Development of the Ground Fault Protective Relay That Uses No Auxiliary Energizing Source

DC high voltage ground fault relays (ground fault protective relays) equipped to DC railway substations are devices to monitor the voltage between the grounding mat of the substation and rails. If a ground fault occurs within a substation, they also detect the voltage rise and immediately send out an open command to related circuit breakers to stop the supply of power to the point of the ground fault. However, some ground faults can cause damage to surrounding facilities as well as the point of the accident. At the same time, they could also possibly hamper ground fault protection due to contact faults with auxiliary energizing sources. We have therefore conducted development of a ground fault protective relay that needs no auxiliary energizing source (DC 110V) to achieve a protection system where power supply is stopped without fail in case of ground faults. We have thus-far finished production of a prototype and confirmed that the target performance has been met, including stable output of that prototype even for unstable input voltage that modeled ground faults. This article will introduce the development results.

Keywords: DC feeding protection, DC ground fault, Contact fault, DC high voltage ground fault relay, Using no auxiliary energizing source

1 Introduction

A DC high voltage ground fault relay (64P), one of the feeding protection systems of DC railway substations, is a device for monitoring the voltage (the difference in potential) between the grounding mat of the substation and the return wire corresponding to the rail. If a ground fault occurs within a substation, it also detects the voltage rise and immediately sends out an open command to related circuit breakers to stop the supply of power to the point of the ground fault. However, some ground faults can cause damage to surrounding facilities as well as the point of the accident. At the same time, they could also possibly hamper ground fault protection due to contact fault with auxiliary energizing sources, spreading the damage.

We have therefore conducted development of a ground fault protective relay that needs no auxiliary energizing source (DC 110V) to drive the protection device with an aim of improving reliability of ground fault protection.

2 Feeding Protection System of DC Railway Substations

2.1 DC Feeding System

In a DC feeding system, DC 1,500V (standard voltage) stepped down from 66kV special high voltage and rectified by a rectifier at substations is supplied to feeders and contact wires as shown in Fig. 1. This is done at substations set up at intervals of a few kilometers to approx. 10 km (the higher the transport density, the shorter the interval). The adjacent substations supply the power required for train operation in parallel. This is called a “parallel feeding system”.

2.2 DC Feeding Protection System

A highly reliable feeding protection system needs to be built to minimize disruption of train operation in case of ground faults or short circuit faults within a substation or along a line.

Fig. 2 shows an overview of a DC feeding protection system. The main protective relays (devices) used for DC feeding protection systems are as follows.
(1) DC high speed circuit breaker (54F)
This is a circuit breaker that can switch on and off the normal feeding circuits and also detect overcurrent of the feeding circuit with the circuit breaker itself to rapidly breaking the circuit.

(2) Fault selective device for feeding circuit (50F)
Using the difference between the current change (ΔI) of load current and that of fault current, this selector detects a sharp change of current in faults and sends out a breaking signal to just the damaged feeder line.

(3) Interlinked breaking device
As the direct current feeding system employs a parallel feeding system, sometimes it is difficult to detect a fault at the opposite substation when a feeding fault occurs near a substation. So, when a fault is detected and the circuit broken at a substation, the interlinked breaker sends out a breaking signal to the high-speed circuit breaker of the opposite line of the next substation to ensure that power is cut off for the section where the fault occurs.

(4) DC high voltage ground fault relay (64P)
This relay detects the potential rise between the grounding mat and the rails in a ground fault within a substation and sends out a breaking command to DC high-speed circuit breakers and AC circuit breakers. It also locks input circuits of the circuit breakers to prevent the circuit breakers from being switched on before on-site check. Furthermore, it makes a breaking command for the opposite line of the next substation using interlocked breaking equipment to immediately stop power supply to the point of the ground fault.

In order to limit the area where transport is affected when the relay is operated, JR East uses the 64P that has a function for distinguishing faults within or outside a substation (64PB).

