

# Grounding fault detection and type determination of substation DC system

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**Abstract.** The DC system is used as the power supply for all kinds of protection, measurement and control, safety automation and other devices in the substation. It is the fundamental guarantee of power system control and protection. If the substation DC system fails, it will have a destructive impact on the entire substation system and function. Based on this, in order to solve the problems of maloperation and refusal of protection device caused by grounding fault of DC system, a method combining unbalanced bridge method with leakage current sensor is proposed to detect the grounding resistance of bus and branch. On this basis, the neural network optimized by quantum particle swarm optimization is used to determine the fault type. Finally, the effectiveness of the proposed method is verified by MATLAB/Simulink simulation.

## 1 Introduction

The main fault types of substation DC system can be divided into undervoltage, overvoltage, overload, insulation degradation, grounding, ring network, short circuit, etc [1-2]. Usually, minor faults can not be handled in time, and will gradually accumulate, and finally develop to serious faults such as short circuit and disconnection.

For DC system grounding fault detection, the commonly used methods include resistance balance method, voltage measurement method, AC signal injection method and unbalanced bridge method [3]. The resistance balance method can quickly judge the grounding condition of DC bus and select the grounding bus. However, when the grounding of branch feeder occurs, the voltage of DC bus will decrease, and it is unable to judge the grounding of branch feeder [4]. The voltage measurement method uses the voltage change to judge the grounding fault, and can quickly judge whether the bus voltage changes. But, the bus voltage change caused by branch feeder grounding cannot be effectively identified, and the bus voltage change caused by operation in DC system cannot be identified whether it is grounded [5]. The low frequency signal is injected into the ground between the AC bus and the ground to detect the ground fault. However, the detection results of this method are greatly affected by the distributed capacitance of the system. Unbalanced bridge method can accurately identify the positive and negative bus single pole grounding or two pole simultaneous grounding. However, the detection accuracy of branch fault detection is not accurate [6]. In order to accurately identify the ground fault and improve the fault detection accuracy. In this paper, an unbalanced bridge method combined with leakage current sensor is

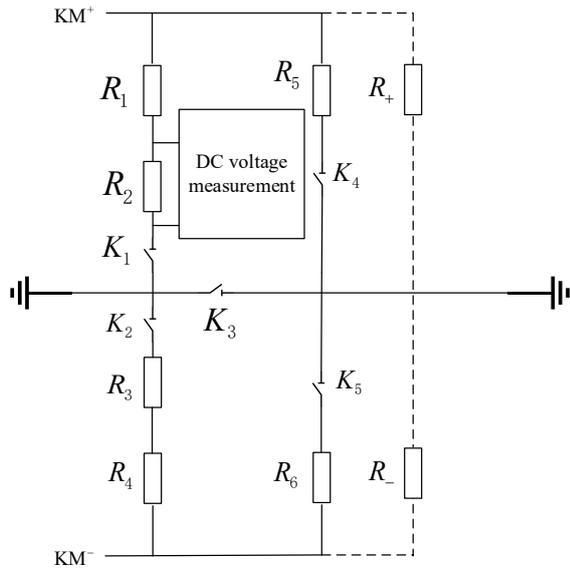
proposed to comprehensively detect the grounding resistance of bus and branch. On this basis, the neural network optimized by quantum particle swarm optimization is used to judge the fault type. Finally, the effectiveness of the proposed method is verified by simulation.

## 2 DC system ground fault detection and type determination

### 2.1 DC system ground fault detection

*2.1.1. Detection of DC bus grounding resistance.* The unbalanced bridge method is used to detect the grounding resistance of DC bus, and the detection schematic diagram is shown in Figure 1.  $KM^+$  and  $KM^-$  are DC buses in substation. For the convenience of analysis,  $R_1=R_4$ ,  $R_2=R_3$ ,  $R_5=R_6$ . When  $K_1-K_3$  is closed,  $R_1-R_6$  forms a traditional unbalanced bridge. By measuring the voltage  $U_1$  of  $R_2$  ends under the corresponding topology of  $K_1$  and  $K_2$  alternately on and off. The resistance values of positive grounding resistance  $R_+$  and negative grounding resistance  $R_-$  can be calculated.

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**Figure 1.** Detection principle of unbalanced bridge

Open  $K_3$ - $K_5$ , close  $K_1$  and  $K_2$ , and measure the DC voltage  $U_1$  at both ends of  $R_2$ . The positive and negative bus voltage  $U_K$  of DC system is calculated; Open  $K_5$  and close other switches. Measure DC voltage  $U'_1$  at both ends of  $R_2$ ;  $K_4$  is disconnected, other switches are closed, and DC voltage  $U''_1$  at both ends of  $R_2$  is measured; The positive and negative bus voltage  $U_K$  of DC system is calculated. The calculation formula of grounding resistance is as follows:

