Overcurrent Protection of Radial Feeders

**EXERCISE OBJECTIVE**
When you have completed this exercise, you will be familiar with the overcurrent protection of a radial feeder. You will learn the importance of discrimination in radial feeder protection. You will learn about various methods to achieve discrimination in radial feeder protection systems, namely based on current, based on time, and based on time and current. You will learn a generic method to adjust the settings of overcurrent relays to obtain proper discrimination in a radial feeder protection system. You will learn how to coordinate a relay with a fuse or with a relay having a different type of time-current characteristic.

**DISCUSSION OUTLINE**
The Discussion of this exercise covers the following points:

- Radial feeders
- Protection of a radial feeder with overcurrent relays
- Discrimination based on coordination in current
- Discrimination based on coordination in time
  - Current settings. Time settings.
- Discrimination based on coordination in both time and current
- Generic procedure to achieve time-current coordination of IDMT overcurrent relays
- Coordination of IDMT overcurrent relays with different types of time-current characteristics
  - Relays with different types of time-current characteristics. Coordination between an IDMT overcurrent relay and a fuse.

**DISCUSSION**
**Radial feeders**

A **radial feeder** is a line used to convey electric power, generally in a distribution network or an industrial application, which has a radial structure and is powered at one end only. Figure 42 shows the single-line diagram of a radial feeder.

The power source side of the radial feeder is called the **infeed**. It generally consists of a single power transformer or two or more power transformers connected in parallel. Along the radial feeder, substation busses are present to which loads are connected, for example, to provide power to a small town or village (see Figure 43). The power lines between the substations are called feeder segments. The infeed of a feeder segment refers to its end on the source side. Power transformers are used in the radial feeder to adjust the voltage supplied to the loads. These power transformers are generally protected by fuses. Note that the radial feeder ends with the load connected to the transformer located at the right-hand side of Figure 42.
Exercise 3 – Overcurrent Protection of Radial Feeders  •  Discussion

Figure 42. Single-line diagram of a radial feeder.

Figure 43. Distribution line conveying power to small towns and villages. Transmission lines can be seen in the background.
Protection of a radial feeder with overcurrent relays

It is common to use overcurrent protection to protect radial feeders against faults that give rise to the flow of excessive currents. Protection of radial feeders is commonly achieved by installing a circuit breaker and an overcurrent relay with its associated current transformers at the infeed of each feeder segment. Figure 44 shows a radial feeder protected this way. For the sake of simplicity, only the circuit breaker at the infeed of each feeder segment is shown in this figure. Also, the power transformers and fuses feeding the loads at substation busses A, B, C, and D have been omitted. The same simplifications are used in most other figures in this exercise.

Using circuit breakers and overcurrent relays at different locations along a radial feeder is essential to achieve discriminative protection. This type of protection disconnects the minimum amount of circuit to isolate the fault and thereby limits the number of loads that lose power. For instance, using a single circuit breaker and a single overcurrent relay, both located close to the infeed of a radial feeder, would not be acceptable. This would disconnect the whole feeder when a fault occurs, and all loads would lose power no matter where the fault is located along the radial feeder.

To obtain proper discrimination when protecting a radial feeder with several circuit breakers and overcurrent relays, the operation of the overcurrent relays must be properly coordinated. This is commonly referred to as relay coordination or relay grading. In short, you must determine the characteristics of the protected radial feeder and adjust the settings of the overcurrent relays in such a manner that the relay closest to the fault trips first. For example, for the fault shown in Figure 45, the overcurrent relay at substation 2 should trip before the overcurrent relay at substation 1, otherwise load 2 would be disconnected in vain.
Discussion

Several methods exist to achieve relay coordination. These methods are discussed in the following sections. Briefly put, they rely on adjusting the current setting and/or time setting of each overcurrent relay to make sure the relay closest to the fault trips first.

Discrimination based on coordination in current

Coordination in current, generally referred to as current coordination or current grading, can be used to achieve proper discrimination in a radial feeder protection system.

Current coordination is based on the fact that the value of the fault current decreases as the distance from the infeed of the radial feeder increases. It will be seen further on that current coordination is possible only when the different segments of the feeder have sufficient impedance to cause the value of the fault current to vary significantly along the radial feeder. Otherwise, it is not relevant.

To achieve current coordination, instantaneous overcurrent relays (ANSI device no. 50 function) with properly adjusted current settings are used. The current setting of each instantaneous overcurrent relay is based on the value of the fault current at the farthest end of the feeder segment that it protects. In fact, the current setting of each instantaneous overcurrent relay is generally set to the value of this fault current to ensure that the relay detects any fault along the feeder segment that it protects.

Figure 46 shows a radial feeder with the fault level at each substation and the current setting of each instantaneous overcurrent relay set to the fault level at the farthest end of the feeder segment that it protects. One exception to this rule, however, is the current setting of the instantaneous overcurrent relay at substation D, which is set at a value higher than the value of the equivalent fault current at the feeder side of the power transformer when a fault occurs at the load side of the power transformer. The reason for this is to ensure proper discrimination of faults at the feeder (primary) and load (secondary) sides of the power transformer. This is covered in more detail later in this discussion.
Exercise 3 – Overcurrent Protection of Radial Feeders | Discussion

Figure 46. Radial feeder protected with instantaneous overcurrent relays. The fault level at each substation and the current setting of each relay are indicated.

You may notice in Figure 46 that the current settings of the relays decrease as the distance from the infeed of the radial feeder increases.

Figure 47 represents the fault levels and the current settings of the instantaneous overcurrent relays graphically. Each relay has its current setting properly adjusted with respect to the fault level for which it must operate. For example, the relay at substation B has a current setting of 2900 A and the expected fault level along the feeder segment that it protects (i.e., feeder segment B-C) ranges from 2900 A to 8800 A. Consequently, this ensures that the relay at substation B detects any fault along feeder segment B-C.

Figure 47. Current settings of the instantaneous overcurrent relays in Figure 46. The colored dots indicate the fault levels at various locations along the radial feeder.
Discrimination based on current coordination in radial feeder protection systems seems to work properly up to this point. Nevertheless, discrimination based on current coordination is seldom used in practice, even when it is theoretically feasible, because of the two following drawbacks:

1. The values of the fault current resulting from a fault at the farthest end of a feeder segment and a fault at the closest end (infeed end) of the next feeder segment are too close to be properly discriminated. In the limit, these two locations could be separated by no more than the path going through a substation bus and a circuit breaker, as shown in Figure 48. In this example, the difference between the values of fault current to be discriminated is of the order of about 0.1%. Such a low difference in the values of fault current avoids proper discrimination of the fault location, because it requires incredibly accurate settings in the instantaneous overcurrent relays.