Since power is cut in a wide area in operation of a 64PB, the operating time of the 64PB is set based on the detection and operating time of the 50F that can select the damaged line and the breaking time of the opposite line by the interlinked breaking equipment (to wait for the protection time by a 50F) for faults outside of a substation.

A 64P is a relay that monitors the voltage between the grounding mat and the rails and operates when the voltage in a fault exceeds a setting value. The value can be set at three taps of 400V, 500V or 600V, and JR East usually sets at 500V. A 64PB, which can distinguish faults within or outside of a substation, is a 64P relay with the newly added function of a 64B that monitors the potential difference between the grounding mat and the standard grounding by setting the latter to 500V. A 64PB, which can distinguish faults within or outside a substation (64PB).

Since power is cut in a wide area in operation of a 64PB, the operating time of the 64PB is set based on the detection and operating time of the 50F that can select the damaged line and the breaking time of the opposite line by the interlinked breaking equipment (to wait for the protection time by a 50F) for faults outside of a substation.

In a ground fault within a substation, the potential of the grounding mat increases and the 64P (P element) that monitors the potential difference between the grounding mat and the rails operates. At the same time, the 64B (B element) between the grounding mat and the standard grounding operates to determine that a ground fault is within a substation. In case of a ground fault outside of a substation, the potential difference between the grounding mat and the standard grounding shows no change. So, only the 64P element between the grounding mat and the rails operates to determine that a ground fault is outside a substation, as the conventional 64P does.

Fig. 3  Overview of 64PB

Fig. 4 shows a system overview of the developed ground fault protective relay using no auxiliary energizing source. The presently used protecting device requires an auxiliary energizing source (DC 110V) to drive the logic unit of the device. So, in some ground faults, there is a risk of contact fault between the auxiliary energizing source and DC 1,500V power supply occurring, hampering ground fault protection. We have therefore developed a ground fault protective relay using no auxiliary energizing source that requires no external power supply to ensure protection even in case of a contact fault. Instead of an external auxiliary energizing source, we have applied a power supply system where the relay supplies required power itself using the overvoltage between the grounding mat and the rails to be monitored.

Fig. 4  Overview of the Developed Relay (Comparison to the Existing Relay)

The relay device consists of two units: a power supply unit that supplies stable power to the logic unit through a constant voltage circuit and a detection, and logic unit that determines if ground faults are within or outside of a substation.
The most important issue in this development was how to create stable power to appropriately drive the logic unit from the voltage between the grounding mat and the rails that fluctuates with arcing. So, we first made a simple power unit prototype (Fig. 4 (1)) and then developed the ground fault protective relay integrated with detection and logic units based on the performance verification of the prototype.

5 Development of the Power Unit

5.1 Main Specs of the Power Unit
The main specs of the power unit are as follows.

(1) The power unit outputs 10V drive voltage for the logic unit of the ground fault protective relay to the voltage between the grounding mat and the rails (input voltage). For the 200V or higher input voltage that is half the 400V voltage set as the minimum criteria for judging of a ground fault, the power unit outputs 10V without fail.

(2) Overvoltage input withstand between the grounding mat and the rails is to be 2kVDC for 1 minute.

(3) The power unit is to always be used together with a JEC-2500 power supply protective relay and have the insulation performance (insulating resistance, commercial frequency withstand voltage, lightning impulse withstand voltage) listed in Table 1.

The reason why we employed 200V or higher input voltage in spec (1) above is that we considered that value the risk area of a ground fault. The power supply unit is to secure power at 200V and instantly carry out calculation when reaching the setting value (400V).

Fig. 5 shows the appearance of the developed power unit. Table 2 shows the approximate size and weight of the unit.