$$U_K = \frac{R_1 + R_2 + R_3 + R_4}{R_2} * U_1 \quad (1)$$

$$U'_+ = \frac{R_1 + R_2}{R_2} * U'_1 \quad (2)$$

$$U''_+ = \frac{R_1 + R_2}{R_2} * U''_1 \quad (3)$$

$$U'_- = U_K - U'_+ \quad (4)$$

$$U''_- = U_K - U''_+ \quad (5)$$

$$\frac{U'_+}{R_1 + R_2} + \frac{U'_+}{R} + \frac{U'_+}{R_+} = \frac{U'_-}{R_-} + \frac{U'_-}{R_3 + R_4} \quad (6)$$

$$\frac{U''_+}{R_1 + R_2} + \frac{U''_+}{R_+} = \frac{U''_-}{R_-} + \frac{U''_-}{R_3 + R_4} + \frac{U''_-}{R} \quad (7)$$

where  $U_K$  is DC bus voltage;  $U'_+$  is positive bus to ground voltage when  $K_5$  is disconnected and other switches are closed;  $U''_+$  is positive bus to ground voltage when  $K_4$  is disconnected and other switches are closed;  $U'_-$  is negative bus to ground voltage when  $K_5$  is disconnected and other switches are closed;  $U''_-$  is negative bus to ground voltage when  $K_4$  is disconnected and other switches are closed;  $R_+$  is grounding resistance of DC positive bus;  $R_-$  is the DC negative bus grounding resistance.

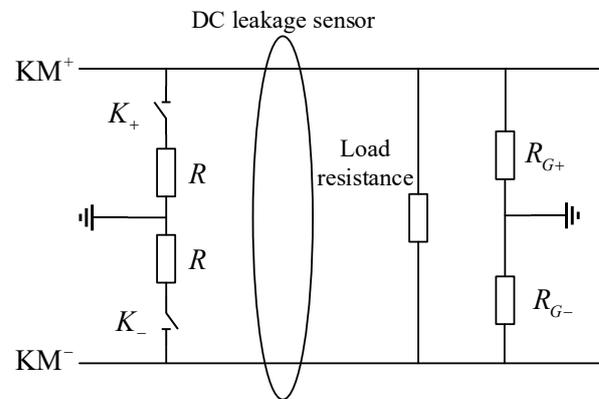
The positive and negative grounding resistance

can be obtained by solving equation (1) - equation (7).

$$R_+ = \frac{[(U'_+ - U'_-)R_7 + U'_+(R_1 + R_2)]U''_- + [(U''_+ - U''_-)R_7 - U''_+(R_1 + R_2)]U'_-}{(R_1 + R_2)R_7} \quad (8)$$

$$R_- = \frac{[(U''_+ - U''_-)R_7 + U''_+(R_1 + R_2)]U'_+ + [(U'_+ - U'_-)R_7 - U'_+(R_1 + R_2)]U''_-}{(R_1 + R_2)R_7} \quad (9)$$

**2.1.2. Detection of grounding resistance of fault branch.** The detection method of branch grounding resistance is to connect the unbalanced bridge with leakage current sensor. Figure 2 takes the case of single branch with both positive and negative grounding as an example. When there is no insulation grounding in the branch, the current  $I_+$  and  $I_-$  flowing through the leakage current sensor are equal in size and opposite in direction, so the output of leakage current sensor is 0.



**Figure 2.** Schematic diagram of branch circuit grounding detection

When  $K_+$  is closed and  $K_-$  is open, the negative grounding resistance  $R_-$  and the detection resistance  $R$  form a loop through the earth. At this time,  $I_-$  is greater than  $I_+$ , and the difference through the leakage current sensor is not zero, and the output of leakage current sensor is  $I_{G-}$  and negative. Similarly, when  $K_+$  is disconnected and  $K_-$  is closed, the positive grounding resistance  $R_{G+}$  and the detection resistance  $R$  form a loop through the earth. At this time,  $I_+$  is greater than  $I_-$ , and the difference value of leakage current sensor is not zero, and the output of leakage current sensor is  $I_{G+}$  and positive. According to whether the output value of leakage current sensor is zero and voltage polarity, the grounding fault point and grounding polarity can be determined.

## 2.2 Grounding fault type determination

In order to classify the grounding fault accurately and ensure the safe maintenance of the staff when the grounding fault occurs in the DC system. Using the method of BP neural network, the current and voltage information of the sensor is taken as the input vector and the fault condition as the output vector. On this basis, the weight of hidden layer is optimized by quantum particle swarm optimization algorithm.

The relationship between the input and output of neurons is as follow.

$$y = f\left(\sum_{i=1}^R X_i W_i + b\right) \quad (10)$$

where  $X_i$  is the input of the neuron, the coefficient between the other neurons connected to it is  $W_i$ ,  $b = W_0$  is the initial limit value,  $f$  is the transfer function, and  $y$  is the output of the neuron.

In the quantum space, the particle is moving around the point  $P$ , so the state of the particle is represented by the wave function  $\Psi_Y$ .

$$\psi(Y) = \frac{1}{\sqrt{L}} e^{-\frac{|Y|}{L}} \quad (11)$$

$$L = \frac{1}{\beta} = \frac{\hbar^2}{mr} \quad (12)$$

where  $l$  is the characteristic length of  $\delta$  potential drop. The particle position equation is calculated by Monte Carlo method.

$$x = p \pm \frac{L}{2} \cdot \ln \frac{1}{u} \quad (13)$$

where  $u \in [a, b]$ , at a certain time  $t$ , the position equation of the particle is as follows.

$$x(t+1) = p(t) \pm \frac{L(t)}{2} \cdot \ln \frac{1}{u} \quad (14)$$

When  $t \rightarrow \infty$ , if  $L(t) \rightarrow 0$ , then  $x(t+1)$  will slowly converge to point  $p$ , where  $p$  is the historical optimal value of each particle.