![Figure 48. Faults too close to be discriminated in a radial feeder.](image)

2. When the infeed of the radial feeder consists of two or more power transformers and one of these transformers is disconnected for any reason, the value of the short-circuit power at the infeed of the feeder generally decreases significantly. For instance, when two power transformers having the same rating are used to supply a radial feeder, the short-circuit power at the infeed of the feeder is cut in half when either one of the power transformers is disconnected. Any significant decrease of the short-circuit power at the infeed of a radial feeder causes the values of fault current to decrease. For faults at certain locations along the feeder, the values of fault current decrease below the current setting of the overcurrent relay protecting the corresponding feeder segment, thereby avoiding these faults from being detected.

This drawback is illustrated in Figure 49 and Figure 50. These figures provide the current settings of the instantaneous overcurrent relay, the maximum values of fault current, and the minimum values of fault current at the various substations along a radial feeder. The maximum values of fault current at the various substations along the radial feeder are the values obtained with the two transformers connected at the infeed of the feeder. On the other hand, the minimum values of fault current are the values obtained with one of the two transformers disconnected from the infeed of the feeder. Close inspection of the current settings of the overcurrent relays and the values of fault current reveals that the current setting (8800 A) of the overcurrent relay at substation A is higher than the minimum values (6850 A and 5400 A) of fault current at both ends (i.e., substation A and substation B) of feeder segment A-B. Consequently, the
overcurrent relay at substation A no longer protects feeder segment A-B when the short-circuit power at the infeed of the radial feeder decreases significantly. Similarly, the current setpoint (2900 A) of the overcurrent relay at substation B is higher than the minimum value (2400 A) of fault current at the farther end (i.e., substation C) of feeder segment B-C. Consequently, the overcurrent relay at substation B no longer protects the farthest portion of feeder segment B-C when the short-circuit power at the infeed of the radial feeder decreases significantly. The same applies to the overcurrent relay at substation C.

Figure 49. Radial feeder protected with instantaneous overcurrent relays. The maximum and minimum fault levels at each substation and the current setting of each instantaneous overcurrent relay are indicated. Any significant change in the short-circuit power at the infeed of a radial feeder makes discrimination based on current ineffective.

However, there is one situation when discrimination based on current coordination can be used in a radial feeder protection system. This is when a component having a significant impedance, like a power transformer, is in series...
with a feeder segment. In this case, the values of the fault current flowing through this feeder segment for faults at the primary and secondary of the power transformer differ significantly no matter what the infeed condition is, thereby allowing proper fault discrimination using current coordination.

For example, in Figure 49 and Figure 50, the current setting of the instantaneous overcurrent relay at substation D is adjusted to a value (750 A) slightly higher than the maximum value (630 A) of the equivalent fault current at the feeder side (primary) of the power transformer that is caused by a fault at the load side (secondary) of the power transformer. This prevents tripping of the relay at substation D when a fault occurs at the load side of the power transformer (in this situation, the fuse at the load side of the power transformer should blow). On the other hand, the relay at substation D should trip when a fault occurs at the feeder side of the power transformer because the minimum value (1100 A) of fault current at this location largely exceeds the current setting (750 A) of the relay.

**Discrimination based on coordination in time**

Coordination in time, generally referred to as time coordination or time grading, can be used to achieve proper discrimination in a radial feeder protection system.

Time coordination is achieved by making the protective relay farthest from the infeed of the radial feeder operate in the shortest time possible. Then, when one moves toward the infeed of the radial feeder, every other protective relay should operate in a progressively longer time. Proceeding this way ensures that the relay closest to the location of a fault (i.e., the relay protecting the feeder segment where the fault occurs) has time to trip before the relays located closer to the infeed of the radial feeder, thereby providing proper fault discrimination. The difference between the operating times of two adjacent relays is referred to as the grading margin. The grading margin is generally 0.4 s, but can be a little less (e.g., 0.35 s) when numerical overcurrent relays and modern switchgear are used.

To achieve time coordination, definite time overcurrent relays (ANSI device no. 51 DT function) with properly adjusted time and current settings are used.
The radial feeder in Figure 51 is used to demonstrate discrimination using time coordination. This feeder will also be used to demonstrate time-current coordination in the next section of this discussion. The infeed of the radial feeder consists of two 10 MVA power transformers, each having a 7% impedance, that lower the voltage from 33 kV to 11 kV. The way to determine the current and time settings of each definite time overcurrent relay in the feeder is explained next.

Current settings

The current setting of each definite time overcurrent relay is determined from the primary system currents (i.e., line currents). The current setting of each relay is set to a value that is well above the maximum load current in the feeder segment that it protects and well below the value of the minimum fault level at the location of the relay. This ensures that each relay is insensitive to normal load currents. This also ensures that each relay detects faults even when the short-circuit power at the infeed of the radial feeder is minimum. Table 6 presents the minimum and maximum values of system impedance (i.e., values of system impedance for maximum and minimum power at the infeed of the radial feeder, respectively), the minimum and maximum fault levels, the maximum load current, and the relay current setting at given locations along the radial feeder of Figure 51.

Time settings

The time setting of the relay farthest from the infeed is determined first. In the radial feeder of Figure 51, relay D has a time setting of 0.22 s, which is enough to coordinate with the fuse at the end of the feeder. Then, the grading margin is used (0.4 s here) to determine the time setting of every other relay in the feeder. This leads to a time setting of 1.42 s for relay A, as shown in Table 6. Figure 52 displays the time-current characteristic of each relay in the radial feeder of Figure 51. The arrows in Figure 52 indicate the grading margin of 0.4 s.
Exercise 3 – Overcurrent Protection of Radial Feeders  

**Discussion**

Table 6. Settings of the definite time overcurrent relays.

<table>
<thead>
<tr>
<th>Location</th>
<th>System impedance (Ω)</th>
<th>Fault level (A)</th>
<th>Maximum load current (A)</th>
<th>Relay current setting (A)</th>
<th>Relay time setting (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min. (max. power at infeed)</td>
<td>Max. (min. power at infeed)</td>
<td>Max.</td>
<td>Min.</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>0.504</td>
<td>0.928</td>
<td>12 596</td>
<td>6846</td>
<td>390</td>
</tr>
<tr>
<td>B</td>
<td>1.104</td>
<td>1.528</td>
<td>5753</td>
<td>4156</td>
<td>225</td>
</tr>
<tr>
<td>C</td>
<td>2.204</td>
<td>2.628</td>
<td>2882</td>
<td>2417</td>
<td>130</td>
</tr>
<tr>
<td>D</td>
<td>4.504</td>
<td>4.928</td>
<td>1410</td>
<td>1289</td>
<td>50</td>
</tr>
</tbody>
</table>

The impedance values take into account the impedance of the power system up to the 33 kV side of the power transformers feeding the radial feeder.

