Module 13

General Electric Type BDD Transformer Differential Relay With Percentage and Harmonic Restraint

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INTRODUCTION

The General Electric Type BDD Transformer Differential relay with percentage and harmonic restraint is designed specifically for transformer protection. The BDD is available for application on power transformers for protection of two-winding transformers, three-winding transformers, or three-winding transformers and a section of bus.

The BDD relay has currents applied to it from instrument current transformers located on each side of the transformer. These two currents are compared, and if they are of the same magnitude there is no protection problem; however, if the two currents are not the same, a protection problem exists. The relay operates at a percentage difference between the two currents.

**NOTE:** From this point forward all General Electric Type BDD transformer differential relays will be referred to as type BDD relays.

OBJECTIVES

Upon completion of this module and lab exercise, the participant will be able to perform the following tasks related to the type BDD Transformer differential relay with percentage and harmonic restraint:

1. Describe its application.
2. Describe its components.
3. Describe its operating principles.
4. Interpret an external wiring connection diagram.
5. Interpret an internal schematic diagram for it.
6. Describe and perform the minimum pickup test.
7. Describe and perform the through fault test.
8. Describe and perform the slope test.
9. Describe and perform the harmonic restraint unit pickup test.
10. Describe and perform the instantaneous unit pickup test.
11. Describe and make calibration adjustments.

APPLICATIONS

The BDD relay is applied to power transformers to detect internal faults. The current entering one end of a winding must be within a specified percentage of the current at the other end. The difference in this current is called slope. The slope incorporated is to allow for small instrument current transformer (CT) errors, due possibly to CT ratio mismatch and/or CT saturation. Available percentage slopes include 15%, 25%, and 40%.

On internal faults, percentage differential relays are sensitive and fast operating. For external faults, they are reasonably safe from false operation.
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COMPONENTS

The BDD relay is a single-unit transformer differential relay. Principal parts of the relay and their locations are shown in Figure 1. The BDD uses a sensitive, polarized, plug-in, electromechanical relay as the operating element.

FIGURE 1
General Electric Type BDD Transformer Differential with Harmonic Restraint Relay
There are two tap blocks found on the type BDD relay, as shown. These ratio matching taps are to match current input from current transformers on both sides of the protected transformer. There is also an instantaneous unit and auxiliary trip unit. The auxiliary trip unit is not a seal-in unit.

<table>
<thead>
<tr>
<th>RANGE</th>
<th>TAPS</th>
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<tbody>
<tr>
<td>2.9 – 8.7</td>
<td>2.9 3.2 3.5 3.8 4.2 4.6 5 8.7</td>
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**OPERATING PRINCIPLES**

The differential unit is supplied with currents, which are modified by current restraint taps so “normal” mismatch is at a minimum. In addition, they have a slope characteristic, to compensate for mismatch up to a percent of difference current. This gives the relay greater selectivity to restrain from operation on through faults, and still be sensitive for operation on internal faults. In addition, transformer differential relays must be able to discriminate between inrush current on transformer energization and actual internal fault current. Therefore, they are designed with harmonic restraint circuitry. The instantaneous unit is provided to ensure high-speed operation, with no restraint on heavy internal faults.

To better understand the operation of the BDD, the internal schematic (Figure 2) is used to explain the relay’s operation under different system conditions.
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FIGURE 2
Internal Schematic for General Electric Type BDD
Transformer Differential with Harmonic Restraint Relay
**NORMAL CONDITIONS**

When the system is under normal conditions, current flows through the differential transformer and the restraint transformer. The differential transformer output is the vector sum (difference) of the two relay input currents. This output feeds the instantaneous unit, then the input terminals of the fundamental filter and the harmonic filter. Since the waveform should be 60 Hz, only the fundamental filter should have an output. This output is fed to the operating coil of the main unit (polar relay).

The two relay input currents also flow to the restraint transformer. The output of the through restraint transformer is the vector sum (additive) of the two relay inputs. This output is fed to the restraint coil of the main unit, after it passes through the percent slope adjustment resistor.

Under normal system conditions, within the slope characteristic, the restraint coil is stronger than the operating coil of the main unit; therefore, the main unit does not close its contacts.

