Electricity and New Energy

Overcurrent and Overload Protection Using Protective Relays

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Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>![DANGER]</td>
<td><strong>DANGER</strong> indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.</td>
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<tr>
<td>![WARNING]</td>
<td><strong>WARNING</strong> indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.</td>
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<tr>
<td>![CAUTION]</td>
<td><strong>CAUTION</strong> indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.</td>
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<tr>
<td>![CAUTION]</td>
<td><strong>CAUTION</strong> used without the <em>Caution, risk of danger</em> sign, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.</td>
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<tr>
<td>![Caution, risk of electric shock]</td>
<td>Caution, risk of electric shock</td>
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<td>![Caution, hot surface]</td>
<td>Caution, hot surface</td>
</tr>
<tr>
<td>![Caution, risk of danger. Consult the relevant user documentation.]</td>
<td>Caution, risk of danger. Consult the relevant user documentation.</td>
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<tr>
<td>![Caution, lifting hazard]</td>
<td>Caution, lifting hazard</td>
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<tr>
<td>![Caution, hand entanglement hazard]</td>
<td>Caution, hand entanglement hazard</td>
</tr>
<tr>
<td>![Notice, non-ionizing radiation]</td>
<td>Notice, non-ionizing radiation</td>
</tr>
<tr>
<td>![Direct current]</td>
<td>Direct current</td>
</tr>
<tr>
<td>![Alternating current]</td>
<td>Alternating current</td>
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<tr>
<td>![Both direct and alternating current]</td>
<td>Both direct and alternating current</td>
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<tr>
<td>![Three-phase alternating current]</td>
<td>Three-phase alternating current</td>
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<tr>
<td>![Earth (ground) terminal]</td>
<td>Earth (ground) terminal</td>
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## Safety and Common Symbols

<table>
<thead>
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<th>Symbol</th>
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<tr>
<td><img src="image" alt="Symbol" /></td>
<td>Protective conductor terminal</td>
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<tr>
<td><img src="image" alt="Symbol" /></td>
<td>Frame or chassis terminal</td>
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<tr>
<td><img src="image" alt="Symbol" /></td>
<td>Equipotentiality</td>
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<tr>
<td><img src="image" alt="Symbol" /></td>
<td>On (supply)</td>
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<tr>
<td><img src="image" alt="Symbol" /></td>
<td>Off (supply)</td>
</tr>
<tr>
<td><img src="image" alt="Symbol" /></td>
<td>Equipment protected throughout by double insulation or reinforced insulation</td>
</tr>
<tr>
<td><img src="image" alt="Symbol" /></td>
<td>In position of a bi-stable push control</td>
</tr>
<tr>
<td><img src="image" alt="Symbol" /></td>
<td>Out position of a bi-stable push control</td>
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Preface

The production of energy using renewable natural resources such as wind, sunlight, rain, tides, geothermal heat, etc., has gained much importance in recent years as it is an effective means of reducing greenhouse gas (GHG) emissions. The need for innovative technologies to make the grid smarter has recently emerged as a major trend, as the increase in electrical power demand observed worldwide makes it harder for the actual grid in many countries to keep up with demand. Furthermore, electric vehicles (from bicycles to cars) are developed and marketed with more and more success in many countries all over the world.

To answer the increasingly diversified needs for training in the wide field of electrical energy, the Electric Power Technology Training Program was developed as a modular study program for technical institutes, colleges, and universities. The program is shown below as a flow chart, with each box in the flow chart representing a course.

The Electric Power Technology Training Program.
Preface

The program starts with a variety of courses providing in-depth coverage of basic topics related to the field of electrical energy such as ac and dc power circuits, power transformers, rotating machines, ac power transmission lines, and power electronics. The program then builds on the knowledge gained by the student through these basic courses to provide training in more advanced subjects such as home energy production from renewable resources (wind and sunlight), large-scale electricity production from hydropower, large-scale electricity production from wind power (doubly-fed induction generator [DFIG], synchronous generator, and asynchronous generator technologies), smart-grid technologies (SVC, STATCOM, HVDC transmission, etc.), storage of electrical energy in batteries, and drive systems for small electric vehicles and cars.

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.
The authors and Festo Didactic look forward to your comments.
About This Manual

Manual objectives

When you have completed this manual, you will be familiar with the operation and settings of the instantaneous (ANSI device no. 50), definite-time (ANSI device no. 51DT), and inverse definite minimum time (ANSI device no. 51) overcurrent relays. You will be able to adjust the settings of an overcurrent relay to obtain a specific time-current characteristic. You will know applications where it is common to use overcurrent relays and high-voltage circuit breakers in conjunction to achieve overcurrent protection of electrical equipment. You will be familiar with the operation and settings of the machine or transformer thermal relay (ANSI device no. 49) of the temperature-sensor type or the thermal-replica type. You will know how to combine protection functions in a numerical protective relay to achieve overcurrent and overload protection of an ac machine or a power transformer. You will also know how to implement overcurrent protection of a radial feeder using either definite-time overcurrent relays or inverse definite minimum time (IDMT) overcurrent relays. You will be able to use the internal relay test system of a numerical protective relay to assess that the relay operates as expected.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Prerequisite

As a prerequisite to this course, you should have read the manuals titled DC Power Circuits, part number 86350, Single-Phase AC Power Circuits, part number 86358, Single-Phase Power Transformers, part number 86377, Three-Phase AC Power Circuits, part number 86360, and Three-Phase Transformer Banks, part number 86379.

Systems of units

Units are expressed using the International System of Units (SI) followed by units expressed in the U.S. customary system of units (between parentheses).
To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Detailed procedure in Exercise 1

It is recommended to perform the exercises in the order proposed in this manual, as Exercise 1 features more detailed explanations than the rest of the exercises.
Overcurrent and Overload Protection Using Protective Relays

**MANUAL OBJECTIVE**
When you have completed this manual, you will be familiar with the operation and settings of the instantaneous (ANSI device no. 50), definite-time (ANSI device no. 51DT), and inverse definite minimum time (ANSI device no. 51I) overcurrent relays. You will be able to adjust the settings of an overcurrent relay to obtain a specific time-current characteristic. You will know applications where it is common to use overcurrent relays and high-voltage circuit breakers in conjunction to achieve overcurrent protection of electrical equipment. You will be familiar with the operation and settings of the machine or transformer thermal relay (ANSI device no. 49) of the temperature-sensor type or the thermal-replica type. You will know how to combine protection functions in a numerical protective relay to achieve overcurrent and overload protection of an ac machine or a power transformer. You will also know how to implement overcurrent protection of a radial feeder using either definite-time overcurrent relays or inverse definite minimum time (IDMT) overcurrent relays. You will be able to use the internal relay test system of a numerical protective relay to assess that the relay operates as expected.

**DISCUSSION OUTLINE**
The Discussion of Fundamentals covers the following points:

- Distinguishing overcurrent protection from overload protection
- Evolution of the protective relay technology
- Protective relay testing

**DISCUSSION OF FUNDAMENTALS**

**Distinguishing overcurrent protection from overload protection**

The objective of overcurrent protection is to prevent excessive current flow in an electric power circuit from damaging the circuit or from initiating fire in the circuit that could lead to more serious damage and even endanger people’s lives. In this statement, the term “excessive current flow” refers to the flow of a current whose value greatly exceeds the nominal full-load current of the circuit, like the current resulting from a short-circuit. Overcurrent protection works by first detecting excessive current flow in the protected circuit and then opening the path through which the excessive current flows as quickly as possible.

The objective of overload protection is to prevent damage to a component in an electric power circuit when this component is subjected to prolonged overload. When a component (e.g., a power transformer, an induction motor) is over loaded, the value of the current flowing in the component exceeds the nominal full-load current of the component to a certain extent. Consequently, the heating effect due to current flow in the component (this effect is proportional to $I^2$) is increased and the component starts to overheat, causing its temperature to increase. Operation under overload conditions for an extended period causes the component’s temperature to eventually increase beyond safe limits and cause damage to the component. The larger the severity of the overload (i.e., the more the nominal full-load current of the component is exceeded), the lower the...
time required for overheating to cause damage to the component. Overload protection can be achieved by first detecting when the current flowing through the protected component exceeds the nominal full-load current and then disconnecting the component from the power source before overheating causes damage to the component (i.e., before the component’s temperature goes beyond safe limits).

An overload is a form of overcurrent since it causes the value of the current flowing through a component to exceed the nominal full-load current of the component. In the rest of this manual, however, the term overcurrent is used only to refer to current flow that greatly exceeds the nominal full-load current of a circuit (e.g., current flow due to a short-circuit), unless otherwise notified.

With the objective of overcurrent protection being different from that of overload protection, it is common to apply these two types of protection to the same electric power circuit. Overcurrent protection can be achieved using a variety of means: fuses, low-voltage (LV) circuit breakers like **miniature circuit breakers** (MCBs) and **molded-case circuit breakers** (MCCBs), **protective relays** used in conjunction with high-voltage (HV) circuit breakers, etc. Overload protection can be achieved using a contactor operated by a device including a thermal-overload detection function as well as by using any one of the means mentioned above. The means selected to achieve overcurrent and/or overload protection in a particular application mainly depends on the technical requirements of the application as well as on economical considerations. This manual focuses on overcurrent protection and overload protection achieved with protective relays used in conjunction with HV circuit breakers.

