, and has been located by several methods[1,3], but the low-resistance grounding fault is difficult to locate because of limited information when the fault occurs. The low-resistance grounding fault is a very serious fault and can cause a serious threat to the DC traction system, so it is important to detect the fault and locate the fault position rapidly.

Generally, three fault location methods are used to locate the fault position[4]. First is the impedance method, which is the most prevalent fault location method and can be used to locate accurately the high-resistance fault position. But for the low-resistance fault, the short-circuit current is very high and the protection device operates very quickly, current and voltage sensors cannot record the complete fault data, so it makes this method unsuitable. The last two methods are based on traveling wave and failure analysis. The traveling wave method has been frequently used in large power system, particularly the long distance transmission system. The method is based on a simple principle and has been realized, but is unusable for the DC traction system because of its short distance transmission line and special structure.

The approach of this paper is to use the failure analysis method. Reliable and precise location of low-resistance grounding fault in the DC railway is hard to realize because of the high short-circuit current and the sensitive breaker[1]. Incomplete current and voltage values make location work seems impossible. Therefore, how to use these very limited values to analyze the fault characteristic and get the fault position is a vital process. This paper presents a new method based on the Bergeron circuit to take fully use of the limited values to obtain the fault position.

2 GROUNDING FAULT IN DC SYSTEM

There are many traction electrifications with different voltage levels in DC railway systems all around the world, such as DC 600V, DC 650V, DC 750V, DC 1500V and DC 3000V[1,2,3]. In China, the main voltage levels are DC 750V level and DC 1500V level[1]. The main power supply equipment of DC 750V is the third rail, while the DC 1500V is the catenary. The feeding current passes through the third-rail or catenary to provide power to trains, and returns by reflux line. DC feeder links the DC bus bar to feed power to the third-rail or catenary, which is shown in figure 1. After operating for a long time, grounding fault will inevitably occur. Thus protection device and breakers are installed on every DC feeder to ensure rapidly operation of the protection system. Current sensors and voltage sensors are used to record the values of current and voltage when a fault occurs. These values will be the most important information to locate the fault position.

There are two kinds of grounding fault in DC traction power supply system, high-resistance grounding fault and low-resistance grounding fault. The reasons of these faults are as follows.

(1) Natural factor: after operating for a long time, insulation aging, mutual extrusion, jacket layer corrosion may cause high-resistance grounding fault[1].

(2) Human factor: a classic case for a low-resistance

fault is the negligence of maintenance staff, such as metal equipment left on the running rail and the third rail after maintenance work. When the power system operates again, a low-resistance fault could occur and lead to a serious consequence.

(3) Climatic factors: Grounding due to precipitation caused by rain or fog is the most anticipated factor for giving rise to the reduced insulation or arc which may result in DC grounding fault. For the DC traction system in north of China, snow is also a potential factor for a grounding fault.

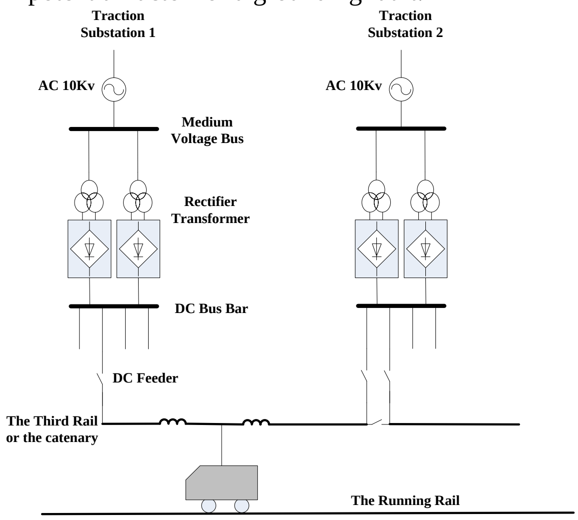

Figure 1 DC Traction Power Supply system

A high-resistance grounding fault is easier than a low-resistance grounding fault to be located. But if a high-resistance grounding fault cannot be detected and located in time, it could be developed into a low-resistance grounding fault and can seriously threaten the safety of the whole system. Therefore, a method to locate a low-resistance fault is completely necessary. The following section presents an approach to locate a low-resistance fault quickly.

3 THE BERGERON EQUIVALENT CIRCUIT AND FAULT LOCATION METHOD

Bergeron method makes use the electromagnetic wave transmission principle on the transmission line to record the current instantaneous value of $u(t)$, $i(t)$ and its historical value $u(t-\tau)$, $i(t-\tau)$. It then presents these values to the transmission line's Bergeron model to obtain the two concentrated equivalent circuit parameters.[4].