Figure 52. Time-current characteristics of the definite time overcurrent relays used in the radial feeder of Figure 51. The arrows indicate the grading margin (0.4 s).

The main drawback of using time coordination to achieve discrimination in a radial feeder protection system is that faults close to the infeed of the radial feeder, where the fault level (in terms of MVA) is highest, are cleared in the longest time (1.42 s), as shown in Figure 52. This is not desirable, because such faults can potentially cause more damage and are more likely to affect the stability of the electric power system than faults located farther from the radial feeder infeed.

---

1 The maximum system impedances are calculated with one power transformer instead of two at the infeed of the radial feeder.
Discrimination based on coordination in both time and current

The previous two sections demonstrated that radial feeder protection systems with discrimination based on either current coordination or time coordination have some disadvantages. The use of current coordination is limited to the specific situation involving a component (generally a power transformer) with a significant impedance connected in series with a feeder segment. In the case of time coordination, the faults having the highest levels (in terms of MVA) are cleared in the longest time. Discrimination based on coordination involving both time and current overcomes these disadvantages. It will be seen later on in the discussion that using time-current coordination to achieve discrimination in a radial feeder protection system results in fault clearance times for faults close to the infeed of the radial feeder that are significantly shorter than those that would be obtained if discrimination based on time coordination were used.

Discrimination involving both time and current (generally referred to as time-current coordination or time-current grading) is achieved with inverse definite minimum time (IDMT) overcurrent relays (ANSI device no. 511 function) with properly adjusted current and time settings. A generic procedure to achieve proper coordination between the IDMT overcurrent relays protecting a radial feeder is described below.

Generic procedure to achieve time-current coordination of IDMT overcurrent relays

Information about the system

Prior to performing the time-current coordination procedure of IDMT overcurrent relays used to protect a radial feeder, one must gather information about the system: impedances (values expressed in ohms, percentages, or per-unit values), maximum load current values, fuse characteristics, etc. The system impedance values are necessary to calculate the maximum and minimum fault levels at various locations along the radial feeder. The time-current coordination of the IDMT relays is performed using the maximum fault levels. When proper discrimination is achieved at the maximum fault levels, discrimination at the minimum fault levels is generally adequate. This is especially true when IDMT overcurrent relays with the same type of time-current characteristic are used. In all cases, however, the grading margin obtained at the minimum fault levels should also be verified to make sure proper coordination is achieved.

Time-current characteristics of the IDMT overcurrent relays

IDMT overcurrent relays having the same type of time-current characteristic (e.g., the IEC standard inverse (SI) time-current characteristic or the ANSI moderately inverse time-current characteristic) are generally used to achieve time-current coordination, because this eases the coordination procedure in most cases. Coordination of IDMT overcurrent relays having different types of time-current characteristics is more challenging. This topic is addressed shortly at the end of this discussion.
Current settings

The current setting of the IDMT overcurrent relays used to protect the radial feeder can be determined once the necessary information about the system has been gathered and a type of time-current characteristic has been selected for each relay. The current setting of each IDMT overcurrent relay is set to a value higher than the maximum load current of the feeder segment that it protects. The value of the relay current setting must be large enough to prevent the relay from operating under normal short-time overload condition (e.g., when a large motor starts). On the other hand, one must remember that the more the current setting of the relay exceeds the maximum load current, the more protection of the feeder segment against overload is sacrificed. The above two statements are a bit contradictory but since radial feeder protection systems are mainly concerned with overcurrent protection, it is acceptable to sacrifice overload protection when required. Once the current setting of every IDMT overcurrent relay has been determined, the relay farthest from the infeed of the radial feeder should have the lowest current setting and the current setting of each relay encountered when going back toward the infeed should be higher than the setting of the previous relay.

Time settings

Once the current setting of every IDMT overcurrent relay protecting the radial feeder is determined, relay coordination can be performed, i.e., the time settings of the relays can be adjusted to obtain the desired grading margin. Relay coordination begins with the relay located farthest from the infeed of the radial feeder. Also, relay coordination is performed by considering one pair of relays at a time, i.e., the relay whose time setting is to be determined and the next relay when moving away from the infeed of the radial feeder. In the case of the relay located farthest from the infeed of the radial feeder, coordination is done with the device (e.g., fuses) protecting the load at the end of the radial feeder. Figure 53, which shows two adjacent IDMT overcurrent relays along a radial feeder, is used to describe the generic method used for relay coordination. Relay 2 is the relay farthest from the infeed of the radial feeder, while relay 1 is the relay closest to it. Coordination of relay 1 with relay 2 must be performed. At this point, current settings have been determined for both relays and the time setting of relay 2 is known from a previous grading with a relay or a fuse.

Figure 53. Relay coordination is done considering a single pair of IDMT overcurrent relays at a time.
Some calculations are required to coordinate relays properly. Tables like the one shown in Table 7 are used to ease the coordination procedure. The numbers in Table 7 refer to the step number of the coordination procedure given below.

Table 7. Coordination calculations between relay 1 and relay 2.

<table>
<thead>
<tr>
<th>Relay</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current setting (A)</td>
<td>CS₂</td>
<td>CS₁</td>
</tr>
<tr>
<td>Maximum fault current at substation 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple of current setting (Iᵣ)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Time setting (TMS or TD)</td>
<td>known</td>
<td>5</td>
</tr>
<tr>
<td>Operating time (t)</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>

To obtain the time setting of relay 1:

1. Calculate the multiple of the current setting of relay 2 (Iᵣ₂) at the maximum fault current considered (i.e., the maximum fault current at substation 2).

\[
I_{R₂} = \frac{\text{Maximum fault current at substation 2}}{\text{Current setting of relay 2}} = \frac{I_{F₂,\text{max}}}{CS₂}
\]

2. Calculate the multiple of the current setting of relay 1 (Iᵣ₁) at the maximum fault current considered (i.e., the maximum fault current at substation 2).

\[
I_{R₁} = \frac{\text{Maximum fault current at substation 2}}{\text{Current setting of relay 1}} = \frac{I_{F₂,\text{max}}}{CS₁}
\]

3. Calculate the operating time of relay 2 at the maximum fault current considered using the multiple of the current setting Iᵣ₂ calculated in step 1, the time setting (TMS or TD) of relay 2, and the equation related to the type of time-current characteristic selected for relay 2. For instance, use the equation below when the IEC standard inverse (SI) time-current characteristic is selected.

\[
t (\text{relay 2 @ } I_{F₂,\text{max}}) = TMS \cdot \frac{0.14}{I_{R₂}^{\text{TMS}}} - 1
\]

4. Add the grading margin to the operating time of relay 2 calculated in the previous step to obtain the desired operating time for relay 1. See Figure 54. The grading margin is generally 0.4 s, but can be a little less (e.g., 0.35 s) when numerical overcurrent relays and modern switchgear are used.

\[
t (\text{relay 1 @ } I_{F₂,\text{max}}) = t (\text{relay 2 @ } I_{F₂,\text{max}}) + \text{grading margin}
\]
5. Calculate the time setting (TMS or TD) of relay 1 using the operating time of relay 1 calculated in the previous step, the multiple of the current setting $I_{R1}$ calculated in step 2, and the equation related to the type of time-current characteristic selected for relay 1. For instance, use the equation given in step 3 when the IEC standard inverse (SI) time-current characteristic is selected. Refer to Figure 55.