**Evolution of the protective relay technology**

A protective relay is an intelligent device that detects faults or abnormal operating conditions (e.g., an overload) in an electric power circuit and makes an HV circuit breaker (or several HV circuit breakers) open to isolate the faulty portion of the circuit and avoid or limit damage to the circuit. To detect a fault or an abnormal operating condition, the protective relay generally measures currents in the electric power circuit via current inputs. However, some protective relays measure both currents and voltages in the electric power circuit via current and voltage inputs while some other protective relays measure only circuit voltages via voltage inputs. Control (opening) of the HV circuit breaker is achieved by actuating a set of contacts in the protective relay upon detection of a fault or an abnormal operating condition in the electric power circuit. Figure 1 is a simplified single-line diagram showing the connection of a protective relay and an HV circuit breaker used in conjunction to protect a three-phase electric power circuit. Notice that the current and voltage inputs of the protective relay are connected to the electric power circuit via current and voltage transformers. These transformers are required to match the current and voltage levels in the electric power circuit with the current and voltage ratings of the protective relay inputs.
The use of protective relays to protect electric power circuits dates back to the beginning of the 20th century. The first protective relays were electromechanical units. In any electromechanical protective relay, the protection function (e.g., the time-current characteristic of an overcurrent protective relay) is implemented using electromechanical devices. The operation of an electromechanical protective relay can be summarized as follows: currents and/or voltages measured in an electric power circuit via current transformers and/or voltage transformers are applied to coils mounted on magnetic cores in the relay to produce a mechanical force. This force is used to actuate the relay contacts. When the mechanical force produced in the relay is strong enough to overcome a counteracting force in the relay (e.g., the force provided by a spring), the relay contacts are actuated.

Electromechanical relays, though reliable, had a few weaknesses. They applied a high load (burden) on the current transformers and/or voltage transformers. They had a long operating time due to the inertia of the moving parts used in the relay. They also had a high maintenance cost. In the early 1960s, static protective relays appeared and gradually replaced most of the electromechanical relays in service, mainly because they provided shorter operating times than electromechanical protective relays and reduced the load applied to current transformers and/or voltage transformers. In a static protective relay, the protection function is implemented with solid-state analog circuits (i.e., electronic circuits with no moving parts) instead of electromechanical components. The improved operating times and the reduction in the load applied to current transformers and/or voltage transformers achieved in static protective relays are largely due to this change in relay technology.
Static protective relays, though considered more efficient than electromechanical protective relays, also have weaknesses of their own. Their operation requires a highly reliable source of electric power and is sensitive to both interference and ambient temperature. Some static protective relays are still in use today, but replacement of these relays began in the middle of the 1980s when the first digital protective relays became available. In a digital protective relay, the measured currents and/or voltages are first sampled and converted to digital form, then a microprocessor is used to implement the protection function instead of electromechanical devices or solid-state analog circuits. The use of a sophisticated algorithm in the microprocessor allows the protection function to be implemented with greater accuracy and generally results in a wider range of settings. Also, the presence of a microprocessor in a digital protective relay allows communication with a computer for relay programming, analysis of recorded data, etc. In other words, digital protective relays are clearly superior to electromechanical and static protective relays in terms of both performance and functionality. Because of these advantages, many digital protective relays are currently in use to protect electric power circuits of all kinds. However, digital protective relays should eventually be superseded by numerical protective relays.

The numerical protective relays are the natural evolution of the digital protective relays resulting from progress in computer technology. A numerical protective relay (see Figure 2) uses at least one digital signal processor (DSP) instead of a single microprocessor to implement the protective relay function. This results in operating times shorter than those that can be achieved using digital protective relays. Furthermore, this allows several protection functions (e.g., overcurrent protection and overload protection) to be implemented in the same protective relay. This also allows the implementation of logic functions (e.g., interlocking between a circuit breaker and its associated disconnecting switches in an electric power substation) in the protective relay. In short, numerical protective relays provide high-performance protection while being cost effective since several protection functions can be performed by a single unit. Consequently, numerical protective relays are now commonly selected to replace older protective relays in existing installations as well as to implement protection systems in new installations.

Figure 2. Numerical protective relay.
Protective relay testing

The main task of a protective relay is to protect a particular element in an electric power system (e.g., a synchronous generator, a power transformer, a transmission line) against specific faults and/or abnormal operating conditions. Various settings in the protective relay must be adjusted to properly adapt the protection to the characteristics of both the electric power system and the element to be protected. Once this is done, protective relay testing should be performed before the relay is definitely put into service. In short, protective relay testing consists of conducting the tests necessary to assess that the protective relay operates properly under certain specific faults and/or abnormal operating conditions. Traditionally, this task is achieved using a relay test system.

A relay test system is an instrument which mainly consists of several (generally 3 to 6) ac current sources and several (generally 3) ac voltage sources. These sources are able to supply ac currents and voltages of the magnitude required to drive the current and voltage inputs of protective relays of any type of technology. Furthermore, the magnitude and phase angle of the current produced by each ac current source can be adjusted. Similarly, the magnitude and phase angle of the voltage produced by each ac voltage source can be adjusted. A generic procedure for protective relay testing using a relay test system is summarized below.

- The current and/or voltage inputs of the protective relay to be tested are connected to ac current sources and/or ac voltage sources of the relay test system. Figure 3 shows the connection of a relay test system to a protective relay having three current inputs and three voltage inputs.
- The relay test system is used to produce currents and/or voltages whose magnitudes and phase angles are identical to those that the protective relay would measure under a specific fault condition or abnormal operating condition.
- The response of the protective relay to the test currents and/or voltages is recorded, then analyzed to assess that the protective relay operates properly (i.e., as expected according to the set characteristic of the protection function).
The procedure above should be repeated for each of the specific fault conditions or abnormal operating conditions for which the protective relay should operate (i.e., actuate its trip output contacts).

Some numerical protective relays (e.g., relays from the Siemens SIPROTEC® 5 series) include an internal relay test system. This allows protective relay testing to be performed without the need for an external relay test system, which is generally expensive. The simplified block diagram of a numerical protective relay including an internal relay test system is shown in Figure 4.

Figure 3. Connection of a relay test system to a protective relay.
Figure 4. Simplified block diagram of a numerical protective relay including an internal relay test system.
The numerical protective relay shown in Figure 4 has three current inputs and three voltage inputs. In normal operation (Mode selector in the Normal position), the current or voltage at each input is sampled at regular time intervals and converted to digital format by six analog-to-digital (A/D) converters. A continuous stream of data is thus obtained for each of the currents and voltages applied to the inputs of the numerical protective relay. Data coming from all A/D converters is routed to a digital signal processor (DSP) which implements the protection function(s).

To perform relay testing, the protective relay is switched to the test mode (Mode selector in the Test position in Figure 4). In test mode, data produced by the internal relay test system is routed to the DSP instead of data coming from the A/D converters. The internal relay test system consists of three ac current sources and three ac voltage sources. The output of each of these sources is readily in digital format and is routed to the digital signal processor (DSP). An external computer connected to the protective relay is used to control the magnitude and phase angle of each of the currents and voltages produced by the sources in the internal relay test system. This allows currents and voltages whose magnitudes and phase angles are identical to those of the currents and voltages measured under any specific fault condition or abnormal operating condition to be easily reproduced. The response of the protection function(s) implemented in the DSP to the currents and voltages generated by the internal relay test system is sent to the external computer connected to the numerical protective relay for display purposes. Analyzing this response allows verifying whether or not the numerical protective relay operates as expected.
Sample Exercise
Extracted from
the Student Manual
and the Instructor Guide
Exercise 1

Overcurrent Protection

**Exercise Objective**
When you have completed this exercise, you will be familiar with overcurrent and overload protection of power lines, power transformers, and ac motors implemented with fuses or low-voltage circuit breakers. You will know the operation and settings of the instantaneous (ANSI device no. 50), definite-time (ANSI device no. 51DT), and inverse definite minimum time (ANSI device no. 51I) overcurrent relays. You will be able to adjust the settings of an overcurrent relay to obtain a specific time-current characteristic. You will know applications where it is common to use overcurrent relays and high-voltage circuit breakers in conjunction to achieve overcurrent protection of electrical equipment. You will be able to use the internal relay test system of a numerical protective relay to assess that the relay operates as expected.

**Discussion Outline**
The Discussion of this exercise covers the following points:

- Introduction
- Overcurrent protection and overload protection using fuses
- Overcurrent protection and overload protection using LV circuit breakers (MCBs and MCCBs)
- Overcurrent protection and overload protection using protective relays and HV circuit breakers
- Instantaneous overcurrent relay
- Definite-time overcurrent relay
- Inverse definite minimum time (IDMT) overcurrent relay
- Standard time-current characteristics of IDMT overcurrent relays
- Overcurrent protection of a power transformer using a numerical overcurrent relay
- Main features of protection implemented with numerical overcurrent relays and HV circuit breakers

**Discussion**
Introduction

As mentioned in the introduction of this manual, overcurrent protection and overload protection each can be achieved using a variety of means: fuses, low-voltage (LV) circuit breakers like miniature circuit breakers (MCBs) and molded-case circuit breakers (MCCBs), protective relays used in conjunction with high-voltage (HV) circuit breakers, etc. Each of these three means of achieving overcurrent protection and overload protection are examined in this discussion. However, note that due to the abundance of material, the present discussion focuses on overcurrent protection implemented with overcurrent relays. Combined overcurrent and overload protection using protective relays is discussed more extensively in the next exercise of this manual.
Overcurrent protection and overload protection using fuses

A fuse is a two-terminal electric component. The two terminals of the fuse are interconnected by a fusible element that consists of a metallic (nickel-chrome and silver are both commonly used) wire or strip, enclosed in an insulating sleeve (generally cylindrical). The fusible element has very low resistance, thereby allowing the fuse to be connected in series with a component in an electric power circuit without perturbing the circuit operation. However, when the current flowing through the fuse exceeds a certain value, the fusible element heats up considerably and eventually starts to melt. After a certain time, the fusible element has melted completely, thereby breaking the electric path between the fuse terminals and interrupting current flow. This feature enables a fuse connected in series with an electric power circuit to protect the circuit against overcurrent, and possibly, against overload too. Once the fusible element in a fuse has melted completely, the fuse is said to have blown. After the cause of overcurrent or overload has been corrected, the blown fuse must be replaced with a new unit having the same specifications. Figure 5 shows fuses of various sizes used for different applications.