**EXTERNAL FAULT**

When the system is under external fault condition, current flows through the restraint transformer and the differential transformer. Everything, as previously stated under normal conditions, occurs once again. The difference is in the magnitude of current input, however the results will be the same (that is, there is no contact closure of the main unit).
INTERNAL LOSS/HIGH IMPEDANCE INTERNAL FAULT

When the transformer has an internal loss or a high impedance internal fault, the output of the differential transformer increases and the output of the restraint transformer decreases. This causes the operating coil of the main unit to increase in strength. If this increase is above the slope characteristic of the relay, the operating coil overcomes the restraint coil and the main unit closes its contacts.

When the main unit contacts close, the path for the auxiliary relay unit is complete. The auxiliary relay unit operates and closes its contacts. The closure of the auxiliary relay unit contacts either cause a direct trip of the breaker, or more typically, energize an 86 relay.

INTERNAL FAULT

When the transformer has an internal fault, the output of the differential transformer increases and the output of the restraint transformer decreases. This causes the operating coil of the main unit to increase in strength. If this increase is above the slope characteristic of the relay, the operating coil overcomes the restraint coil, and the main unit closes its contacts.

If the internal fault is a low impedance fault (bolted) and the fault is above the instantaneous unit pickup setting, the instantaneous unit picks up and closes its contacts.
INRUSH CONDITION

When the transformer is being energized, a current surge takes place. The current surge is the current required to establish the magnetic field of the transformer core. This magnetizing current is called inrush current. The inrush current could cause the differential relay to operate and the transformer to trip off line.

Since the inrush current has not only a large fundamental current (60 Hz) content, but also a large harmonic content (120 Hz plus), the waveform output from the differential transformer also has a harmonic content. This waveform is fed to both the fundamental filter and the harmonic filter. The fundamental filter blocks the harmonic current, but allows the fundamental current to pass.

The harmonic filter passes the harmonic current and blocks the fundamental current. The output of the harmonic filter feeds the restraint coil of the main unit relay, thereby increasing the restraint coil’s strength. Therefore, even though the output from the fundamental filter has increased due to the imbalance the transformer is under during this inrush, the main unit relay does not close its contacts, because the restraint coil overcomes the operating coil.

PROTECTION SCHEME

Typical external wiring diagrams for the type BDD relay is shown in Figure 3.
The following is a guide for the tests that should be performed on the BDD relay. Figure 2 is a typical internal schematic for a BDD15B relay.

When performing tests and adjustments, always refer to the manufacturer’s instruction leaflet for that particular relay.
TYPES OF TESTS

1. Insulation Resistance*
2. Minimum Pickup
3. Through Fault
4. Slope
5. Harmonic Restraint
6. Instantaneous Unit Pickup
7. Main Unit Dropout

PICKUP TEST

This test is performed to determine the minimum operating current of the relay, that is, the minimum current needed to close the relay contacts for a particular TAP setting. A test circuit connection diagram for performing this test is shown in Figures 4A and 4B. The type BDD15B transformer differential relay is designed for a pickup equal to 30% of tap value ±10%.

* The procedures for performing insulation resistance testing can be found in the Appendix. Check the manufacturer’s instruction literature for the specific way to perform this test.
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FIGURE 4A
Winding 1 Pickup Test Connection Diagram
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FIGURE 4B
Winding 2 Pickup Test Connection Diagram
The following is an outline of the winding 1 pickup test:

1. Connect the relay as per Figure 4A.
2. Apply the proper DC voltage to relay studs 1(+) and 7(–).
3. Connect an AC current across relay studs 5 and 6 with current polarity on stud 5.
4. Increase the AC current until the relay operates. This should be 30% of the winding 1 tap value.
5. Record this current value as the winding 1 pickup.

The following is an outline of the winding 2 pickup test:

1. Connect the relay as per Figure 4B.
2. Apply the proper DC voltage to relay studs 1(+) and 7(–).
3. Connect an AC current across relay studs 4 and 5 with current polarity on stud 5.
4. Increase the AC current until the relay operates. This should be 30% of the winding 2 tap value.
5. Record this current value as the winding 2 pickup.
**Testing Through Fault Restraint**

The through fault restraint test is performed to check that the relay does not operate upon an external fault condition. A test circuit connection diagram for performing this test is shown in Figure 5.

