A Method for Detecting Parasitic Circuits in the Same DC System

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Abstract: In the electric power system, the DC power supply system used in substation station in power system is related to the normal operation of primary and secondary equipment in substation, and its importance is self-evident. Therefore, in the early power design of substations, the dual-loop power supply mode is specially designed for some important loads or equipment in order to ensure the reliability of power supply for these important loads. However, due to the construction of lines, maintenance of equipment, equipment failure, and management is not in place, design drawings are missing and other reasons, often lead to some load parasitic loop phenomenon. Because of the existence of parasitic circuit, it will cause some hidden dangers to the DC power supply system. Therefore, the detection of parasitic circuits is also one of the most concerned issues in the field of electric power engineering, which needs further extensive and in-depth study.

1. Introduction
In the power system, the DC power system plays an extremely important role in substations and power plants, like the human heart in our bodies. DC power supply system is the system that provides power supply for protection. Under normal circumstances, it provides reliable DC power supply for control signal, relay protection, automatic device, circuit breaker jumping and closing operation circuit, etc. Whether the DC system is reliable or not plays a crucial role in the safe operation of power plants and substations, and is the guarantee of safe operation [1,2], which directly affects the success of protection work. In the power system, there are many factors that affect the stability and reliability of the DC power system, such as ground fault, AC inrush, DC mutual channeling, and parasitic circuit fault caused by faulty construction or device or line fault.

The safe operation of DC power system is the guarantee of protection and control system of the transformer substation, and the lifeline of relay protection equipment [3]. Its importance is self-evident. However, one of the major hazards in DC power systems is the parasitic circuit. Therefore, in 1994, the Ministry of Electric Power issued the “Anti-accident Measures for Relay Protection and Safety Automatic Devices” [7], specifying the configuration requirements of DC fuses. The first is to eliminate parasitic circuits. It can be seen that attention must be paid to the DC parasitic circuit and the hidden danger should be eliminated as soon as possible. However, at present, there are few devices or tools for the detection of parasitic circuits, which may be due to the lack of awareness and attention to the harm of parasitic circuits, leading to the lack of research investment in the detection technology of parasitic circuits in some equipment manufacturers.
In the DC power system, the insulation monitoring device is one of the important means to ensure its normal operation [4]. Its performance directly affects the safe operation of DC power system. However, at present, the installed insulation monitoring device is basically not equipped with the parasitic circuit detection function, unable to timely detect the parasitic circuit fault and alarm. Therefore, in order to improve the safety and reliability of DC power system, it is very necessary to develop an insulation device which can detect the fault of parasitic circuit.

2. Causes and harms of parasitic circuit

There are many reasons for causing parasitic circuit, mainly because the circuit design is not reasonable, or the actual equipment and the secondary circuit design drawings do not match, or the construction is not standard and equipment internal problems caused by various reasons. In the early power design, some important loads or equipment in the substation were supplied by double circuit, in order to ensure the power supply reliability of these important load lines and avoid power failure. However, in the daily operation of the DC power supply system of the substation, parasitic circuit faults often occur in some normal power supply circuits due to the construction of lines, maintenance of equipment and internal faults of equipment. Because of the complexity of the parasitic circuit, it is often impossible to detect it simply by using the normal whole group test method. At present, the inspection method of parasitic circuit still depends on the operation and maintenance personnel to carry out inspection or pull the circuit according to the relay protection principle strictly. Because some lines of the substation are impossible to check the power failure anytime and anywhere, the process of inspection becomes very complicated.

The parasitic circuit is very harmful. It might make the equipment run in abnormal working state, provide error information for the operators, bring great trouble and difficulty to the equipment maintenance, overhaul, fault troubleshooting, thus bringing difficulties to the normal operation of the equipment and fault handling. What’s worse, it may cause relay protection or rejection, leading to a large area of power failure or even a man-made electric shock accident or equipment damage [6].