Figure 5. Fuses of different sizes. The small ones are typically used in electronic devices, whereas the larger one is more characteristic of a power utility application.

The time required for the fusible element in a fuse to melt completely and the electric path to break, which is commonly referred to as the total clearing time, decreases with the magnitude of the current flowing through the fuse. Consequently, the greater the current flowing through the fuse, the shorter the total clearing time. Figure 6 shows an example of the time-current characteristic of a fuse, i.e., the relationship between the current flowing through a fuse and the total clearing time. The time-current characteristic of a fuse is also commonly referred to as the inverse-time characteristic or simply the inverse characteristic of the fuse because the total clearing time varies inversely with the value of the current flowing through the fuse. Note that the total clearing time becomes infinite when the current decreases to a certain value. This is because below this value, the current flowing through the fuse is not sufficient to make the fusible element melt, thereby preventing the fuse from interrupting current. The minimum value of current required for the fusible element to start melting is known as the minimum melting current. The current rating of the fuse, i.e., the maximum value of current that can flow through the fuse continuously without causing the fuse to blow, is necessarily lower than the minimum melting current of the fusible element.
Fuses are commonly used to protect power lines in distribution networks and industrial applications. In this case, the fuse provides overcurrent protection of the power line only. For this purpose, the current rating of the fuse should be several times the nominal full-load current of the power line to be protected (e.g., 5 times [500%] the nominal full-load current). Power lines in distribution networks and industrial applications generally have a radial structure and are powered at one end only. Such power lines are commonly referred to as radial feeders. Overcurrent protection of radial feeders using protective relays is covered in Exercise 3 of this manual.

Fuses are also commonly used to protect power transformers in distribution networks and industrial applications. For instance, a single fuse connected in series with the primary winding of a single-phase power transformer can be used (minimally) to provide both overcurrent (OC) and overload (OL) protection of the transformer, as shown in Figure 7. Figure 8 shows a pole-mounted secondary distribution transformer with its OC fuse.
To achieve proper overload protection, the current rating of the fuse must be selected carefully, i.e., it must be kept as close as possible to the nominal full-load current of the primary winding (generally, not more than 1.25 times [125%] of the nominal full-load current). Overload protection is gradually sacrificed as the selected current rating exceeds the nominal full-load current of the primary winding more and more. Note that the fuse selected must be of the slow-blow type to ensure that it can sustain, without blowing, the magnetizing current inrush that occurs when voltage is applied to the power transformer. Also, note that protecting a power transformer using a fuse at the primary winding only is applicable only to transformers having a single secondary winding.

Figure 7. Overcurrent and overload protection of a single-phase power transformer using a single fuse (at the primary winding).

Current rating of fuse generally selected for both OC and OL protection

To source                      Primary                      Secondary                       To load

It is also common to protect a single-phase power transformer with two fuses, as shown in Figure 9. One fuse is connected in series with the primary winding and another fuse is connected in series with the secondary winding. The current rating of the fuse at the secondary winding is generally selected to provide both overcurrent and overload protection of the winding as described earlier in the discussion. On the other hand, the current rating of the fuse at the primary
winding is selected to provide overcurrent protection against faults in the power transformer windings, with overload protection being generally provided by the fuse at the secondary winding. Note that when a power transformer has multiple secondary windings, a fuse is connected in series with each secondary winding and the current rating of each of these fuses is generally selected to provide both overcurrent and overload protection of the winding.

**Figure 9. Overcurrent and overload protection of a single-phase power transformer using fuses at the primary and secondary windings.**

Similarly, it is common to protect a three-phase power transformer with fuses connected at the primary and secondary windings, as shown in Figure 10. In this case, a fuse is connected with each power line going to and coming from the power transformer. The three fuses at the primary windings must have the same current rating. The same applies for the three fuses at the secondary windings.

**Figure 10. Overcurrent and overload protection of a three-phase power transformer using fuses at the primary and secondary windings.**

Fuses are also commonly used to protect ac motors in industrial applications (generally induction motors, though synchronous motors may also be protected with fuses). Figure 11 shows how fuses can protect the stator windings of a three-phase induction motor. In this case, the fuses provide overcurrent protection of the induction motor only. This is because the current which any induction motor draws when voltage is applied to its stator windings (starting-current inrush) can reach 3 to 8 times the nominal full-load current of the motor (also known as full-load amps or FLA). Furthermore, the starting-current inrush lasts until the motor approaches its nominal speed, with the duration being dependent on the motor power rating and load inertia (the duration can be any
value between a fraction of a second and several minutes). These considerations preclude the use of fuses having a current rating close to the induction motor FLA, a requirement to achieve proper overload protection of the induction motor. Consequently, the current rating of the fuses is selected for overcurrent protection only. For instance, if the starting-current inrush has a value of 5 times (500%) the FLA, fuses having a current rating of about 6 times (600%) the FLA would be appropriate to achieve overcurrent protection of the induction motor. To provide overload protection of the three-phase induction motor, a three-phase contactor and an overload detection unit are often connected in series with the fuses, as shown in Figure 11. The unit detects when the motor is overloaded and then opens the three-pole contactor before excessive overheating causes damage to the motor.

The first column in Table 3 (located at the end of this discussion) summarizes the main protection features implemented with fuses. Fuses can operate at voltages up to 161 kV. They are available at current ratings up to 6000 A and can interrupt currents up to 200 kA. Fuses have an inverse time-current characteristic and their minimum operating time can be less than 0.01 s. The latter feature puts fuses among the fastest devices available for overcurrent protection. Fuses have some drawbacks: they cannot be reset (once blown, a fuse has to be replaced), their nominal current and operating time cannot be adjusted, and their inverse-time characteristic is sensitive to ambient temperature. Devices holding fuses (commonly referred to as fuse holders) generally allow electric power circuits to be closed or opened manually. Finally, from a protective relaying perspective (i.e., referring to ANSI standard C37.2), fuses are equivalent to the function performed by standard device no. 51 (ac time overcurrent relay). The function of standard device no. 51 is discussed later in this manual.
Overcurrent protection and overload protection using LV circuit breakers (MCBs and MCCBs)

A single-pole, low-voltage (LV) circuit breaker, such as an MCB or an MCCB, is a two-terminal electric component which consists of a current sensor, an actuation mechanism, and a pair of contacts, all enclosed in a plastic case. Figure 12 shows the arrangement of the current sensor, actuation mechanism, and contacts in a single-pole LV circuit breaker. The current sensor and contacts have very low resistance, thereby allowing the circuit breaker to be connected in series with an electric power circuit without perturbing the circuit operation. When the current flowing through the circuit breaker exceeds a certain value, the current sensor triggers the actuation mechanism to make the contacts open. This breaks the electric path between the circuit breaker terminals and interrupts current flow. This feature enables an LV circuit breaker connected in series with an electric power circuit to protect the circuit against overcurrent, and possibly, against overload too. However, contrary to the fuse, the LV circuit breaker does not need to be replaced with a new unit once open. The contacts are simply reclosed using a reset lever in the actuation mechanism, as shown in Figure 13.

![Figure 12. Arrangement of the current sensor, actuation mechanism, and contacts in a single pole, LV circuit breaker.](image1)

![Figure 13. Contrary to the fuse, the circuit breaker does not need to be replaced with a new unit once open. The contacts may be reclosed using a reset lever.](image2)
The actuation mechanism and contacts of an LV circuit breaker can rapidly extinguish the arc that strikes when the contacts are opened, thereby providing the unit with a high current-interrupting capability. Figure 14 shows the symbols that are commonly used to represent a single-pole circuit breaker in circuit diagrams.

The current sensor in an LV circuit breaker can be of the thermal type. In this case, the circuit breaker is referred to as a thermal circuit breaker. A thermal-type current sensor is basically a small bi-metallic element that heats up significantly when the current flowing through the circuit breaker exceeds the current rating of the circuit breaker. The heat produced eventually triggers the actuation mechanism of the circuit breaker. The more the current flowing through the circuit breaker exceeds the current rating of the circuit breaker, the higher the heating effect and consequently, the shorter the time required to trigger the actuation mechanism. In other words, the operating time of a thermal circuit breaker varies inversely with the value of current, thereby leading to an inverse time-current characteristic similar to that of a fuse. Thermal circuit breakers can thus be used the same way as fuses to achieve overcurrent protection and overload protection, as discussed in the previous section of this discussion.

The current sensor in an LV circuit breaker can also be of the magnetic type. In this case, the circuit breaker is referred to as a magnetic circuit breaker. A magnetic-type current sensor is basically a solenoid that triggers the actuation mechanism of the circuit breaker as soon as the current flowing through the circuit breaker reaches a predetermined value (e.g., 5 times the current rating of the circuit breaker). Figure 15 shows the resulting time-current characteristic. Such a characteristic is commonly referred to as an instantaneous time-current characteristic because the tripping time of the circuit breaker is minimum. In fact, the tripping time is reduced to the time required for the circuit breaker contacts to open. The time-current characteristic of magnetic circuit breakers makes them perfectly suited for overcurrent protection since any short-circuit current is interrupted in a minimum time. However, they are not suitable for overload protection.
It is common practice to express current in the time-current characteristic of circuit breakers as multiples of the current rating of the circuit breaker.

It is common to combine a thermal-type current sensor with a magnetic-type current sensor in the same LV circuit breaker. In this case, the LV circuit breaker is referred to as a thermal-magnetic circuit breaker. Figure 16 shows the resulting time-current characteristic. The thermal-type current sensor provides overload protection similar to that obtained with a fuse while the magnetic-type current sensor provides overcurrent protection with a minimum tripping time.
Figure 16. Time-current characteristic of a thermal-magnetic circuit breaker.