Table 1 Insulation Performance of the Power Unit

<table>
<thead>
<tr>
<th>Item Applied to</th>
<th>Insulating resistance</th>
<th>Power-frequency withstand voltage AC 50Hz 1 min.</th>
<th>Lightning impulse withstand voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>All terminals of main circuit - Between all output terminals and grounding</td>
<td>1.000V, mega 50MΩ or greater</td>
<td>5,000V</td>
<td>± 4,500V</td>
</tr>
<tr>
<td>Between all output terminals and grounding</td>
<td>500V, mega 10MΩ or greater</td>
<td>2,000V</td>
<td>± 4,500V</td>
</tr>
</tbody>
</table>

The developed power unit consists mainly of a pressure dividing circuit, a constant voltage circuit using Zener diodes and an insulation circuit that ensures insulation between input and output. As shown in Fig. 6, the constant voltage circuit is a circuit that increases the output voltage proportionally until the input voltage reaches a set value (200V for this power supply unit) and outputs a constant value (10V) once the input voltage exceeds a set value.

5.2 In-Factory Tests of the Power Unit
To check the basic performance of the developed power supply unit, we carried out the following in-factory tests, achieving results where specifications were met.

(1) Input/output voltage characteristics:
Characteristics of the output voltage to the change in input voltage

(2) Load characteristics:
Characteristics of the output voltage to the change in output (load) current

(3) Output response characteristics:
Rise characteristics of the output voltage in change of load capacity

(4) AC input test:
Check of non-operation by AC input

(5) Lightning impulse test:
Check of the insulation performance against lightning impulse

(6) DC 2kV input test:
Check of overvoltage withstand for the input voltage

(7) Heat cycle test:
Performing above-mentioned tests after changing temperature (−10°C – 50°C) and humidity in a constant temperature bath in a fixed cycle
5.3 Performance Tests of the Power Unit

Since stability of the output voltage in relation to unstable input voltage that fluctuates with arcing cannot be checked in in-factory tests, we checked that in performance tests.

Fig. 7 and 8 show overviews of the test power circuit and the arc test circuit used in the power unit performance tests.

Using an arc tester (a pantograph contact strip elevator) in the large current testing building of the Research and Development Center of JR East Group, we artificially made a gap between the contact strip and the contact wire to generate an arc and fluctuate input voltage. Combining the power supply circuit with resistance, that test machine allows continuous burn-in tests up to DC 1,800V and 1,000A.

The input voltage to the power unit is the value achieved when the arc voltage generated by arcing is subtracted from DC 900V.

We used a voltage divider (400:1) to transform high voltage such as input voltage to the voltage appropriate to the voltage measurement device and conducted measurements.

5.4 Test Results of the Power Supply Unit

Fig. 9 shows an example of the function test results for the power unit. As shown there, a constant output voltage (10V) was achieved in relation to unstable input voltage with arcing.

This result shows some temporary drops of the 10V output; however, this is because largely fluctuating arc voltage lowers the input voltage to less than 200V. This is correct operation according to specification.

6.1 Main Specs of the Ground Fault Protective Relay That Uses No Auxiliary Energizing Source

As explained in Chapter 5 above, we confirmed that stable output to drive the logic unit was achieved even in relation to unstable input voltage; thus, we conducted development of a ground fault protective relay that uses no auxiliary energizing source and integrates the power unit and the detection and logic unit.

Table 3 Determination Criteria for Ground Faults within or Outside of a Substation and Operating Time

<table>
<thead>
<tr>
<th>Ground fault within a substation</th>
<th>P element</th>
<th>B element</th>
<th>Operating time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operates</td>
<td>Operates</td>
<td></td>
<td>15ms</td>
</tr>
</tbody>
</table>

When a ground fault occurs within the substation, the ground fault protective relay has to make immediate operation output. Accordingly, we set the time at 15 ms, considering the time required to avoid unnecessary operation due to AC ground faults or instantaneous noise.

On the other hand, we set the operating time for faults outside of the substation at 400 ms considering the above-mentioned detection time of 50F to identify the damaged line and minimize transport disruption.

Fig. 10 shows the appearance of the ground fault protective relay using no auxiliary energizing source. The structure includes two units on the attachment base and terminal boards at the bottom.

Table 4 shows the approximate size and weight of the relay.
6.2 In-Factory Test of the Ground Fault Protective Relay That Uses No Auxiliary Energizing Source

To check the basic performance of the developed relay, we carried out the following in-factory tests other than the test items conducted for the power unit, achieving test results that specifications are met.