3. Types and characteristics of parasitic circuits

According to the DL/T 1392-2014 standard, when DC system has DC cross-channeling fault, the product should be able to send DC cross-channeling alarm information, and select the fault branch that has DC cross-channeling [8]. Therefore, for parasitic circuits between two sets of DC, most of the current insulation devices can meet the monitoring requirements. It can be determined by detecting the relationship between the two busbar voltage changes whether the DC cross-channeling fault occurs between two sets of DC systems. However, for the parasitic circuit generated in the same set of DC system, the busbar voltage to the ground does not change at all, so it is impossible to determine whether there is a parasitic circuit fault by monitoring the change of busbar voltage to the ground. At present, there are mainly 3 types of parasitic circuit faults in the same DC system, as described below.

3.1 Positive parasitic circuit

As shown in Figure 1, abnormal electrical connection occurs between the positive terminals of two independent power supply circuits, that is, the positive parasitic circuit fails. When no parasitic circuit fault occurs in the DC power supply system, the parasitic circuit current i15 = 0, so the positive and negative load current i11 and i12 of load A are equal to i12, and the positive and negative load current i13 and i14 of load B are equal to opposite in magnitude, i11 - i12 = 0, and i13 - i14 = 0. Therefore, the current transformers CT1 and CT2 installed in the power supply circuit of load A and load B detect that the leakage current of the positive and negative load current of the feeder is 0. When the positive poles of load A and load B in the DC power system have abnormal electrical connection, the parasitic circuit occurs. As shown in figure 1, the parasitic circuit i15 is not equal to 0. Since the parasitic circuit current i15 is not equal to 0, the positive and negative load current for load A and load B i11 – i12 ≠ 0, and i13 – i14 ≠ 0. Therefore, the current transformers CT1 and CT2 installed in the power supply circuit of load A and load B detect that the leakage current of the positive and negative load current of
the feeder is not 0.

Figure 1. the positive parasitic circuit fails Model

3.2 Negative parasitic circuit
As shown in Figure 2, the negative electrode between the two independent power supply circuits has abnormal electrical connection, that is, the negative parasitic circuit has failed. When no parasitic circuit fault occurs in the DC power supply system, the parasitic circuit current $i_{25}=0$, so the positive and negative load current $i_{21}$ and $i_{22}$ of load A are equal to $i_{22}$, and the positive and negative load current $i_{23}$ and $i_{24}$ of load B are the same, and the direction is opposite, $i_{21}-i_{22}=0$, and $i_{23}-i_{24}=0$. Therefore, the current transformers CT1 and CT2 installed in the power supply circuit of load A and load B detect that the leakage current of the positive and negative load current of the feeder is 0. When the DC power system load A and the negative electrode of load B have abnormal electrical connection, the parasitic circuit occurs, as shown in FIG. 2, the parasitic circuit $i_{25}$ is not equal to 0. Since the parasitic circuit current $i_{25}$ is not equal to 0, the positive and negative load current for load A and load B $i_{21} - i_{22} \neq 0$, and $i_{23} - i_{24} \neq 0$. Therefore, the current transformers CT1 and CT2 installed in the power supply circuit of load A and load B detect that the leakage current of the positive and negative load current of the feeder is not 0.

Figure 2. the negative parasitic circuit fails Model

3.3 Dipolar parasitic circuit
As shown in Figure 3, abnormal electrical connection occurs between the positive and negative poles of two independent power supply circuits, that is, the parasitic circuit fault of the poles occurs. When no parasitic circuit fault occurs in the DC power supply system, the parasitic circuit current $i_{35}=0$ and $i_{36}=0$, so the positive and negative load current $i_{31}$ and $i_{32}$ of load A are equal to $i_{32}$, and the positive and negative load current $i_{33}$ and $i_{34}$ of load B are the same, and the direction is opposite, $i_{31}-i_{32}=0$ and $i_{33}-i_{34}=0$. Therefore, the current transformers CT1 and CT2 installed in the power supply circuit of load A and load B detect that the leakage current of the positive and negative load current of the
feeder is 0. When abnormal electrical connection occurs between the two poles of load A and load B in the DC power system, the parasitic circuit occurs, as shown in Figure 3. The parasitic circuit i35 and i36 are not equal to 0. Since the parasitic circuit current i35 and i36 are not equal to 0, the positive and negative load current for load A and load B i31 – i32 ≠ 0, and i33 – i34 ≠ 0. Therefore, the current transformers CT1 and CT2 installed in the power supply circuit of load A and load B detect that the leakage current of the positive and negative load current of the feeder is not 0.