The 5-step procedure above is repeated to determine the time setting of each IDMT overcurrent relay up to the infeed of the radial feeder.

The generic procedure to achieve time-current coordination of IDMT overcurrent relays is applied to the radial feeder used earlier in this discussion to explain time coordination. The single line diagram of this radial feeder is repeated in Figure 56. The infeed of the radial feeder consists of two 10 MVA power transformers, each having a 7% impedance, that lower the voltage from 33 kV to 11 kV. Every IDMT overcurrent relay has an IEC standard inverse (SI) time-current characteristic. Details of the coordination between the relay at substation D and the fuse at the end of the radial feeder is omitted at this point. It is simply considered that the operating time of the relay at substation D at the maximum fault current is equal to 0.141 s.
Figure 55. Calculate the necessary time setting (TMS or TD) of relay 1 to obtain the desired operating time for relay 1 and respect the grading margin.

Figure 56. Radial feeder to be protected with definite time overcurrent relays.
Table 8 presents the system impedances, the minimum and maximum fault currents, the maximum load currents, and the current setting of the IDMT overcurrent relays at the various substations.

Table 8. Radial feeder impedance and current characteristics.

<table>
<thead>
<tr>
<th>Location</th>
<th>System impedance (Ω)</th>
<th>Fault level (A)</th>
<th>Maximum load current (A)</th>
<th>Relay current setting (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min. (max. power at infeed)</td>
<td>Max. (min. power at infeed)</td>
<td>Max.</td>
<td>Min.</td>
</tr>
<tr>
<td>A</td>
<td>0.504</td>
<td>0.928</td>
<td>12 596</td>
<td>6846</td>
</tr>
<tr>
<td>B</td>
<td>1.104</td>
<td>1.528</td>
<td>5753</td>
<td>4156</td>
</tr>
<tr>
<td>C</td>
<td>2.204</td>
<td>2.628</td>
<td>2882</td>
<td>2417</td>
</tr>
<tr>
<td>D</td>
<td>4.504</td>
<td>4.928</td>
<td>1410</td>
<td>1289</td>
</tr>
</tbody>
</table>

The impedance values take into account the impedance of the power system up to the 33 kV side of the power transformers feeding the radial feeder.

Table 9 shows the results of the coordination procedure between relay C (relay 1 in generic procedure) and relay D (relay 2 in generic procedure). Step numbers referring to the generic coordination procedure explained above are indicated in parentheses to ease comprehension. The grading margin is 0.4 s.

Table 9. Coordination calculations between relay C and relay D.

<table>
<thead>
<tr>
<th>Relay</th>
<th>D</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current setting (A)</td>
<td>125</td>
<td>150</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum fault current at substation D</th>
<th>1410 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple of current setting (Iₚ)</td>
<td>11.280 (1)</td>
</tr>
<tr>
<td>Time setting (TMS)</td>
<td>0.050</td>
</tr>
<tr>
<td>Operating time (t)</td>
<td>0.141 s (3)</td>
</tr>
</tbody>
</table>

When the coordination between relay C and relay D is finished, the coordination between relay B and relay C can be performed. Referring to the generic coordination procedure, relay C becomes relay 2 and relay B becomes relay 1.

---

The maximum impedances are calculated with one power transformer instead of two at the infeed of the radial feeder.

---

2 The maximum impedances are calculated with one power transformer instead of two at the infeed of the radial feeder.
Table 10 presents the coordination calculations for the whole radial feeder of Figure 56.

<table>
<thead>
<tr>
<th>Relay</th>
<th>D</th>
<th>C</th>
<th>B</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current setting (A)</td>
<td>125</td>
<td>150</td>
<td>300</td>
<td>500</td>
</tr>
<tr>
<td>Maximum fault current at substation D</td>
<td>1410 A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple of current setting (Iᵣ)</td>
<td>11.280</td>
<td>9.400</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Time setting (TMS)</td>
<td>0.050</td>
<td>0.177</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Operating time (t)</td>
<td>0.141 s</td>
<td>0.541 s</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Maximum fault current at substation C</td>
<td>2882 A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple of current setting (Iᵣ)</td>
<td>-</td>
<td>19.208</td>
<td>9.604</td>
<td>-</td>
</tr>
<tr>
<td>Time setting (TMS)</td>
<td>-</td>
<td>0.177</td>
<td>0.267</td>
<td>-</td>
</tr>
<tr>
<td>Operating time (t)</td>
<td>-</td>
<td>0.407 s</td>
<td>0.807 s</td>
<td>-</td>
</tr>
<tr>
<td>Maximum fault current at substation B</td>
<td>5753 A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple of current setting (Iᵣ)</td>
<td>-</td>
<td>-</td>
<td>19.172</td>
<td>11.503</td>
</tr>
<tr>
<td>Time setting (TMS)</td>
<td>-</td>
<td>-</td>
<td>0.267</td>
<td>0.363</td>
</tr>
<tr>
<td>Operating time (t)</td>
<td>-</td>
<td>-</td>
<td>0.614 s</td>
<td>1.014 s</td>
</tr>
<tr>
<td>Maximum fault current at substation A</td>
<td>12596 A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multiple of current setting (Iᵣ)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>25.192</td>
</tr>
<tr>
<td>Time setting (TMS)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.363</td>
</tr>
<tr>
<td>Operating time (t)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.762 s</td>
</tr>
</tbody>
</table>

Table 11 presents the summary of the current and time settings of the IΔMT overcurrent relays used to protect the radial feeder of Figure 56. Figure 57 illustrates the time-current characteristic of these relays. The arrows indicate the grading margin of 0.4 s at the maximum fault currents. At any fault level lower than the fault level at which coordination is performed, the difference between the operating times of the relays increases, which ensures that proper relay coordination is maintained. For example, at a fault level of 1410 A, the operating time of relay C is 0.541 s, whereas the operating time of relay B is 1.189 s. The difference between the operating times of relay B and relay C at a fault level of 1410 A is then 0.648 s, which is higher than the grading margin of 0.4 s.
Table 11. Settings of the IDMT overcurrent relays.