(1) Measurement of minimum operating voltage: Measurement of the minimum operating voltage for each set voltage
(2) Measurement of operating time: Measurement of the operating time from reaching the set voltage to operation output
(3) Measurement of current consumption: Check of relay running at the power unit allowable current of 10mA or less

6.3 Performance Test of the Ground Fault Protective Relay That Uses No Auxiliary Energizing Source

As conducted in the performance test of the power unit, we carried out a performance test of the developed relay using a pantograph contact strip elevator.

Fig. 11 shows an example of the performance test results for a ground fault outside of the substation (P element setting value of 600V).

Since the input voltage to the relay in this test was the power supply voltage minus the arc voltage, a voltage that was almost the same as the power supply voltage (1,500V) was input just after beginning the test, and establishment of the 10V output voltage and monitoring of the P element started. Input voltage fluctuation was observed because of arcing, but confirmed that the output voltage remained stable and within specification operating time (voltage monitoring time in ground faults outside of a substation: 400 ms).

We also confirmed that the output voltage of the relay after the operation output remained stable in relation to the largely fluctuating input voltage.

Fig. 12 is the magnification of the rise of the power in the test shown in Fig. 11. Considering the operating time 15 ms in ground faults within a substation, the response time until reaching 90% of maximum output is approx. 1.0 ms, which is acceptable.

We secured approx. 1.7 ms response time with 200V input voltage (minimum voltage to establish 10V output voltage) and approx. 1.0 ms response time with 400V input voltage that is the minimum tap voltage for operation output, the same as in the test with 1,500V input voltage.

Fig. 13 shows an example of the performance test results in ground faults within the substation (P element setting value of 400V, B element setting value of 30V).

In this test, we specified the voltage between the contact strip and the contact wire (arc voltage) as the input voltage to the relay and checked both of P element and B element at the same input voltage due to the limitation of the test circuit. Just after starting the test, no arc was generated; however, upon lowering the contact strip, arc occurred. The longer the arc length was, the higher the input voltage.
(arc voltage) became. At the point when the input voltage reached 200V, constant 10V output was established. At the point when the arc length extended to exceed the 400V setting value, monitoring of P element started (B element already being monitored). We confirmed that the voltage monitoring time was 15 ms for detecting a ground fault within the substation; that is, the output was made within the specification operating time also in ground faults in the substation.

These performance test results proved stability of the output voltage in relation to fluctuating input voltage, and that the operation output of the developed relay was achieved according to the set voltage and time as well.

7 Field Test

As we confirmed that the target performance level was achieved in the performance test in the large current test building and in the factory, we carried out a field test to check durability and unnecessary operation due to factors such as noise.

7.1 Overview of the Field Test Circuit

As shown in Fig. 14, the input voltage to the developed relay in the field test was supplied in a parallel connection from the input terminals of an existing 64PB.

7.2 Field Test Result

Fig. 15 indicates an example of the measurement results in the field test.

The measurement results show that the output voltage immediately rose according to a sharp change in voltage between the grounding mat and the rails (grounding mat side as negative), reached a constant value, and then decreased as the input voltage decreased.

The voltage between the grounding mat and the rails remained almost the same during the above-mentioned change.

We are currently continuing to take measurements. The number of data instances that was obtained in the measurement for approx. a month under the trigger conditions was 11 including the data of Fig. 15. So far, we have observed no event where the developed relay has made unnecessary operation due to a sharp change of the input voltage less than the setting value.

With an aim of improving reliability of the ground fault protective function, we developed a ground fault protective relay that uses no external auxiliary energizing source (DC 110V). An important success was that we could achieve stable output of the power unit in relation to unstable input voltage with arcing, the original issue.

We are planning to continue field tests, and to consider building a highly reliable feeding protection system with an aim of introducing the developed ground fault protective relay that uses no auxiliary energizing source.

Reference:
1) Hitoshi Hayashiya: Arc Phenomena Between the Contact Wire and the Pantograph, p. 16, Japan Railway Engineer’s Association, May 2007