![Figure 3. the parasitic circuit fault of the poles occurs Model](image)

According to the above parasitic circuit types and characteristics, the following can be concluded. For the parasitic circuit in the same DC power system, there is no change in the busbar voltage to ground. However, due to the parasitic circuit current on the circuit where the parasitic circuit occurs, the load current between the positive and negative terminals of the normal power supply circuit of the load is not equal. Therefore, the current transformer can be used to monitor the change of leakage current in the feeder circuit, so as to detect whether there are parasitic circuit faults between feeders in the same DC power system.

4. Detection principle and method of parasitic circuit

![Figure 4. The current transformer](image)

According to the theory of electromagnetic fields, a time-varying electric field can generate a magnetic field, and a time-varying magnetic field can generate an electric field. The current transformer (CT) is the product of this principle. Its principle is shown in Figure 4 below. After the signal current passes through the primary side coil of the current transformer, under the action of electromagnetic field, the secondary sideline coil will sense the tiny signal of corresponding characteristics. After the first-level discharge circuit, it is processed by the band-pass filter circuit to filter out the interference signal and noise and other signals, and then output after the second-level signal discharge circuit, and then the acquisition unit is responsible for the collection and calculation. According to the relationship between the size of the current signal passing through the coil and the size of the sampled voltage signal, the current of the characteristic signal passing through the coil can be converted. The positive and negative electrodes of the load current pass through the CT from two directions, one in and one out, and the magnetic field cancels each other out, while the characteristic signal current cannot cancel after passing through the CT. Therefore, the load current through the CT does not have any output, but has an output response to the characteristic signal current. Through the
current transformer CT1 and CT2 installed in the power supply circuit loaded in the DC system, the leakage current of the positive and negative load current of the feeder line and the changes are detected, and the parasitic circuit fault is determined. The following is the leakage current signal waveform of the positive and negative load current of the feeder detected by the CT before and after the failure of the three parasitic circuit fault types. Red is the waveform of CT 1, and yellow is the waveform of CT 2.

Figure 5. Before the positive parasitic circuit fails

Figure 6. After the positive parasitic circuit fails

Figure 7. Before the negative parasitic circuit fails
From the waveforms of current transformers on the above feeder lines, it can be concluded that when there is no parasitic circuit fault in the system, the difference value of positive and negative load current detected by the current transformer is 0, that is, the leakage current is 0. The current transformer outputs almost stable voltage, which can be regarded as a straight line. When the parasitic circuit fault occurs in the system, the difference value of the positive and negative load current detected by the current transformer on the feeder line is not zero, that is, the leakage current is not zero,
and is changing, so the output voltage of the current transformer fluctuates in a certain range. Moreover, the output of the current transformer on the two feeder lines of the parasitic circuit is relatively close, because the change of current I in the parasitic circuit leads to the same trend of leakage current in the two feeders. Obviously, the output of CT before and after the parasitic circuit is very different.

Therefore, the characteristic amplitude of the output waveform of the CT is calculated through analysis and comparison, so as to determine whether there is a parasitic circuit.

5. Conclusion

DC power supply system is to provide working power supply for control signal, relay protection, automatic device, circuit breaker jumping and closing operation circuit, etc., as well as standby operation power supply to quickly restore normal operation of power system after power grid failure. It is also an important equipment to ensure the safe operation of power plant booster station, substation, converter station and so on. The parasitic circuit failure in the same DC power system seriously affects the safe operation of the DC power system. The parasitic circuit has an important influence on the safe operation of the DC system in the substation, which loads a lot of DC systems. Ensuring its safe management is related to the operation stability of the power station. Parasitic circuits are generally generated in the construction and transformation of substations. At the beginning of substation construction, relevant prevention work should be done to ensure strict specifications in each aspect and eliminate potential hazards at the source [5]. Therefore, it is very important to propose an effective fault detection technique for parasitic circuits.

From what has been discussed above, through the analysis of the various parasitic circuits of DC power system fault phenomenon and characteristics, we discussed the parasitic circuit fault detection technology in the substation DC power supply system, expounded and analyzed its principle and method of detection circuit, which allows accurate monitoring and calculation of DC system and parasitic circuit of the feeder, and sending the alarm information in a timely manner. This paper provided a reference for the device with the function of fault detection of parasitic circuit.

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