<table>
<thead>
<tr>
<th>Relay</th>
<th>Current setting (A)</th>
<th>Time setting (TMS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>500</td>
<td>0.363</td>
</tr>
<tr>
<td>B</td>
<td>300</td>
<td>0.267</td>
</tr>
<tr>
<td>C</td>
<td>150</td>
<td>0.177</td>
</tr>
<tr>
<td>D</td>
<td>125</td>
<td>0.050</td>
</tr>
</tbody>
</table>

Figure 57. Time-current characteristics of the IDMT overcurrent relays. The arrows indicate the grading margin of 0.4 s.

Using discrimination based on time-current coordination allows heavy faults near the infeed of a radial feeder to be cleared in times shorter than those that would be obtained if discrimination based on time coordination were used. This is demonstrated by comparing the operating times of the IDMT overcurrent relays obtained above with the operating times of the definite time overcurrent relays obtained earlier in the section about time coordination (remember that the same radial feeder is protected in both cases).

Figure 58 shows the time current characteristics of the IDMT overcurrent relays and the definite time overcurrent relays. The arrows indicate the time difference between the two types of relay at the maximum fault levels. It is clear from this figure that it is advantageous to use IDMT overcurrent relays instead of definite time overcurrent relays to clear the most severe faults in shorter times. For instance, the operating time of the IDMT overcurrent relay at substation A for the maximum fault level (12 596 A) is 0.762 s (from Table 10) whereas that of the definite time overcurrent relay is 1.42 s (from Table 6).
Figure 58. Comparison between the time-current characteristics of IDMT overcurrent relays and definite time overcurrent relays used to protect the same radial feeder. The arrows indicate the difference between the operating times of the two types of relay at the maximum fault levels.

Coordination of IDMT overcurrent relays with different types of time-current characteristics

When IDMT overcurrent relays having the same type of time-current characteristic are used in a radial feeder, the generic relay coordination procedure ensures that the operating time of any relay, at the fault level at which coordination is performed, is higher (by the value of the grading margin used) than the operating time of the next relay encountered when moving away from the infeed of the radial feeder. Also, at any fault level lower than the fault level at which coordination is performed, the difference between the operating times of these relays increases, which ensures that a proper relay coordination is maintained.

In certain situations, it may be necessary to use IDMT overcurrent relays with different types of time-current characteristics in a radial feeder. For example, you may have to coordinate a relay having an IEC standard inverse (SI) characteristic with a relay having an IEC extremely inverse (EI) characteristic (see Figure 59), or a relay having an ANSI moderately inverse characteristic with a relay having an ANSI extremely inverse characteristic. The extremely inverse characteristic curve (IEC or ANSI) is commonly used when coordinating an IDMT overcurrent relay with a fuse. On the other hand, it is common in electric power utilities to use IDMT overcurrent relays with an IEC standard inverse characteristic or an ANSI moderately inverse characteristic to protect radial feeders.
Figure 59. Portion of a radial feeder protected with IDMT overcurrent relays having different types of time-current characteristics.

When coordination between an IDMT overcurrent relay with a given characteristic and another IDMT overcurrent relay with a different type of characteristic or with a fuse is considered, it may be necessary to readjust the time-current characteristic of the relay (via the time setting and/or current setting) after the generic relay coordination procedure has been performed. This is to ensure that the time-current characteristics of the two protective devices do not intersect, which hinders proper coordination in the radial feeder. Two scenarios are discussed below: coordination between two IDMT overcurrent relays having different types of time-current characteristics and coordination between an IDMT overcurrent relay and a fuse. The radial feeder in Figure 59 is used as a reference.

Relays with different types of time-current characteristics

The coordination between the IEC standard inverse (SI) relay and the IEC extremely inverse (EI) relay shown in Figure 59 is examined in this section. A grading margin of 0.35 s between the relays is used in this example. Figure 60 shows the time-current characteristic of the EI relay and the time-current characteristic of the SI relay that is obtained with the current and time settings determined using the generic relay coordination procedure.

With these initial settings (SI0, refer to Table 12), one can see from Figure 60 that the time-current characteristics of the two relays intersect. This is not acceptable, because coordination fails when the time-current characteristic of the SI relay is below that of the EI relay. Indeed, the SI relay operates before the EI relay in this range of fault current, and consequently disconnects an unnecessary portion of the radial feeder.
When the time-current characteristics intersect, three options are available to readjust the time-current characteristic of the relay closest to the infeed of the feeder (the SI relay in the present case):

1. Increase the relay time setting so that the two time-current characteristics no longer intersect, leaving the current setting unchanged. This corresponds to relay settings SI1 in Table 12. Using this option, however, significantly increases the difference between the operating times of the two relays at the fault level at which relay coordination is performed. In other words, it is like applying a larger grading margin.

2. Increase the relay current setting so that the two time-current characteristics no longer intersect, leaving the time setting unchanged. This corresponds to relay settings SI2 in Table 12. Using this option also increases the difference between the operating times of the two relays at the fault level at which relay coordination is performed. It is also like applying a larger grading margin.
3. Redo the generic relay coordination procedure using a relay current setting that is slightly higher, then verify that the two time-current characteristics no longer intersect. If the two characteristics still intersect, the relay time setting can be increased slightly until the two characteristics no longer intersect (this corresponds to relay settings SI3.1 in Table 12). Choosing this option is like applying a larger grading margin. It is also possible to redo the generic relay coordination procedure using a higher relay current setting until the two characteristics no longer intersect (this corresponds to relay settings SI3.2 in Table 12). Choosing this option generally takes more time, but provides the desired grading margin.

Table 12. Settings of the standard inverse (SI) relay (maximum load current = 150 A) to be coordinated with an extremely inverse (EI) relay.

<table>
<thead>
<tr>
<th>Settings</th>
<th>SI0</th>
<th>SI1</th>
<th>SI2</th>
<th>SI3.1</th>
<th>SI3.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjustments</td>
<td>-</td>
<td>Increase the <strong>time</strong> setting only (option 1)</td>
<td>Increase the <strong>current</strong> setting only (option 2)</td>
<td>Redo the procedure with a higher <strong>current</strong> setting, then increase the <strong>time</strong> setting if needed (option 3)</td>
<td>Redo the procedure with a higher <strong>current</strong> setting (option 3)</td>
</tr>
<tr>
<td>Current setting (A)</td>
<td>250</td>
<td>250</td>
<td>325</td>
<td>300</td>
<td>360</td>
</tr>
<tr>
<td>Time setting (TMS)</td>
<td>0.135</td>
<td>0.270</td>
<td>0.135</td>
<td>0.18</td>
<td>0.111</td>
</tr>
<tr>
<td>Coordination satisfactory?</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The choice of option 1, 2, or 3 depends on your particular situation. Option 1 (increasing the relay time setting only) keeps the same level of protection against overload (because the current setting remains unchanged), but leads to a significant increase of the operating times of the relay, and thus, of the grading margin achieved. This is shown in Figure 61. Option 2 (increasing the relay current setting only) lowers the level of protection against overload. Also, it slightly increases the operating time of the relay at any particular value of current, thereby increasing the grading margin achieved, as shown in Figure 61. Option 3.1, similarly to option 2, lowers the level of protection against overload and slightly increases the operating time of the relay at any particular value of current, thereby increasing the grading margin achieved. This is shown in Figure 62. Finally, option 3.2 achieves the desired grading margin, as shown in Figure 62, but at the expense of overload protection, since it results in the highest relay current setting. In the end, the choice between options 1, 2, and 3 to achieve coordination of IDMT overcurrent relays having different types of time-current characteristics mainly depends on the specific goal pursued in a particular radial feeder protection system.
Figure 61. Time-current characteristics of the SI relay and the EI relay in the radial feeder shown in Figure 59. The SI relay is adjusted by either increasing the time setting (left) or increasing the current setting (right).