3.1 The Bergeron equivalent circuit

A classical sketch map of Bergeron equivalent circuit is shown in Figure 2:

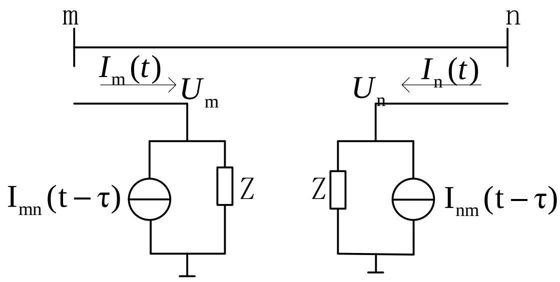

Figure 2 Bergeron equivalent circuit model

From this circuit we can get a following formula:

$$I_m(t) = I_{mn}(t-\tau) + U_m(t)/Z$$
$$I_n(t) = I_{nm}(t-\tau) + U_n(t)/Z \quad (1)$$

Which is the relationship between the voltage and current at both ends, m and n.

In formula (1) Z is the wave impedance of lossless transmission line

$$\tau = l/v = l \bullet \sqrt{L_0 C_0}$$
$$v = \frac{1}{\sqrt{L_0 C_0}} \quad (2)$$

where l is the whole length of the catenary, L_0 and C_0 are the inductance and capacitance of a unit length, v is the wave velocity on transmission line.

From the wave equation of lossless uniform transmission line:

$$\frac{\partial i^2}{\partial x} = L_0 C_0 \frac{\partial^2 i}{\partial t^2} \quad (3)$$

We can get the following formula:

$$I_m(t-\tau) = -I_{nm}(t-\tau) - U_n(t-\tau)/Z$$
$$I_n(t-\tau) = -I_{mn}(t-\tau) - U_m(t-\tau)/Z \quad (4)$$

From formula (1) and formula (4):

$$U_m(t) = \frac{1}{2}[U_n(t+\tau) - Zi_n(t+\tau)]$$
$$+\frac{1}{2}[U_n(t-\tau) + Zi_n(t-\tau)]$$
$$I_m(t) = \frac{1}{2Z}[U_n(t+\tau) - Zi_n(t+\tau)]$$
$$-\frac{1}{2Z}[U_n(t-\tau) + Zi_n(t-\tau)] \quad (5)$$
$$U_n(t) = \frac{1}{2}[U_m(t+\tau) - Zi_m(t+\tau)]$$
$$+\frac{1}{2}[U_m(t-\tau) + Zi_m(t-\tau)]$$

$$I_n(t) = \frac{1}{2Z}[U_m(t+\tau) - Zi_m(t+\tau)]$$
$$-\frac{1}{2Z}[U_m(t-\tau) + Zi_m(t-\tau)]$$

3.2 The voltage distribution

If we want to get a voltage from a distance of x to the end n at time t, we only need to convert τ -(l/v) into x/v, then the voltage distribution along the catenary is shown as formula (6):.

$$U_m(x,t) = \frac{1}{2}[U_m(t+x/v) - Zi_m(t+x/v)]$$
$$+\frac{1}{2}[U_m(t-x/v) + Zi_m(t-x/v)]$$
$$U_n(x,t) = \frac{1}{2}[U_n(t+x/v) - Zi_n(t+x/v)] \quad (6)$$
$$+\frac{1}{2}[U_n(t-x/v) + Zi_n(t-x/v)]$$

From the both end of voltage and current, the voltage distribution along the catenary is calculated and will be used to locate the fault position.

3.3 Grounding fault location approach

To locate a low-resistance grounding fault, some information should be recorded, such as the voltages and currents before and after the fault, and the catenary parameters of the faulted line.

When a low-resistance grounding fault occurs, the voltage of the fault position is very low (maybe nearly 0V). The further the distance is away from the fault position, the higher the voltage is. Thus a criterion is proposed to precisely locate the fault position.

From formula (6) we can get a following formula:

$$U_n(x,t)$$
$$= \frac{1}{2}[U_n(t+x/v) - Zi_n(t+x/v)]$$
$$+\frac{1}{2}[U_n(t-x/v) + Zi_n(t-x/v)]$$
$$= U_m(l-x,t) \quad (7)$$

Thus,

$$u_n(x,t) = u_m(l-x,t) = 0 \quad (8)$$

Combine formula (6) and formula (8), the fault distance x to end n is calculated.

The next section proposes a modified criterion and presents its simulation and results.

4 Simulation and results

This paper uses MATLAB/SIMULINK to model the Shenzhen subway 1500V three-phase bridge 6-pulse DC traction system. The data is recorded by computer to calculate the fault position.

(1) DC cable resistance in the substation is $R_s = 0.0006\Omega$.

(2) DC cable inductance in the substation is $L_s = 0.03mH$.

(3) Modified catenary inductance per unit is $L_0 = 3.01831715\times10^{-3} H/km$.

(4) Modified catenary capacitance per unit is $C_0 = 3.35368\times10^{-8} F/km$.

4.1 modified criterion

In order to reduce the error, we need a modified criterion to calculate the fault position before simulation.