On certain thermal-magnetic circuit breakers, like electronic MCCBs, the thermal portion of the characteristic is adjustable in current and time (i.e., it can be shifted left and right as well as up and down) while the magnetic portion of the characteristic is adjustable in current (i.e., it can be shifted left and right). This allows both the overload protection and the overcurrent protection to be optimized for a specific application. For instance, a three-pole, thermal-magnetic electronic MCCB connected in series with a three-phase induction motor can provide both overcurrent protection and overload protection when properly adjusted. This is shown in Figure 17.
Exercise 1 – Overcurrent Protection

The second row in Table 3 summarizes the main protection features implemented with LV circuit breakers. LV circuit breakers can operate at voltages lower than 1 kV, which is much less than fuses and HV circuit breakers. They are available at current ratings up to 3200 A and can interrupt currents up to 200 kA. LV circuit breakers have an inverse and/or instantaneous time-current characteristic and their minimum operating time can be less than 0.01 s. The latter feature makes LV circuit breakers as fast as fuses for overcurrent protection. LV circuit breakers, contrary to fuses, are re-usable, i.e., they can be reset after tripping. Also, LV circuit breakers allow electric power circuits to be closed or opened manually, though motorized units are available to allow remote switching of circuits. LV circuit breakers have a few drawbacks: their nominal current and operating time cannot be adjusted and their inverse-time characteristic is sensitive to ambient temperature. Note that electronic MCCBs do not have such drawbacks. Finally, from a protective relaying perspective (i.e., referring to ANSI standard C37.2), most LV circuit breakers are equivalent to the combination of the functions performed by standard device no. 50 (instantaneous overcurrent or rate-of-rise relay) and standard device no. 51 (ac time overcurrent relay). The functions of these ANSI standard devices are discussed later in this manual.

Overcurrent protection and overload protection using protective relays and HV circuit breakers

It is common to use fuses or LV circuit breakers to implement overcurrent protection of power lines in distribution networks and industrial applications. It is also common practice to use fuses or LV circuit breakers to implement overcurrent and overload protection of power transformers and ac motors. In both cases, using fuses or LV circuit breakers is a solution that provides satisfactory protection while being cheaper than opting for protective relays used in conjunction with high-voltage (HV) circuit breakers. However, protection that is more efficient and flexible is generally required as the importance or monetary value of the equipment to be protected increases. Such performance and flexibility can be achieved with protective relays used in conjunction with HV circuit breakers. Consequently, it is common to use overcurrent protective relays in conjunction with HV circuit breakers to implement overcurrent protection of any important or valuable power lines in distribution networks and industrial
applications. Similarly, it is common to use an overcurrent protective relay in conjunction with an HV circuit breaker to implement overcurrent and overload protection of any important or valuable power transformer or ac motor. Note that an overcurrent protective relay is commonly referred to as an **overcurrent relay**.

Figure 18 is a simplified diagram showing the connections of an overcurrent relay and a three-pole HV circuit breaker used to protect a three-phase power circuit. The relay has three current inputs to measure each of the line currents in the three-phase power circuit. Recall that current transformers are required to match the value of the line currents with the current rating of the overcurrent relay inputs, which is generally either 1 A or 5 A.

![Figure 18. Protection of a three-phase power circuit using an overcurrent relay and an HV circuit breaker.](image)

Figure 19 is a single-line diagram that corresponds to the circuit shown in Figure 18. Note that the number inside the protective relay symbol indicates the exact function performed by the relay as per ANSI standard C37.2. In this particular case, number 50 indicates that the protective relay is an instantaneous overcurrent relay. ANSI device numbers related to overcurrent relays are discussed later in the manual.
Instantaneous overcurrent relay

Three types of overcurrent relay are commonly available: instantaneous, definite time, and inverse definite minimum time (IDMT). Each of these three types of overcurrent relay has its own time-current characteristic. These three types of overcurrent relays are described in this section as well as in the next two sections of this discussion.

An overcurrent relay can have an instantaneous time-current characteristic very similar to that of a magnetic-type MCB or MCCB, as shown in Figure 20. The operating time is fixed and has a minimum value limited by the time required for the overcurrent relay contacts to close (i.e., for the overcurrent relay to actuate its trip output). Contrary to most MCBs and MCCBs, the current threshold (i.e., the current at which the relay trips) can be adjusted in an overcurrent relay. An overcurrent relay with an instantaneous time-current characteristic is commonly referred to as an instantaneous overcurrent relay. An instantaneous overcurrent relay is referred to as a device no. 50 as per ANSI standard C37.2. In this standard, device no. 50 is termed “instantaneous overcurrent or rate-of-rise relay” and is defined as “a relay that functions instantaneously on an excessive value of current or on an excessive rate of current rise, thus indicating a fault in the apparatus or circuit being protected”.

The adjustable current threshold of an overcurrent relay is commonly referred to as the current setting. Also, the operating time of an overcurrent relay is sometimes called the trip time.

Figure 19. Single-line diagram representing the circuit in Figure 18.
Figure 20. Time-current characteristic of an instantaneous overcurrent relay (ANSI device no. 50).

Instantaneous overcurrent relays are ideally suited to implement overcurrent protection since any short-circuit current is interrupted in a minimum time. Instantaneous overcurrent relays are commonly used as the main protection of power transformers of up to about 5 to 10 MVA and ac motors. It is also common to use instantaneous overcurrent relays to provide backup protection of various types of electric devices such as synchronous generators, power transformers larger than about 5 to 10 MVA, busses in an electric power substation, transmission lines, etc. Note that the ANSI device no. 50 function is seldom used alone in overcurrent relays: it is generally combined with other ANSI device functions to obtain more complete equipment protection. This is discussed later in this manual.
Definite-time overcurrent relay

An overcurrent relay can have a time-current characteristic similar to that of an instantaneous overcurrent relay in which the operating time can be adjusted (to a value higher than the minimum operating time of the overcurrent relay) in addition to the current threshold (current setting), as shown in Figure 21. Such a time-current characteristic is commonly referred to as a definite time characteristic because the operating time of the overcurrent relay has a predetermined value that is independent of the magnitude of current. An overcurrent relay with a definite time characteristic is commonly referred to as a definite-time overcurrent relay. A definite-time overcurrent relay is referred to as a device no. 51 as per ANSI standard C37.2. In this standard, device no. 51 is termed “AC time overcurrent relay” and is defined as “a relay with either a definite or inverse time characteristic that functions when the current in an ac circuit exceeds a predetermined value”. Note that the letters “DT” (standing for definite time) are sometimes added to device no. 51 to make clear the nature of the time-current characteristic of the overcurrent relay.

Figure 21. Time-current characteristic of a definite-time overcurrent relay (ANSI device no. 51DT).
Definite-time overcurrent relays are commonly used to implement overcurrent protection of radial feeders. A definite-time overcurrent relay can also be used to implement backup overcurrent protection of the low voltage side (secondary side) of a power transformer (for transformers up to about 5 to 10 MVA). Overcurrent protection of radial feeders using overcurrent relays is discussed in Exercise 3 of this manual. Overcurrent protection of power transformers using overcurrent relays is discussed later on.

**Inverse definite minimum time (IDMT) overcurrent relay**

An overcurrent relay can have an inverse time-current characteristic similar to that of a fuse or a thermal circuit breaker. In an overcurrent relay, however, the inverse time-current characteristic is adjustable in current and time (via current and time settings, respectively), i.e., it can be shifted left and right as well as up and down. This is shown in Figure 22. An overcurrent relay with an inverse time-current characteristic is commonly referred to as an inverse definite minimum time (IDMT) overcurrent relay. An IDMT overcurrent relay is referred to as a device no. 51 as per ANSI standard C37.2. In this standard, device no. 51 is termed “AC time overcurrent relay” and is defined as “a relay with either a definite or inverse time characteristic that functions when the current in an ac circuit exceeds a predetermined value”. Note that the letter “I” (standing for inverse) is sometimes added to device no. 51 to make clear the nature of the time-current characteristic of the overcurrent relay.

The current transformers that feed the inputs of any overcurrent relay no longer operate linearly when they are subjected to high current levels (e.g., currents exceeding 20 times the current setting of the relay), thereby leading to a significant error in the measured value of current. Such an error in the measured value of current leads directly to a significant error in the operating time of any IDMT overcurrent relay. To avoid errors in the relay operating time at high current levels, most digital or numerical IDMT overcurrent relays stop following their inverse characteristic and pass to a definite time characteristic when the current reaches about 20 to 30 times the current setting of the relay. For instance, the time-current characteristic of Figure 22 shows that the IDMT overcurrent relay stops following the inverse characteristic and passes to a definite time characteristic when the current reaches 20 times the current setting of the relay. The time setting of the definite time characteristic (i.e., the definite minimum time) is equal to the time value calculated using the equation of the inverse characteristic and a current value of 20 times the current setting of the relay. In short, these overcurrent relays combine an inverse characteristic with a definite time characteristic, hence the name inverse definite minimum time (IDMT) overcurrent relay.
IDMT overcurrent relays are commonly used to implement overload protection of AC motors. In fact, this is an alternative to the use of a thermal-magnetic electronic MCCB. IDMT overcurrent relays are also commonly used to implement overcurrent protection of radial feeders. Overload protection of an AC motor using an IDMT overcurrent relay is discussed in Exercise 2 of this manual. Overcurrent protection of radial feeders using overcurrent relays is discussed in Exercise 3 of this manual.