You may think the curves are too close to each other at low currents. This is not the case: they are about 0.5 seconds apart. The logarithmic vertical scale may be misleading, so read the scale carefully when you wish to calculate time differences.
Coordination between an IDMT overcurrent relay and a fuse

In radial feeder overcurrent protection applications mixing IDMT overcurrent relays with fuses, it is a good practice to use an extremely inverse time-current characteristic for a relay that must be coordinated with a fuse. Fuses usually have very steep time-current characteristics. Among the types of time-current characteristics available for IDMT overcurrent relays, the extremely inverse characteristic resembles the characteristic of fuses more closely. When coordination with a fuse is needed, the grading margin may be smaller than 0.4 s. A grading margin of 0.2 s is used in the following example.

The fuse considered has a current rating of 60 A. The first current setting used for the IDMT overcurrent relay with an IEC extremely inverse characteristic (EI relay) to achieve coordination is 100 A (EI0, refer to Table 13). This does not ensure proper coordination with the fuse at low values of current, as shown in Figure 63. Adequate coordination is obtained with a current setting of 200 A and a time setting of 0.12 (EI1).
As a rule of thumb, keep in mind that the current setting of the IDMT overcurrent relay should be approximately 3 times the current rating of the fuse to ensure proper coordination.

Table 13. Settings of the EI relay (maximum load current = 50 A) to be coordinated with a fuse.

<table>
<thead>
<tr>
<th>Settings</th>
<th>EI0</th>
<th>EI1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current setting (A)</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Time setting (TMS)</td>
<td>0.43</td>
<td>0.12</td>
</tr>
<tr>
<td>Coordination satisfactory?</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
The Procedure is divided into the following sections:

- Set up and connections
- Overcurrent protection of a radial feeder
  - Operation of relay C
  - Operation of relay B
  - Operation of relay A
  - Coordination verification
  - Comparison with definite time overcurrent relays.
- Ending the exercise

**Set up and connections**

*In this section, you will set up a protective relay so that it can be programmed and tested using a host computer.*

1. Refer to the Equipment Utilization Chart in Appendix A to obtain the list of equipment required to perform this exercise.

   Install the Numerical Directional Overcurrent Relay (Model 3812) and the host computer on your work surface.

   *This exercise can also be performed using the Numerical Distance Relay (Model 3813) or the Numerical Differential Protective Relay (Model 3819). The term protective relay is used throughout the remainder of this exercise procedure to refer to the protective relay that is used to perform the exercise.*

2. Connect the protective relay and the host computer to an ac power wall outlet.

   Turn the protective relay on. Wait for the protective relay to complete its initialization routine.

3. Connect the USB port of the protective relay to a USB port of the host computer.

4. Turn the host computer on, then start the DIGSI 5 software.

**Overcurrent protection of a radial feeder**

*In this section, you will verify the coordination of the protective relays used to protect a radial feeder.*

5. In DIGSI 5, open project file *Overcurrent Protection Radial Feeder.dp5v6* created for the protective relay that you are using to perform the exercise.

   You will use this project to verify the overcurrent protection of a radial feeder comprising three protective relays, as shown in Figure 64.
Table 14 shows the values of impedance, fault current, and maximum load current at various locations along the radial feeder.

Table 14. Radial feeder impedance and current characteristics.

<table>
<thead>
<tr>
<th>Location</th>
<th>Impedance (Ω)</th>
<th>Fault current (A)</th>
<th>Maximum load current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min. (max. power at infeed)</td>
<td>Max. (min. power at infeed)</td>
<td>Max.</td>
</tr>
<tr>
<td>A</td>
<td>1.936</td>
<td>3.872</td>
<td>6561</td>
</tr>
<tr>
<td>B</td>
<td>3.736</td>
<td>5.672</td>
<td>3400</td>
</tr>
<tr>
<td>C</td>
<td>6.536</td>
<td>8.472</td>
<td>1943</td>
</tr>
<tr>
<td>D</td>
<td>10.736</td>
<td>12.672</td>
<td>1183</td>
</tr>
</tbody>
</table>

The generic relay coordination procedure outlined in the discussion of this exercise has been used to coordinate the relays and achieve proper discrimination. A grading margin of 0.35 s has been used. The resulting current and time settings of the relays at locations A, B, and C (relays A, B, and C) are given in Table 15. Note that an IDMT overcurrent relay with an extremely inverse time-current characteristic is used at location C to facilitate coordination with the fuse at location D.

Table 15. Settings of the protective relays.

<table>
<thead>
<tr>
<th>Relay</th>
<th>Type of characteristic curve</th>
<th>Current setting (A)</th>
<th>Time setting (TMS)</th>
<th>CT ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>IEC standard inverse</td>
<td>400</td>
<td>0.27</td>
<td>300 A / 1 A</td>
</tr>
<tr>
<td>B</td>
<td>IEC standard inverse</td>
<td>300</td>
<td>0.18</td>
<td>150 A / 1 A</td>
</tr>
<tr>
<td>C</td>
<td>IEC extremely inverse</td>
<td>200</td>
<td>0.12</td>
<td>50 A / 1 A</td>
</tr>
</tbody>
</table>

3 The maximum values of impedance are calculated with a source power of 125 MVA SC.
Table 15 also presents the ratio of the current transformers paired with each of the protective relays.

To select proper CT ratios, it is a good practice to choose a primary rating close to the nominal current (maximal load current) in the protected section of the radial feeder (see Table 14).

Figure 65 illustrates, on the same graph, the time-current characteristics of the fuse and the relays protecting the radial feeder of Figure 64.

Figure 65. Time-current characteristics of the fuse and the protective relays.

What is the grading margin achieved between relay C and the fuse at the maximal fault current (1410 A) at location D?
6. In DIGSI 5, display the single-line diagram showing the connection of the protective relay to the electric power circuit.