1. Connect the relay as per Figure 5.
2. Apply the proper DC voltage to relay studs 1(+) and 7(–).
3. Connect an AC current across relay studs 4 and 6 with current polarity on stud 4.
4. Apply 10 amps to studs 4 and 6.
5. Ensure that the auxiliary unit contacts do not close.
6. Record the fact that the relay did not operate on through fault current.

**Testing Slope Characteristic**

The slope test is conducted to check the relay’s percentage slope, in accordance with the manufacturer’s curves. The BDD relay slope characteristic curve is shown in Figure 6.

The slope characteristic tolerance is plus 10% of the curve value. In addition, care should be taken not to overheat the relay. Allow sufficient cooling time between tests.
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FIGURE 5
Through Fault Test Connection Diagram
Note: For two-winding transformer relays “through current” is taken as the smaller of the two currents. For three-winding transformers, it is taken as the sum of the incoming or outgoing currents, whichever is smaller. (Each current to be expressed as a multiple of tap.)
Use the values in Figure 8 to determine the amount of current to be applied to the relay.

The following is an outline of the slope test:

**NOTE:** Two current source with no phase shift between them is necessary to perform this test.

1. Connect the relay as per Figure 7.
2. Apply appropriate DC voltage to studs 1(+) and 7(–).
3. Connect a current source to relay studs 4 and 6 with polarity on 4. (This will be the restraining current of 30 amps.)
4. Connect a current source to relay studs 5 and 6 with polarity on stud 5. (This is the operate current).
5. Turn on the 30 restraint amps.
6. Turn on and increase the operating current until the relay operates. (Approximately 7.5 – 8.3 amps)
7. Turn off both currents and calculate % slope using the % slope formula.
8. Record the percent slope.
FIGURE 7
Percent Slope Test Connection Diagram
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**In-Service Relay Taps**

When the type BDD15B transformer differential relay is required to be tested as found (in-service), the manufacturer’s literature must be followed for the specific test connection diagrams and characteristic curves. Figure 8 shows the manufacturer’s recommended current values and formula for performing an in-service tap test.

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**FIGURE 8**
Slope Test Operating Values
PERCENT HARMONIC RESTRAINT

The manufacturer’s harmonic restraint characteristic curve is given in Figure 9. The following is a brief explanation of the manufacturer’s suggested test. Two currents are passed into the operating coil and one restraint coil in series. The first current (I₁) is a pure 60 Hertz sine wave. The second current I₂ has a known quantity of 2nd harmonic content. I₂ is either a 1/2 wave rectified (by a series diode) sine wave or a 120 Hertz sine wave generated by an electronic test set. I₂ is preset, and I₁ is adjusted until the relay operates.

For a half wave rectified I₂ of 4 amperes DC, the relay should operate for I₁ between 4.5 and 5.5 amperes. These values correspond to 21% and 19% 2nd harmonic respectively. If I₂ is set to 2 amperes at 120 Hertz, the relay should operate for I₁ values between 9.3 (21%) and 10.3 amperes (19%). A typical test circuit connection diagram for performing this test is shown in Figure 10.

The % 2nd harmonic restraint can be calculated for the BDD relay based on whether the test current is 2nd harmonic based or half-wave based.
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FIGURE 9
Percent Harmonic Restraint
Characteristic Curve

\[ I(\text{DC}) = 4.0 \text{ Amperes} \]
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FIGURE 10
Percent Harmonic Restraint
Test Connection Diagram
The following formula is for a 2nd harmonic current produced by the AVO relay test sets.

\[
\% \ \text{2nd Harmonic Restraint} = \frac{I_{2nd}}{\sqrt{(IF)^2 + (I_{2nd})^2}} \times 100
\]

where

- \( I_{2nd} \) = 2nd Harmonic Current
- \( IF \) = Fundamental Current

The following formula is for a half-wave current source.