**Standard time-current characteristics of IDMT overcurrent relays**

Standard time-current characteristics of IDMT overcurrent relays have been defined by IEC and ANSI. Figure 23 shows the time-current characteristics for IDMT overcurrent relays defined in IEC standard 60255. Table 1 provides the equations that define these time-current characteristics. Various types of inverse time-current characteristics have been defined to provide protection engineers with a means to address a large variety of applications. For instance, the Standard Inverse (SI) characteristic is well suited for overload protection. On the other hand, the Extremely Inverse (EI) characteristic is well suited in overcurrent protection applications mixing IDMT overcurrent relays with fuses because it is similar to the time-current characteristic of various fuses.
Figure 23. Time-current characteristics for IDMT overcurrent relays defined in IEC standard 60255 (TMS = 1.0).

Table 1. Equations of the time-current characteristics of IDMT overcurrent relays defined in IEC standard 60255.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Inverse (SI)</td>
<td>[ t = TMS \cdot \frac{0.14}{I^0.02 - 1} ]</td>
</tr>
<tr>
<td>Very Inverse (VI)</td>
<td>[ t = TMS \cdot \frac{13.5}{I} - 1 ]</td>
</tr>
<tr>
<td>Extremely Inverse (EI)</td>
<td>[ t = TMS \cdot \frac{80}{I^2 - 1} ]</td>
</tr>
<tr>
<td>Long-Time Inverse (LTI)</td>
<td>[ t = TMS \cdot \frac{120}{I} - 1 ]</td>
</tr>
</tbody>
</table>

\( I \) = Multiple of relay current setting, \( TMS \) = Time multiplier setting of relay

Table 2 provides the equations that define these time-current characteristics.
The time-current characteristics of IDMT overcurrent relays defined by ANSI are mainly used in North America.

![Time-current characteristics for IDMT overcurrent relays defined by ANSI (TD = 7).](image)

**Figure 24.** Time-current characteristics for IDMT overcurrent relays defined by ANSI (TD = 7).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE Moderately Inverse</td>
<td>( t = \frac{TD}{7} \left[ \frac{0.0515}{I^2 - 1} \right] + 0.114 )</td>
</tr>
<tr>
<td>IEEE Very Inverse</td>
<td>( t = \frac{TD}{7} \left[ \frac{19.61}{I^2 - 1} \right] + 0.491 )</td>
</tr>
<tr>
<td>IEEE Extremely Inverse (EI)</td>
<td>( t = \frac{TD}{7} \left[ \frac{28.2}{I^2 - 1} \right] + 0.1217 )</td>
</tr>
<tr>
<td>US CO8 Inverse</td>
<td>( t = \frac{TD}{7} \left[ \frac{5.95}{I^2 - 1} \right] + 0.18 )</td>
</tr>
<tr>
<td>US CO2 Short-Time Inverse</td>
<td>( t = \frac{TD}{7} \left[ \frac{0.02394}{I^2 - 1} \right] + 0.01694 )</td>
</tr>
</tbody>
</table>

\( I_r \) = Multiple of relay current setting, \( TD \) = Time dial setting of relay

**Table 2.** Equations of the time-current characteristics of IDMT overcurrent relays defined by ANSI.
The time-current characteristic of an IDMT overcurrent relay can be moved left or right as mentioned earlier in this discussion. This is achieved by decreasing or increasing the current setting of the IDMT overcurrent relay. The current setting determines the value of the minimum current that must be exceeded to make the IDMT overcurrent relay trip (this is similar to the melting current of a fuse). For example, adjusting the current setting of an IDMT overcurrent relay to 10 A sets the vertical asymptotic line toward where the inverse characteristic converges to 10 A.

The time-current characteristic of an IDMT overcurrent relay can also be moved up or down, as mentioned earlier in this discussion. This is achieved by increasing or decreasing the time setting of the IDMT overcurrent relay. This setting is referred to as the time multiplier setting (TMS) in IEC standard 60255 and the time dial setting (TD) by ANSI. Increasing the TMS (or TD) value moves the characteristic up, thereby increasing the operating time of the IDMT overcurrent relay for any given value of current. Conversely, decreasing the TMS (or TD) value moves the characteristic down, thereby decreasing the operating time of the IDMT overcurrent relay for any given value of current. Note that adjusting the TMS (or TD) of an IDMT overcurrent relay in fact sets the value of the TMS (or TD) constant in the equations of the time-current characteristics given in the two tables above.

**Overcurrent protection of a power transformer using a numerical overcurrent relay**

Overcurrent protection is commonly used as the main protection of power transformers of up to about 5 to 10 MVA. An instantaneous overcurrent relay (ANSI device no. 50) is well suited to implement overcurrent protection of a power transformer. Also, backup overcurrent protection of the low-voltage side (secondary side) of a power transformer is sometimes added to enhance the overall protection of power transformers up to about 5 to 10 MVA. A definite-time overcurrent relay (ANSI device no. 51DT) can be used to implement backup overcurrent protection of the low-voltage side of a power transformer. Both the main overcurrent protection of the power transformer and the backup overcurrent protection of the low-voltage side of the power transformer can be performed using a single numerical overcurrent relay that combines the functions of ANSI devices no. 50 and no. 51DT. This is illustrated in the single-line diagram of Figure 25.

*In the diagram of Figure 25, the power of the ac power source is rated as 175 MVA SC, SC standing for short-circuit. This value refers to the power which the source can supply when subjected to a symmetrical fault.*
Figure 25. Overcurrent protection of a power transformer using a numerical overcurrent relay that combines the functions of ANSI devices no. 50 and no. 51DT.

The nominal value of the line currents at the primary of the power transformer in Figure 25 (i.e., the value of the line currents when the power transformer load is 8 MVA) is 38.5 A. When a symmetrical fault occurs at the transformer primary (fault F1 in Figure 25), the value of the line currents at the transformer primary can reach up to 842 A. On the other hand, when a symmetrical fault occurs at the low-voltage side (secondary) of the power transformer (fault F2 in Figure 25) and the protection at the transformer secondary (not shown in Figure 25) fails to operate, the value of the line currents at the transformer primary can reach up to 333 A.

The values of current above are the values measured by the numerical overcurrent relay (via the current transformers) under normal and abnormal operating conditions. These values of current are used to determine the value at which the current threshold of the ANSI device no. 50 function in the numerical overcurrent relay should be set to ensure that the main overcurrent protection of the power transformer works properly. These values of current are also used to determine the value at which the current threshold of the ANSI device no. 51DT function in the numerical overcurrent relay should be set to ensure that the backup overcurrent protection of the low-voltage side of the power transformer works properly. For instance, setting the current threshold of the ANSI device no. 50 function to 400 A makes the main overcurrent protection of the power transformer sensitive enough to faults at the transformer primary (fault currents at primary are up to 842 A) and insensitive to faults at the transformer secondary (fault currents at primary are up to 333 A). Similarly, setting the current threshold of the ANSI device no. 51DT function to about 190 A makes the backup overcurrent protection of the low-voltage side of the power transformer sensitive enough to faults at the transformer secondary (fault currents at primary are up to 333 A) and insensitive to the nominal value (38.5 A) of the transformer primary current. The time-current characteristic of the numerical overcurrent relay that results from these current settings is shown in Figure 26.
Figure 26. Time-current characteristic of the numerical overcurrent relay used for overcurrent protection of the power transformer in Figure 25.

Note that the time setting of the ANSI device no. 51DT function in the numerical overcurrent relay is adjusted to the lowest value (1 s in the present case) that allows sufficient time for the protection at the power transformer secondary to operate when a fault occurs at the transformer secondary. Also note that the numerical overcurrent relay does not protect the power transformer from overload since it does not operate for primary currents ranging from the nominal primary current (38.5 A) of the power transformer to 190 A. Another protection function (ANSI device no. 49 function: machine or transformer thermal relay) is required in the numerical overcurrent relay to achieve overload protection of the power transformer. This is discussed further in the next exercise of this manual.
Main features of protection implemented with numerical overcurrent relays and HV circuit breakers

The third row in Table 3 summarizes the main protection features implemented with numerical overcurrent relays used in conjunction with HV circuit breakers. HV circuit breakers can operate at voltages up to 1200 kV, which is much higher than fuses and LV circuit breakers. They are available at current ratings up to 5000 A (this is a little less than fuses) and can interrupt currents up to 90 kA (this is significantly less than fuses and LV circuit breakers). HV circuit breakers, contrary to fuses, are re-usable, i.e., they can be reclosed after tripping. Also, HV circuit breakers allow electric power circuits to be closed or opened either manually or through remote control. Numerical overcurrent relays can have any combination of instantaneous, definite, and inverse time-current characteristics. The time-current characteristic of numerical overcurrent relays is adjustable in current and time, and is not temperature sensitive.

Protection implemented with an overcurrent relay used in conjunction with an HV circuit breaker has one drawback: the minimum operating time is about 0.05 s, which is significantly longer than the minimum operating time (<0.01 s) of fuses and LV circuit breakers. This makes overcurrent relays used in conjunction with HV circuit breakers slower than fuses and LV circuit breakers.

Finally, from a protective relaying perspective (i.e., referring to ANSI standard C37.2), numerical overcurrent relays generally combine functions of two or more of the following ANSI devices: no. 50 (instantaneous overcurrent or rate-of-rise relay), no. 51 (ac time overcurrent), and no. 49 (machine or transformer thermal relay).

Table 3. Summary of the main features of current-based protective devices.