Note the following and very important point: the electric power circuit includes only one protective relay, whereas the protection system of the radial feeder of Figure 64 includes three distinct protective relays.

To confirm that proper coordination of the protective relays in the radial feeder of Figure 64 is achieved, you will:

- Program the protective relay in the DIGSI 5 project to act, in turn, as each of the three protective relays in the radial feeder.
- Obtain the trip time of each relay at the relevant fault currents indicated in Table 14.
- Compare the trip times of two consecutive relays at the fault current at which relay coordination is achieved to ensure the grading margin achieved is satisfactory.

In this exercise, you will verify the coordination between relay B and relay C and between relay A and relay B.

Operation of relay C

7. You will first obtain the trip times of relay C for faults at location C (fault F3 in Figure 66). The maximum and minimum values of fault current at location C are indicated in Table 14.

![Figure 66. Fault F3 in the radial feeder.](image)

8. In DIGSI 5, make sure the ratio of the current transformers is 50 A/1 A. This corresponds to the current transformer ratio of relay C, as stated in Table 15.

9. In DIGSI 5, set the frequency of operation (Rated frequency parameter) of the protective relay to the frequency of your local ac power network.

Set the language used in the front panel display of the protective relay to the language used in DIGSI 5.

10. In DIGSI 5, access the settings of the overcurrent protection function of the protective relay. In the Project tree area of DIGSI 5, the overcurrent protection function is called 50/51 OC-3ph-B1 or 50/51 OC-3ph-A1 and is located in protection function group VI 3ph 1. Figure 67 shows the settings of the overcurrent protection function that should be displayed in the working
area of DIGSI 5. These settings are the same as those presented in Table 15 for relay C.

![Image of DIGSI 5 settings for relay C]

Figure 67. Settings of the overcurrent protection function of relay C.

11. In DIGSI 5, access the parameters of test sequence *Symmetrical fault*. Make the following observations about the test sequence:

- The test sequence consists of two steps.
- The first step (step 1) has a duration of 10.0 s.
- During the first step, the internal relay test system emulates balanced currents of 1.00 A at the current inputs of the relay. This is equivalent to balanced currents of 50 A in the feeder segment C-D, which corresponds to the maximum load current for this feeder segment.
- The second step (step 2) has a duration of 5.0 s.
- During the second step, the internal relay test system emulates balanced currents of 38.86 A at the current inputs of the relay. This is equivalent to balanced currents of 1943 A in feeder segment C-D, which corresponds to the maximum value of fault current at location C (i.e., the maximum current for fault \( F_3 \)).
- The frequency of the balanced currents emulated by the internal relay test system during both steps of the sequence is set to 50 Hz.

Set the frequency of the balanced currents emulated during both steps of test sequence *Symmetrical fault* to the frequency of your local ac power network.

12. Load the configuration to the protective relay using DIGSI 5.

13. Restart the protective relay in the simulation mode.
14. Start test sequence *Symmetrical fault*, then observe the front panel of the protective relay to see how it responds to the currents emulated by its internal relay test system. When the simulation ends, the front panel indicates the trip time of the relay.

Enter the trip time of relay C obtained at the maximum current for fault F₃ in Table 16.

*If you wish, you may use DIGSI 5 to download the latest fault record from the protective relay and display the signals contained in this fault record in SIGRA.*

<table>
<thead>
<tr>
<th>Fault F₃ (location C)</th>
<th>Max. current</th>
<th>Min. current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current during step 2 of the test sequence (A)</td>
<td>1943 (38.86)</td>
<td>1499 (29.98)</td>
</tr>
<tr>
<td>Operating time (ms)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The values between parentheses refer to the values of current at the secondary windings of the current transformer. Use these values in the test sequence in DIGSI 5.*

15. Reset the protective relay by momentarily depressing the Reset button located just below the 16 LED indicators on the left-hand side of the relay front panel.

16. In DIGSI 5, access the parameters of test sequence *Symmetrical fault*. For step 2 of the test sequence, set the value of the balanced current at the inputs of the relay to 29.98 A. This is equivalent to balanced currents of 1499 A in feeder segment C-D, which corresponds to the minimum value of fault current at location C (i.e., the minimum current for fault F₃).

17. Display the test environment and start test sequence *Symmetrical fault*.

18. When the simulation ends, enter the trip time of relay C obtained at the minimum current for fault F₃ in Table 16.

19. Reset the protective relay.
Exercise 3 – Overcurrent Protection of Radial Feeders  ♦  Procedure

**Operation of relay B**

20. You will now obtain the trip times of relay B for faults at locations B and C (faults $F_2$ and $F_3$ in Figure 68). The maximum and minimum values of fault current at locations B and C are indicated in Table 14.

![Figure 68. Faults $F_2$ and $F_3$ in the radial feeder.](image)

21. In DIGSI 5, set the ratio of the current transformers to 150 A/1 A. This corresponds to the current transformer ratio of relay B, as stated in Table 15.

22. Access the settings of the overcurrent protection function of the protective relay. Enter the settings shown in Figure 69. These settings are the same as those presented in Table 15 for relay B.

![Figure 69. Settings of the overcurrent protection function of relay B.](image)

23. Access the parameters of test sequence *Symmetrical fault*, then perform the following manipulations:

- For step 1 of the test sequence, make sure the value of the balanced current at the inputs of the relay is set to 1.00 A. This is equivalent to balanced currents of 150 A in feeder segment B-C, which corresponds to the maximum load current for this feeder segment.
- For step 2 of the test sequence, set the value of the balanced current at the inputs of the relay to 22.67 A. This is equivalent to balanced currents of 3400 A in feeder segment B-C, which corresponds to the maximum value of fault current at location B (i.e., the maximum current for fault F₂).

24. Load the configuration to the protective relay. This is necessary because the settings of the overcurrent protection function of the protective relay now reflects the characteristics of relay B.

25. Display the test environment and start test sequence Symmetrical fault.

26. When the simulation ends, enter the trip time of relay B obtained at the maximum current for fault F₂ in Table 17.

Table 17. Trip times of relay B obtained at the maximum and minimum values of current for faults F₂ and F₃.

<table>
<thead>
<tr>
<th>Fault F₂ (location B)</th>
<th>Fault F₃ (location C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. current</td>
<td>Min. current</td>
</tr>
<tr>
<td>3400 (22.67)</td>
<td>2239 (14.93)</td>
</tr>
<tr>
<td>1943 (12.95)</td>
<td>1499 (9.99)</td>
</tr>
</tbody>
</table>

Operating time (ms)

The values between parentheses refer to the values of current at the secondary windings of the current transformer. Use these values in the test sequence in DIGSI 5.