\[
\% \ \text{2nd Harmonic Restraint} = \frac{0.212 \times I_{DC}}{\sqrt{(0.45 \times IF) + (0.5 \times I_{DC})}} \times 100
\]

where

- \( IF \) = Fundamental Test Current
- \( I_{DC} \) = DC Current
The following is an outline of the percent harmonic restraint test using a diode:

1. Connect the relay as per Figure 10.
2. Apply the proper DC voltage to relay studs 1(+) and 7(–).
3. Apply a half wave rectified current of 4 amps across relay studs 5 and 6 with current polarity on stud 5.
4. Connect an AC current across relay studs 5 and 6 with current polarity on stud 5.
5. Increase the AC current until the relay operates.
6. Calculate the percent harmonic based on the formula on the bottom of page 23.
7. Calibrate the relay using resistor R2 if necessary.

The following is an outline of the percent harmonic test using a true 120 Hz current source:

1. Connect the relay as per Figure 10.
2. Apply the proper DC voltage to relay studs 1(+) and 7(–).
3. Apply a 120 Hz current of 1 amp across relay studs 5 and 6 with current polarity on stud 5.
4. Apply 60 Hz current across relay studs 5 and 6 with current polarity on stud 5.
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5. Increase the 60 Hz current until the relay operates.

6. Calculate the percent harmonic based on the formula on the bottom of page 24.

7. Calibrate the relay using resistor R2 if necessary.

**Instantaneous**

The instantaneous unit is tested by pulsing or jogging current through the instantaneous unit of the relay until the instantaneous unit contacts pick up. The BDD relay’s instantaneous is typically set to pick up at 8 times the winding 1 or winding 2 tap value. A typical test circuit connection diagram for performing this test is shown in Figure 11.

The following is an outline of the instantaneous unit pickup test:

**NOTE:** Do not connect the DC control voltage to the relay.

1. Connect a current source capable of 8 times tap value current to relay studs 5 and 6.
2. Jog the current up until the instantaneous unit contacts close.
3. Record this value of current as the instantaneous unit pickup.
FIGURE 11
Instantaneous Test Connection Diagram
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**DROP OUT OF MAIN UNIT**

This test is performed to check that the polar unit relay is operating correctly. Put all windings in the 2.9 tap and set the relay for 25% slope. Rapidly apply 20 amperes to terminals 5 and 6. Decrease the current quickly at first, and then more slowly. The polar unit should drop out at 0.1 amperes or more. If the dropout current is less than 0.1 amperes, the polar unit is defective.

A typical test circuit connection diagram for performing this test is shown in Figure 12.

**ADJUSTMENTS**

The relay’s calibration is performed by adjusting resistors R1, R2, and R3. Changes made in any one of these resistors affect the other two settings. Adjustments have to be made, until the relay’s three settings are within manufacturer’s tolerances.

**MINIMUM PICKUP**

You can calibrate the minimum pickup value by adjusting the resistor R1. Resistor R1 is located at the top of the relay, left-hand side.

**HARMONIC RESTRAINT**

You can calibrate the harmonic restraint value by adjusting resistor R2. Resistor R2 is located at the top of the relay, next to R1.
FIGURE 12
Typical Test Connection Diagram
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**Slope**

You can calibrate the slope characteristic value by adjusting the resistor R3 based on the selected slope tap. Resistor R3 is located behind the nameplate. There are three adjustable resistor bands. From left to right, there are the 15%, 25% and 40% adjustments.

**Instantaneous Unit**

Adjust the instantaneous unit’s pickup by means of the core screw. Remember to release the lock nut before making any adjustments, then secure it after the desired pickup is achieved.

**Summary**

The transformer differential relay has special features that distinguish it from other differential relays: (1) percentage restraint permits accurate (adjustable) determination between internal and external faults at high current; (2) harmonic restraint enables the relay to distinguish, by the differences in waveform, between the differential current caused by internal fault and that caused by transformer magnetizing inrush; and (3) the instantaneous is a backup operating on very high currents.

To ensure proper operation, the relay is tested to verify minimum pickup, through fault, slope, instantaneous pickup, and main unit dropout. This module also discusses proper calibration procedures, if the relay is found to be out of the allowable tolerances.