<table>
<thead>
<tr>
<th>Device type</th>
<th>Fuse</th>
<th>LV circuit breaker (MCB, MCCB)</th>
<th>Numerical overcurrent relay with HV circuit breaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage rating</td>
<td>Up to 161 kV</td>
<td>Less than 1 kV</td>
<td>Up to 1200 kV</td>
</tr>
<tr>
<td>Current rating</td>
<td>Up to 6000 A</td>
<td>Up to 3200 A</td>
<td>Up to 5000 A</td>
</tr>
<tr>
<td>Current interrupting capability</td>
<td>Up to 200 kA</td>
<td>Up to 200 kA</td>
<td>Up to 90 kA</td>
</tr>
<tr>
<td>Minimum operating time</td>
<td>&lt; 0.01 s</td>
<td>&lt; 0.01 s</td>
<td>~ 0.05 s</td>
</tr>
<tr>
<td>Time-current characteristic</td>
<td>Inverse</td>
<td>Instantaneous and/or inverse</td>
<td>Instantaneous and/or definite time and/or inverse</td>
</tr>
<tr>
<td>Adjustable in current</td>
<td>No</td>
<td>No (Yes, electronic MCCB)</td>
<td>Yes</td>
</tr>
<tr>
<td>Adjustable in time</td>
<td>No</td>
<td>No (Yes, electronic MCCB)</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Exercise 1 – Overcurrent Protection  ♦  Procedure Outline

<table>
<thead>
<tr>
<th>Device type</th>
<th>Fuse</th>
<th>LV circuit breaker (MCB, MCCB)</th>
<th>Numerical overcurrent relay with HV circuit breaker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature sensitive</td>
<td>Yes</td>
<td>No (Yes, electronic MCCB)</td>
<td>No</td>
</tr>
<tr>
<td>Reset capability</td>
<td>No (blown fuse to be replaced)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Circuit switching</td>
<td>Manual</td>
<td>Manual and remote</td>
<td>Manual and remote</td>
</tr>
<tr>
<td>Combined protection functions</td>
<td>No (51 only)</td>
<td>Yes (50 + 51)</td>
<td>Yes (50 + 51 + 49)</td>
</tr>
</tbody>
</table>

**PROCEDURE OUTLINE**

The Procedure is divided into the following sections:

- Set up and connections
- Operation of an instantaneous overcurrent relay
- Operation of a definite time overcurrent relay
- Operation of an inverse definite minimum time (IDMT) overcurrent relay
- Overcurrent protection of a power transformer using a numerical overcurrent relay

**PROCEDURE**

*You might need more than one laboratory period to perform the following exercise procedure if you are not already familiar with the DIGSI® 5 software from Siemens. Appendix C of this manual provides information on how to use software DIGSI 5 to perform various tasks related to SIPROTEC 5 protective relays. You should read this appendix before performing the exercise procedure.*

**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.*

   Insert the LED identification label for Exercise 1 into the front panel of the protective relay. The identification labels can be found in Appendix D.
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 (this generally takes about 45 s).

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.

**Operation of an instantaneous overcurrent relay**

*In this section, you will verify the operation of an instantaneous overcurrent relay (ANSI device no. 50).*

5. In DIGSI 5, open project file *Overcurrent Relay Settings and Operation.dp5v6* created for the protective relay that you are using to perform the exercise. A project file contains the complete configuration of the protective relay for a particular application. By default, the project files required to perform the exercises in this manual should be located in the following folder: `C:\ProgramData\Festo Didactic\Manual 52173, OC and OL Protection\...`

   Appendix C of this manual provides a series of short procedures, with each procedure describing how to use software DIGSI 5 to perform a specific task related to SIPROTEC 5 protective relays. You can refer to this appendix to learn how to perform the task required in most manipulations of this exercise procedure.

6. In DIGSI 5, display the single-line diagram showing the connection of the protective relay to the electric power circuit. Observe that in this project, the current inputs of the protective relay are connected to the electric power circuit (a feeder in an electric power substation) via current transformers having a 1000 A/1 A ratio.

7. 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.

8. 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 27 shows the settings of the overcurrent protection function that should be displayed in the working area of DIGSI 5.
9. Observe that, in this project, the overcurrent protection function of the protective relay can be a combination of three different time-current characteristics (instantaneous overcurrent, definite-time overcurrent, and inverse-time overcurrent). These time-current characteristics are named Definite-T1, Definite-T2, and Inverse-T1 in DIGSI 5. Observe that time-current characteristic Definite-T1 is on (Mode parameter set to on) and that time-current characteristics Definite-T2 and Inverse-T1 are off (Mode parameter set to off). Consequently, the overcurrent protection function of the protective relay is now entirely defined by time-current characteristic Definite-T1.

Observe that the protective relay is set to operate as an instantaneous overcurrent relay (ANSI device no. 50 function) because the time setting (parameter Operate delay in time-current characteristic Definite-T1) is set to 0.00 s.
Observe that the current setting of the protective relay (parameter Threshold in time-current characteristic Definite-T1) is currently set to 8000 A.

Observe that time-current characteristics Definite-T1, Definite-T2, and Inverse-T1 are displayed in the working area of DIGSI 5. However, since time-current characteristics Definite-T2 and Inverse-T1 are off, uncheck the corresponding check boxes under the time-current characteristic displayed in DIGSI 5 to show the time-current characteristic of the overcurrent protection function resulting from the above settings.

The x-axis in the diagram showing the time-current characteristic of the protection function is graduated with values of current at the secondary windings of the current transformers. These values of current must be multiplied by the ratio of the current transformers (1000 A/1 A in the currently-open project) to obtain values of current at the primary windings of the current transformers (i.e., values of current in the electric power circuit).

10. In DIGSI 5, change the current setting of the protective relay by editing the value of the Threshold parameter in time-current characteristic Definite-T1. Observe that the time-current characteristic of the protective relay displayed in the working area of DIGSI 5 is automatically updated after each change of the current setting.

Set the current setting of the protective relay back to its original value (8000 A).

11. In DIGSI 5, access the parameters of test sequence Symmetrical fault. This test sequence is part of the project file currently open in DIGSI 5 and can be used to test the overcurrent protection function of the protective relay using its internal relay test system. Figure 28 shows the parameters of test sequence Symmetrical fault that should be displayed in the working area of DIGSI 5.

![Figure 28. Parameters of test sequence Symmetrical fault displayed in the working area of DIGSI 5.](image-url)
**Exercise 1 – Overcurrent Protection**  

*Procedure*

12. Make the following observations about test sequence *Symmetrical fault*.

- 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 1000 A in the electric power circuit because 1000 A/1 A current transformers are used in this project.
- The second step (step 2) has a duration of 2.0 s.
- During the second step, the internal relay test system emulates balanced currents of 10.00 A at the current inputs of the relay. This is equivalent to balanced currents of 10 000 A in the electric power circuit because 1000 A/1 A current transformers are used in this project.
- By default, 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.

13. Load the configuration (i.e., the content of the project file currently open in DIGSI 5) to the protective relay using DIGSI 5. Loading the configuration to the protective relay generally takes some time.

14. In DIGSI 5, restart the protective relay in the simulation mode to allow the overcurrent protection function of the protective relay (i.e., protection function 50/51 OC-3ph-B1 or 50/51 OC-3ph-A1 in protection function group VI 3ph 1) to be tested using the internal relay test system. Once the restart process is completed, the test environment for the protective relay that you are using should be displayed in DIGSI 5 (see Figure 29). Also, the front panel display of the protective relay should indicate that the unit is operating in the simulation mode (the words *Simulation mode* should appear briefly on the display at regular intervals).

The *Error* LED on the front panel of the protective relay lights up when the unit is in simulation mode. This is normal. Do not be concerned about this error indication.

During this procedure, if you notice that DIGSI 5 lags relay operation, press the *Clear list* button at the top of the test environment. This should restore normal operation of DIGSI 5.
15. Observe that test sequence *Symmetrical fault* is available in the test environment displayed in DIGSI 5. This test sequence originates from the project file currently open in DIGSI 5. It emulates balanced line currents of 1000 A during 10 s then a symmetrical fault producing line currents of 10 000 A during 2 s.

16. In DIGSI 5, 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. Notice that the protective relay displays the value (1000 A) of the balanced line currents during 10 s, then four LED indicators on the relay front panel light up to indicate that the relay picked up and tripped. In this project, LED indicators 1 to 3 (top three LED indicators on the left-hand side of the relay front panel) light up to indicate that the relay picked up on phases A, B, and C, i.e., to indicate that the current setting (8000 A) of the protective relay has been exceeded on phases A, B, and C. Also, LED indicator 16 (bottom LED indicator on the left-hand side of the relay front panel) lights up to indicate that the relay tripped.

Also notice that information (protective function that picked up and tripped the relay, relay pickup time, relay trip time, etc.) about the response of the protective relay to the test sequence is displayed on the front panel display. Use the up and down arrow buttons on the relay front panel to scroll through this information.
17. Whenever the protective relay trips, input signals (i.e., the currents at the three current inputs) as well as internal signals (e.g., relay pickup occurrences, the circuit breaker trip command, etc.) are recorded in the relay. The signals recorded in the protective relay after any trip event are referred to as a fault record. DIGSI 5 can be used to download a fault record from the protective relay and display the signals contained in the fault record in SIGRA. SIGRA is a Siemens application that displays the signals contained in a fault record on time charts. These time charts are useful to analyze the protective relay response to the fault.

A fault record has been created in the protective relay when it tripped earlier in this exercise. Use DIGSI 5 to download the latest fault record from the protective relay and display the signals contained in this fault record in SIGRA. Figure 30 shows the signals (time charts) that should be displayed in SIGRA.

Figure 30. Signals contained in the fault record downloaded from the protective relay displayed in SIGRA.
Observe the signals in the time charts displayed in SIGRA. Notice that when the value of the currents emulated at the relay inputs passed from 1000 A to 10 000 A, the protective relay picked up on all three phases and issued a circuit breaker trip command immediately.

Does the fault record confirm that the protective relay operated as expected?

Yes, because the protective relay is currently set to operate as an instantaneous overcurrent relay with a current setting of 8000 A.