According to the above, the grounding fault is divided into active grounding and passive grounding. Active grounding is divided into direct DC grounding and direct AC grounding. Passive grounding is divided into single branch and multi branch grounding. Therefore, there are four kinds of passive grounding, direct grounding and neutral grounding. 150 groups of sensor data of four kinds of ground fault are selected as the training group to train the neural network.

When the positive and negative bus or a branch grounding fault occurs, the unbalanced bridge method and

leakage current sensor are combined to calculate the grounding resistance. On this basis, the neural network optimized by quantum particle swarm optimization algorithm is used to identify the ground fault. In case of active grounding, special measures shall be taken to ensure the safety of power supply. If it is passive grounding, judge whether it is single branch grounding or multi branch grounding. It greatly simplifies the difficulty for staff to find fault points. The overall process of DC system grounding fault and type determination is shown in Figure 3.

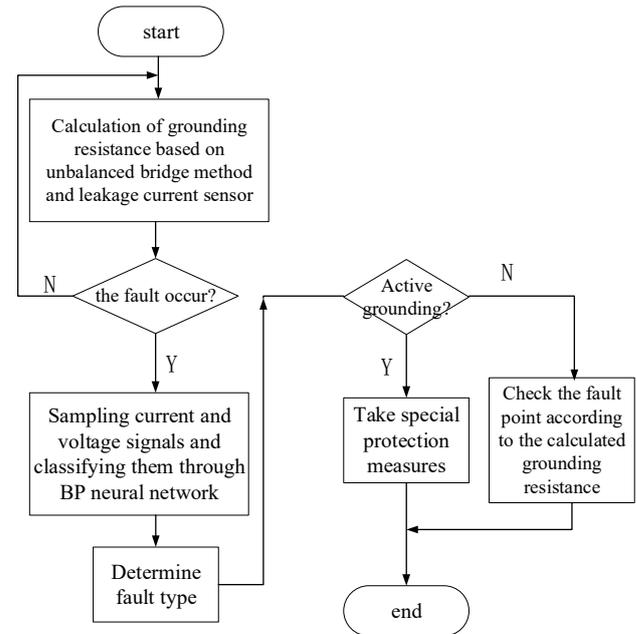


Figure 3. Overall flow chart of DC system grounding fault and type determination

### 3 Simulation Analysis

In this paper, based on MATLAB / Simulink, the DC system fault is simulated and analysed.

#### 3.1 Bus insulation resistance test

The insulation resistance test of bus can be divided into positive bus insulation resistance and negative bus insulation resistance. The inspection results are shown in the table below.

Table 1. Positive bus insulation resistance inspection table

numbers	Actual resistance value of positive bus to ground (KΩ)	Measurement of resistance to ground by positive bus (KΩ)	fault	fault type
1	100	105	NO	-
2	90	89	NO	-
3	60	55	NO	-
4	20	20	YES	one-point grounding

Table 2. Negative bus insulation resistance inspection table

numbers	Actual resistance value of negative bus to ground (KΩ)	Measurement of resistance to ground by negative bus (KΩ)	fault	fault type
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<b>1</b>	100	101	NO	-
<b>2</b>	90	89	NO	-
<b>3</b>	60	62	NO	-
<b>4</b>	30	25	YES	one-point grounding

It can be seen from table 1 and table 2 that the error of positive and negative bus insulation resistance test results is within a reasonable range, and the fault type can be accurately judged.

### 3.2 Branch insulation resistance test

According to figure 2, the insulation resistance and leakage current of branch to ground are detected respectively, and the detection results are shown in Table 3.

**Table 3.** Inspection table of branch insulation resistance

numbers	Positive grounding resistance (KΩ)	value	Negative grounding resistance (KΩ)	value	Leakage current when $K_+$ is closed (mA)	Leakage current when $K_-$ is closed (mA)	fault	fault type
<b>1</b>	3.5	5	5	-3.59	-0.64	YES	Multi-point grounding	
<b>2</b>	3	5	5	-3.05	0	YES	one-point grounding	
<b>3</b>	1	2	2	+0.75	+1.75	YES	Multi-point grounding	
<b>4</b>	7	4	4	0	-10.14	YES	one-point grounding	

## 4 Conclusion

In this paper, an unbalanced bridge method combined with leakage current sensor is proposed to detect the grounding resistance of bus and branch. On this basis, the neural network optimized by quantum particle swarm optimization is used to determine the fault type. The rationality of the detection method is verified by MATLAB/ Simulink simulation. The detection accuracy of grounding resistance meets the operation requirements of DC system. Compared with the traditional single fault detection method, it has more comprehensive detection function and higher detection accuracy.

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