When there is a low-resistance fault, the ideal consequence is $U_n(x,t) = U_m(l-x,t) = 0$, in which x is the distance from fault position to end n . But in the actual calculation, some errors are inevitably introduced, so the voltage of the fault position is not entirely zero. Therefore, a modified criterion is proposed:

$$f(x_1) = u_n(x_1 + \Delta x, t)$$
$$f(x_2) = u_m(l - x_2 - \Delta x, t)$$
$$x = \frac{x_1 + x_2}{2}$$
$$\Delta x = 10m \quad (9)$$

By calculating the minimum value of $f(x_1)$, $f(x_2)$ at the fault time t , and obtaining the corresponding x_1 and x_2, the fault position x will be located.

4.2 low-resistance fault simulation

For a 1200 meters length catanery, the simulation step is $1\times10^{-9}s$, if the distance from fault position to end n (x) is 600 meters, Δx is $10m$, so from formula (2) we can obtain :

$$x/v = x\bullet\sqrt{L_0C_0}$$
$$= 0.6\times\sqrt{3.01831715\times10^{-3}\times3.35368\times10^{-8}},$$
$$= 6.03663\times10^{-6}s$$
$$\Delta x/v = \Delta x\bullet\sqrt{L_0C_0}$$
$$= 0.01\times\sqrt{3.01831715\times10^{-3}\times3.35368\times10^{-8}}$$
$$= 1.0061\times10^{-7}s$$

The voltage and current waveforms at both ends are shown in the following two figures.

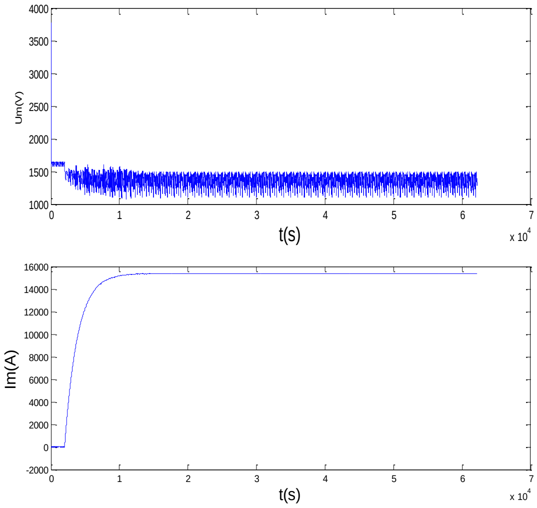

Figure 3 the voltage and current of end m

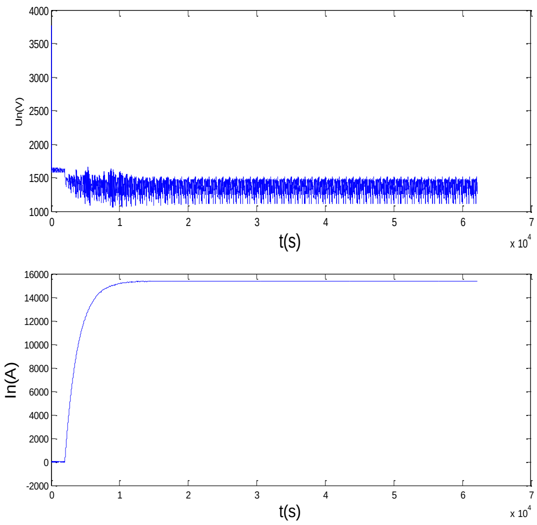

Figure 4 the voltage and current of end n

The value of $u_m(t)$, $i_m(t)$, $u_n(t)$, $i_n(t)$ are obtained from the simulation waveform, the minimum value of $f(x_1)$, $f(x_2)$ and corresponding x_1 and x_2 can then be calculated:

$$x_1 = 640m, x_2 = 570m$$

$$x = \frac{x_1 + x_2}{2} = 605m$$

The relative error is: .

$$\varepsilon_r = \frac{|600 - 605|}{1200} = 0.42\%$$

4.3 further calculation

By setting the Δx as $2m$, the result is:

$$x_1 = 638m, x_2 = 576m$$

$$x = \frac{x_1 + x_2}{2} = 602m$$

The relative error is only: $\varepsilon_r = \frac{|600 - 602|}{1200} = 0.17\%$

Therefore, the smaller the Δx is, the more precise is the result.

4.4 other fault position

Δx \ x		100m	200m	300m	400m	500m
10m	Relative error	3.33 %	2.08 %	1.25 %	1.67 %	0.83 %
2m	Relative error	2.33 %	1.25 %	1.17 %	1.25 %	0.58 %

5 CONCLUSION

The proposed method gives a new approach to locate the low-resistance grounding fault and holds its advantages. It overcomes the limited available information problem and takes fully use of these information to precisely calculate the fault position. The simulation results show the fault location precision can be improved by the simulation step and the smaller Δx. In the future, more comparisons of different fault resistance will be performed to research a more precise criterion. Based on the proposed methods, more analysis and research is required to investigate the feasibility of this method by practical devices.

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