18. 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. The LED indicators should go out and the front panel display should resume normal information display (i.e., it should display the values of the line currents).

Operation of a definite time overcurrent relay

In this section, you will verify the operation of a definite time overcurrent relay (ANSI device no. 51DT).

19. 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.

Turn time-current characteristic Definite-T1 off, turn time-current characteristic Definite-T2 on, and make sure that time-current characteristic Inverse-T1 is turned off. These settings cause the overcurrent protection function of the protective relay to be entirely defined by time-current characteristic Definite-T2.

Observe that the protective relay is set to operate as a definite-time overcurrent relay (ANSI device no. 51DT function) because the time setting (parameter Operate delay in time-current characteristic Definite-T2) is set to 3.00 s. Also, observe that the current setting of the protective relay (parameter Threshold in time-current characteristic Definite-T2) is currently set to 3000 A.

In the working area of DIGSI 5, check the Definite-T2 check box and uncheck the Definite-T1 check box to show the time-current characteristic of the overcurrent protection function resulting from the above settings.

20. In DIGSI 5, change the current and time settings of the protective relay by editing the values of the Threshold and Operate delay parameters in time-current characteristic Definite-T2. Observe that the trip area of the protective relay (i.e., the lightly shaded area in the time-current characteristic of the protective relay displayed in the working area of DIGSI 5) is reduced when either one of these two parameters is increased, and vice versa.
Set the current setting of the protective relay back to its original value (3000 A).

Set the time setting of the protective relay back to its original value (3.00 s).

21. Load the configuration (i.e., the content of the project file currently open in DIGSI 5) to the protective relay using DIGSI 5. This is necessary because the settings of the overcurrent protection function of the protective relay have been modified.

22. In DIGSI 5, access the parameters of test sequence **Symmetrical fault**. Set the duration of step 2 to 2.9 s. Also, set the value of the balanced currents emulated by the internal relay test system during step 2 to 5.00 A. This is equivalent to balanced currents of 5000 A in the electric power circuit because 1000 A/1 A current transformers are used in this project.

23. In DIGSI 5, display the test environment for the protective relay that you are using. 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.

Briefly describe the response of the protective relay to the test sequence.

The protective relay picked up on all three phases (LED indicators 1 to 3 on the relay front panel lit up) but did not trip (LED indicator 16 on the relay front panel remained off).

24. A fault record has been created in the protective relay when it picked up. Use DIGSI 5 to download the latest fault record from the protective relay and display the signals contained in this fault record in SIGRA.

Observe the signals displayed in SIGRA, then briefly explain why the protective relay did not trip.

The test sequence emulated balanced currents of 5000 A (this value exceeds the current setting of the relay) during 2.9 s which is a little less than the time setting of the protective relay. Consequently, the relay picked up during 2.9 s but did not trip.

The following figure shows the signals that should be displayed in SIGRA.
Exercise 1 – Overcurrent Protection ♦ Procedure

Signals contained in the fault record downloaded from the protective relay displayed in SIGRA.

25. 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.

26. In DIGSI 5, access the parameters of test sequence *Symmetrical fault*. Set the duration of step 2 to 3.3 s.

27. In DIGSI 5, display the test environment for the protective relay that you are using. 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.
Did the protective relay trip?

☐ Yes  ☐ No

Yes

28. A fault record has been created in the protective relay when it tripped. Use DIGSI 5 to download the latest fault record from the protective relay and display the signals contained in this fault record in SIGRA.

Observe the signals displayed in SIGRA, then briefly explain why the protective relay tripped.

The test sequence emulated balanced currents of 5000 A (this value exceeds the current setting of the relay) during 3.3 s which is a little more than the time setting of the protective relay. Consequently, the relay picked up during 3.3 s which is sufficient to make it trip.

The following figure shows the signals that should be displayed in SIGRA.
Signals contained in the fault record downloaded from the protective relay displayed in SIGRA.

29. Reset the protective relay.

Operation of an inverse definite minimum time (IDMT) overcurrent relay

In this section, you will verify the operation of an inverse definite minimum time (IDMT) overcurrent relay (ANSI device no. 51I).

30. 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.
Turn time-current characteristic **Definite-T2** off, turn time-current characteristic **Inverse-T1** on, and make sure that time-current characteristic **Definite-T1** is turned off. These settings cause the overcurrent protection function of the protective relay to be entirely defined by time-current characteristic **Inverse-T1**.

Observe that the protective relay is set to operate as an IDMT overcurrent relay (ANSI device no. 51I function) having an IEC standard inverse (SI) time-current characteristic (parameter **Type of character. curve** in time-current characteristic **Inverse-T1** set to **IEC normal inverse**).

Observe that the current setting of the protective relay (parameter **Threshold** in time-current characteristic **Inverse-T1**) is currently set to 1000 A. Also, observe that the time setting of the protective relay (parameter **Time dial** in time-current characteristic **Inverse-T1**) is currently set to 1.50.

In the working area of DIGSI 5, check the **Inverse-T1** check box and uncheck the **Definite-T2** check box to show the time-current characteristic of the overcurrent protection function resulting from the above settings.

31. In DIGSI 5, change the current setting of the protective relay by editing the value of the **Threshold** parameter in time-current characteristic **Inverse-T1**. Observe that the time-current characteristic of the protective relay displayed in DIGSI 5 is displaced horizontally whenever the current setting is changed. Set the current setting of the protective relay back to its original value (1000 A).

In DIGSI 5, change the time settings of the protective relay by editing the value of the **Time dial** parameter in time-current characteristic **Inverse-T1**. Observe that the time-current characteristic of the protective relay displayed in DIGSI 5 is displaced vertically whenever the time setting is changed. Set the time setting of the protective relay back to its original value (1.50).

In DIGSI 5, select a different time-current characteristic for the protective relay by changing the setting of parameter **Type of character. curve** in time-current characteristic **Inverse-T1**. Observe that the shape of the time-current characteristic of the protective relay displayed in DIGSI 5 changes whenever another type of characteristic curve is selected. Set parameter **Type of character. curve** in time-current characteristic **Inverse-T1** back to **IEC normal inverse**.

32. Load the configuration (i.e., the content of the project file currently open in DIGSI 5) to the protective relay using DIGSI 5. This is necessary because the settings of the overcurrent protection function of the protective relay have been modified.

33. In DIGSI 5, access the parameters of test sequence **Symmetrical fault**. Set the duration of step 2 to 50.0 s. Also, set the value of the balanced currents emulated by the internal relay test system during step 2 to 1.25 A. This is equivalent to balanced currents of 1250 A in the electric power circuit because 1000 A/1 A current transformers are used in this project.
34. In DIGSI 5, display the test environment for the protective relay that you are using. Start test sequence Symmetrical fault, then observe the front panel of the protective relay for the complete duration of the test sequence (60 s). The protective relay should trip after a certain time.

Use DIGSI 5 to download the latest fault record from the protective relay and display the signals contained in this fault record in SIGRA. Use the displayed signals to determine the trip time of the protective relay when the value of the emulated currents is 1250 A.

The trip time of the protective relay is about 46.3 s when the value of the emulated currents is 1250 A.

The following figure shows the signals that should be displayed in SIGRA.

35. Reset the protective relay.
36. In DIGSI 5, access the parameters of test sequence *Symmetrical fault*. Set the duration of step 2 to 30 s. Also, set the value of the balanced currents emulated by the internal relay test system during step 2 to 2.50 A. This is equivalent to balanced currents of 2500 A in the electric power circuit because 1000 A/1 A current transformers are used in this project.

37. In DIGSI 5, display the test environment for the protective relay that you are using. Start test sequence *Symmetrical fault*, then observe the front panel of the protective relay for the complete duration of the test sequence (40 s). The protective relay should trip after a certain time.

Use DIGSI 5 to download the latest fault record from the protective relay and display the signals contained in this fault record in SIGRA. Use the displayed signals to determine the trip time of the protective relay when the value of the emulated currents is 2500 A.

The trip time of the protective relay is about 11.3 s when the value of the emulated currents is 2500 A.

The following figure shows the signals that should be displayed in SIGRA.
Exercise 1 – Overcurrent Protection • Procedure

38. Reset the protective relay.

39. In DIGSI 5, access the parameters of test sequence Symmetrical fault. Set the duration of step 2 to 15 s. Also, set the value of the balanced currents emulated by the internal relay test system during step 2 to 5.00 A. This is equivalent to balanced currents of 5000 A in the electric power circuit because 1000 A/1 A current transformers are used in this project.

40. In DIGSI 5, display the test environment for the protective relay that you are using. Start test sequence Symmetrical fault, then observe the front panel of the protective relay for the complete duration of the test sequence (25 s). The protective relay should trip after a certain time.
Exercise 1 – Overcurrent Protection

Procedure

Use DIGSI 5 to download the latest fault record from the protective relay and display the signals contained in this fault record in SIGRA. Use the displayed signals to determine the trip time of the protective relay when the value of the emulated currents is 5000 A.

The trip time of the protective relay is about 6.4 s when the value of the emulated currents is 5000 A.

The following figure shows the signals that should be displayed in SIGRA.

41. Do the trip times (operating times) that you recorded in steps 34, 37, and 40 confirm that the protective relay operates as an IDMT overcurrent relay with an IEC standard inverse (SI) characteristic, a current setting of 1000 A, and a time setting (time multiplier setting) of 1.50? Explain briefly.
Refer to the equations presented in Table 1 of the discussion to calculate the operating times of the protective relay that are expected.

Yes, because the time-current characteristic of an IDMT overcurrent relay with an IEC standard inverse (SI) characteristic, a current setting of 1000 A, and a time setting (time multiplier setting) of 1.50 indicates that the relay should trip in 47.0 s, 11.4 s, and 6.4 s at values of current of 1250 A, 2500 A, and 5000 A, respectively.