27. Reset the protective relay.

28. Access the parameters of test sequence Symmetrical fault. For step 2 of the test sequence, set the value of the balanced current at the inputs of the relay to 14.93 A. This is equivalent to balanced currents of 2239 A in feeder segment B-C, which corresponds to the minimum value of fault current at location B (i.e., the minimum current for fault F₂).

29. Display the test environment and start test sequence Symmetrical fault.

30. When the simulation ends, enter the trip time of relay B obtained at the minimum current for fault F₂ in Table 17.

31. Reset the protective relay.
32. Repeat steps 28 to 31 at the maximum and minimum values of current for fault F₃ (fault at location C). Refer to Table 17 for the values of current.

**Operation of relay A**

33. Finally, you will obtain the trip times of relay A for faults at locations A, B, and C (faults F₁, F₂, and F₃ in Figure 70). The maximum and minimum values of fault current at locations A, B, and C are indicated in Table 14.

![Figure 70. Faults F₁, F₂, and F₃ in the radial feeder.](image)

34. In DIGSI 5, set the ratio of the current transformers to 300 A/1 A. This corresponds to the current transformer ratio of relay A, as stated in Table 15.

35. Access the settings of the overcurrent protection function of the protective relay. Enter the settings shown in Figure 71. These settings are the same as those presented in Table 15 for relay A.

![Figure 71. Settings of the overcurrent protection function of relay A.](image)

36. Access the parameters of test sequence *Symmetrical fault*, then perform the following manipulations:
   - For step 1 of the test sequence, make sure the value of the balanced current at the inputs of the relay is set to 1.00 A. This is equivalent to
balanced currents of 300 A in the feeder segment A-B, which corresponds to the maximum load current for this feeder segment.

- For step 2 of the test sequence, set the value of the balanced current at the inputs of the relay to 21.87 A. This is equivalent to balanced currents of 6561 A in feeder segment A-B, which corresponds to the maximum value of fault current at location A (i.e., the maximum current for fault F₁).

37. Load the configuration to the protective relay. This is necessary because the settings of the overcurrent protection function of the protective relay now reflects the characteristics of relay A.

38. Display the test environment and start test sequence Symmetrical fault.

39. When the simulation ends, enter the trip time of relay A obtained at the maximum current for fault F₁ in Table 18.

| Table 18. Trip times of relay A obtained at the maximum and minimum values of current for faults F₁, F₂, and F₃. |
|--------------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Fault F₁ (location A) | Fault F₂ (location B) | Fault F₃ (location C) |
| Max. current | Min. current | Max. current | Min. current | Max. current | Min. current |
| Current during step 2 of the test sequence (A) | 6561 (21.87) | 3280 (10.93) | 3400 (11.33) | 2239 (7.46) | 1943 (6.48) | 1499 (5.00) |

*The values between parentheses refer to the values of current at the secondary windings of the current transformer. Use these values in the test sequence in DIGSI 5.*

40. Reset the protective relay.

41. Access the parameters of test sequence Symmetrical fault. For step 2 of the test sequence, set the value of the balanced current at the inputs of the relay to 10.93 A. This is equivalent to balanced currents of 3280 A in feeder segment A-B, which corresponds to the minimum value of fault current at location A (i.e., the minimum current for fault F₁).

42. Display the test environment and start test sequence Symmetrical fault.

43. When the simulation ends, enter the trip time of relay A obtained at the minimum current for fault F₁ in Table 18.
44. Reset the protective relay.

45. Repeat steps 41 to 44 at the maximum and minimum values of current for fault F₂ and fault F₃ (faults at locations B and C, respectively). Refer to Table 18 for the values of current.

Coordination verification

46. Fill Table 19 with the trip times entered in Table 16, Table 17, and Table 18. This will ease the analysis of the relay coordination.

Table 19. Summary of the trip times of the protective relays.

<table>
<thead>
<tr>
<th>Relay</th>
<th>Fault F₁ (location A)</th>
<th>Fault F₂ (location A)</th>
<th>Fault F₃ (location A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max. current</td>
<td>Min. current</td>
<td>Max. current</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

47. To verify the coordination between relay B and relay C, you must calculate the difference between their trip times at the maximum and minimum values of current for fault F₃. In both cases, the time difference should be equal to or a little greater than the desired grading margin of 0.35 s.

Indeed, relay C must operate before relay B for fault F₃, otherwise the 100 A load from substation C (refer to Figure 72) will be disconnected in vain.

Recall that relay C has an extremely inverse time-current characteristic whereas relay B has a standard inverse time-current characteristic.

Figure 72. Radial feeder with fault F₃.
Is the coordination between relay B and relay C adequate? Explain.

48. To verify the coordination between relay A and relay B, you must calculate the difference between their trip times at the maximum and minimum values of current for fault $F_2$. In both cases, the time difference should be equal to or a little greater than the desired grading margin of 0.35 s.

Indeed, relay B must operate before relay A for fault $F_2$, otherwise the 150 A load from substation B (refer to Figure 73) will be disconnected in vain.

![Figure 73. Radial feeder with fault $F_2$.](image)

Is the coordination between relay A and relay B adequate? Explain.

49. Imagine that definite time overcurrent relays are used instead of IDMT overcurrent relays for relay A, relay B, and relay C protecting the radial feeder of Figure 64.
What would then be the trip time of relay A at the highest fault current (i.e., the maximum current for fault F₁)? Use a clearing time of 50 ms for the fuse, a grading margin of 200 ms between relay C and the fuse, and a grading margin of 350 ms between the relays.

How does this time compare with the trip time of relay A at the maximum current of fault F₁ when IDMT overcurrent relays are used to protect the radial feeder?

Ending the exercise

50. In DIGSI 5, restart the protective relay in the process mode to allow normal operation of the unit.

51. Close the project open in DIGSI 5 without saving the changes you made to this project.

   Close DIGSI 5.

   Turn the protective relay off, then disconnect it from the host computer.

   Delete the copy of the project file that you opened at the beginning of this exercise.

Conclusion

In this exercise, you saw why it is important to coordinate the different protective relays in a radial feeder protection system. You learned about various methods to achieve discrimination in radial feeder protection systems: based on current, based on time, and based on time and current. You saw a generic relay coordination procedure to establish the settings of IDMT overcurrent relays in order to obtain proper discrimination in a radial feeder protection system. You saw how to coordinate an IDMT overcurrent relay with a fuse or with another IDMT overcurrent relay having a different type of time-current characteristic.

Review Questions

1. Explain what a radial feeder is.
2. Briefly explain why discrimination is important in a radial feeder.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

3. Give the main drawback of discrimination based on coordination in time alone.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

4. Explain when discrimination based on coordination in current alone is adequate.

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

5. Which type of time-current characteristic is typically used for an IDMT overcurrent relay when it must be coordinated with a fuse?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________