42. Reset the protective relay.

Overcurrent protection of a power transformer using a numerical overcurrent relay

In this section, you will configure the numerical protective relay to implement overcurrent protection of a power transformer and backup overcurrent protection of the low-voltage side (secondary side) of the power transformer. You will then perform relay testing using the internal relay test system of the protective relay to make sure that the transformer overcurrent protection operates properly.

43. Figure 31 shows the example of a power transformer protected by a numerical overcurrent protective relay that has been presented in the last section of the discussion. In the next steps of this exercise, you will configure the protective relay that you are using to implement overcurrent protection of this power transformer and backup overcurrent protection of the low-voltage side (secondary side) of this power transformer.

![Figure 31. Overcurrent protection of a power transformer using a numerical overcurrent relay that combines the functions of ANSI devices no. 50 and no. 51DT.](image)

44. The nominal value of the line currents at the primary of the power transformer in the figure above is 38.5 A. Consequently, let us assume that current transformers with a ratio of 40 A/1 A are used to measure the line currents flowing through the transformer primary windings.
In DIGSI 5, set the ratio of the current transformers to 40 A/1 A.

Changing the ratio of the current transformers creates some inconsistencies in the project. The presence of inconsistencies in the project is indicated by stop icons in the Project tree. Do not be concerned about these icons as the inconsistencies in the project will be removed later in the exercise.

45. 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.

Turn time-current characteristic Inverse-T1 off, then turn time-current characteristics Definite-T1 and Definite-T2 on. These settings cause the overcurrent protection function of the protective relay to be a combination of time-current characteristics Definite-T1 and Definite-T2.

In the working area of DIGSI 5, check the Definite-T1 and Definite-T2 check boxes and uncheck the Inverse-T1 check box to show the time-current characteristic of the overcurrent protection function resulting from the above settings.

46. In DIGSI 5, adjust the current setting of the instantaneous overcurrent protection of the protective relay to 400 A (same value as in the next to last section of the discussion) by editing the value of the Threshold parameter in time-current characteristic Definite-T1. Make sure that the Operate delay parameter in time-current characteristic Definite-T1 is set to 0 s.

In DIGSI 5, adjust the current and time settings of the definite-time overcurrent protection of the protective relay to 190 A and 1 s (same values as in the next to last section of the discussion) by editing the values of the Threshold and Operate delay parameters, respectively, in time-current characteristic Definite-T2.

Notice that the project no longer contains inconsistencies.

Observe that time-current characteristic of the overcurrent protection function displayed in the working area of DIGSI 5 is the same as the one shown in the last section of the discussion.

The x-axis in the diagram showing the time-current characteristic of the protection function is graduated with values of current at the secondary windings of the current transformers. These values of current must be multiplied by the ratio of the current transformers (40 A/1 A in the currently-open project) to obtain values of current at the primary windings of the current transformers (i.e., values of current in the electric power circuit).

47. Load the configuration (i.e., the content of the project file currently open in DIGSI 5) to the protective relay using DIGSI 5. This is necessary because several settings of the protective relay have been modified.
48. In DIGSI 5, access the parameters of test sequence *Symmetrical fault*. Set the value of the balanced currents emulated by the internal relay test system during step 1 to 0.96 A. This is equivalent to balanced currents of 38.4 A in the electric power circuit because 40 A/1 A current transformers are used in this project.

Set the duration of step 2 to 5.0 s. Also, set the value of the balanced currents emulated by the internal relay test system during step 2 to 21.05 A. This is equivalent to balanced currents of 842 A in the electric power circuit because 40 A/1 A current transformers are used in this project. Step 2 of test sequence *Symmetrical fault* is now set to emulate the symmetrical fault at the primary of the power transformer shown in Figure 31.

49. In DIGSI 5, display the test environment for the protective relay that you are using. Start test sequence *Symmetrical fault*, then observe the front panel of the protective relay for the complete duration of the test sequence (15 s). The protective relay should trip after a certain time.

50. Use DIGSI 5 to download the latest fault record from the protective relay and display the signals contained in this fault record in SIGRA. Use these signals to describe how the protective relay responded to the symmetrical fault at the transformer primary emulated with the internal relay test system.

The instantaneous overcurrent function picked up as soon as the value of the emulated currents passed from 38.4 A to 842 A because the current setting (400 A) of the function is exceeded. This caused the protective relay to trip immediately.
Is the protective relay set to achieve proper overcurrent protection of the power transformer?

Yes, the protective relay trips immediately when a symmetrical fault occurs at the transformer primary.

The following figure shows the signals that should be displayed in SIGRA.

Signals contained in the fault record downloaded from the protective relay displayed in SIGRA.

51. Reset the protective relay.

52. In DIGSI 5, access the parameters of test sequence Symmetrical fault.

Set the value of the balanced currents emulated by the internal relay test system during step 2 to 8.33 A. This is equivalent to balanced currents of 333 A in the electric power circuit because 40 A/1 A current transformers...
Exercise 1 – Overcurrent Protection • Procedure

are used in this project. Step 2 of test sequence Symmetrical fault is now set to emulate the symmetrical fault at the secondary of the power transformer shown in Figure 31.

53. In DIGSI 5, display the test environment for the protective relay that you are using. Start test sequence Symmetrical fault, then observe the front panel of the protective relay for the complete duration of the test sequence (15 s). The protective relay should trip after a certain time.

54. Use DIGSI 5 to download the latest fault record from the protective relay and display the signals contained in this fault record in SIGRA. Use these signals to describe how the protective relay responded to the symmetrical fault at the transformer secondary emulated with the internal relay test system.

The definite-time overcurrent function picked up as soon as the value of the emulated currents passed from 38.4 A to 333 A because the current setting (190 A) of the function is exceeded. After a delay of 1 s, the protective relay tripped because the value of the emulated currents still exceeded the current setting of the definite-time overcurrent function. On the other hand, the instantaneous overcurrent protection did not pick up because the value of the emulated currents never exceeded the current setting (400 A) of the function.
Is the protective relay set to achieve proper backup overcurrent protection of the low-voltage side (secondary) of the power transformer?

Yes, the protective relay trips after a certain time delay (1 s in the present case) when a symmetrical fault occurs at the low voltage side (secondary) of the power transformer. The time delay is intended to provide enough time for any protection at the transformer secondary to act before the backup overcurrent protection of the low-voltage side of the power transformer trips.

The following figure shows the signals that should be displayed in SIGRA.

```
55. Reset the protective relay.

56. In DIGSI 5, restart the protective relay in the process mode to allow normal operation of the unit. Once the restart process is completed, the display of
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In this exercise, you saw that fuses or low-voltage circuit breakers (MCBs or MCCBs) can be used to implement overcurrent and overload protection of power lines, power transformers, and AC motors. You became familiar with the operation and settings of the instantaneous (ANSI device no. 50), definite-time (ANSI device no. 51DT), and inverse definite minimum time (ANSI device no. 51I) overcurrent relays. You learned how to adjust the settings of an overcurrent relay to obtain a specific time-current characteristic. You saw applications where it is common to use overcurrent relays and high-voltage circuit breakers in conjunction to achieve overcurrent protection of electrical equipment. You learned how to use the internal relay test system of a numerical protective relay to assess that the relay operates as expected.

1. Describe the objective of overcurrent protection and the objective of overload protection.

   The objective of overcurrent protection is to prevent the flow of excessive current in an electric power circuit (i.e., current whose value greatly exceeds the nominal full-load current of the circuit) from damaging the circuit or from initiating fire in the circuit that could lead to more serious damage and even endanger people's lives. On the other hand, the objective of overload protection is to prevent damage to a component in an electric power circuit when this component is subjected to prolonged overload (i.e., to the flow of a current whose value exceeds the nominal full-load current of the component to a moderate extent).

2. Briefly explain what protective relay testing is.

   In short, protective relay testing consists of conducting the tests necessary to assess that the protective relay operates properly under certain specific faults and/or abnormal operating conditions.
3. Briefly describe how the settings of an IDMT overcurrent relay affects its
time-current characteristic.

The type-of-characteristic parameter determines the shape of the
time-current characteristic of the IDMT overcurrent relay. The current setting
allows the time-current characteristic to be moved right or left (i.e., to
increase or decrease the current threshold of the relay). The time setting
(i.e., the time dial setting or the time multiplier setting) allows the time-current
characteristic to be moved up or down (i.e., to increase or decrease the
operating times of the relay).

4. Name applications where it is common to use overcurrent relays in
conjunction with HV circuit breakers to protect electrical equipment.

It is common to use overcurrent relays in conjunction with HV circuit breakers
to implement overcurrent protection of an important or valuable power line in
distribution networks and industrial applications. Similarly, it is common to
use an overcurrent protective relay in conjunction with an HV circuit breaker
to implement overcurrent and overload protection of an important or valuable
power transformer or ac motor.

5. Briefly describe how a single numerical overcurrent relay that combines the
functions of ANSI devices no. 50 and no. 51DT can be used to provide both
main overcurrent protection of a power transformer and backup overcurrent
protection of the low-voltage side of the power transformer.

The instantaneous overcurrent function (ANSI devices no. 50 function)
provides main overcurrent protection of the power transformer. Its current
setting is set to a value that makes the main overcurrent protection sensitive
enough to faults at the transformer primary and insensitive to faults at the
transformer secondary. The definite-time overcurrent function (ANSI devices
no. 51DT function) provides backup overcurrent protection of the low-voltage
side of the power transformer. Its current setting is set to a value that makes
the backup overcurrent protection sensitive enough to faults at the
transformer secondary and insensitive to the nominal value of the
transformer primary current. Its time setting is adjusted to the lowest value
that allows sufficient time for the protection at the power transformer
secondary to operate when a fault occurs at the transformer secondary.


