Electricity and New Energy

Introduction to Electric Power Substations

Courseware Sample

20528-F0

Order no.: 20528-10
First Edition
Revision level: 04/2015

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Printed in Canada

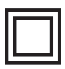
ISBN 978-2-89747-132-3 (Printed version)
ISBN 978-2-89747-133-0 (CD-ROM)
Legal Deposit – Bibliothèque et Archives nationales du Québec, 2015
Legal Deposit – Library and Archives Canada, 2015

Safety and Common Symbols

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

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
⎓	Direct current
∼	Alternating current
≂	Both direct and alternating current
3∼	Three-phase alternating current
⏚	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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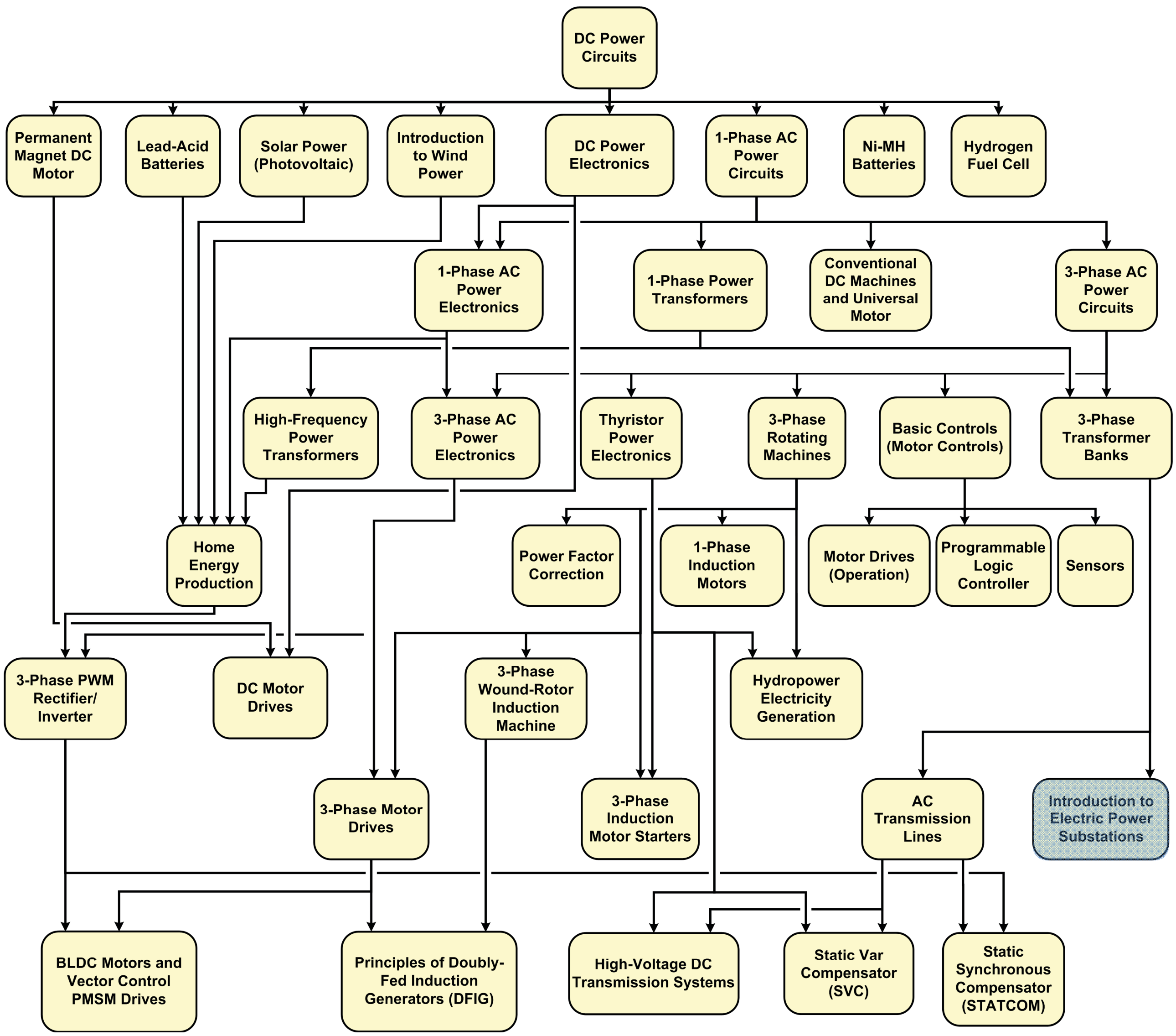
Preface

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 know what an electric power substation is. You will be able to describe the functions and operation of the high-voltage disconnecting switches and circuit breakers used in electric power substations. You will be familiar with two common switching schemes used in electric power substations: the single bus scheme and the double bus, single breaker scheme. You will know the advantages and disadvantages of each of these two schemes, and how they compare in terms of reliability, operating flexibility, and maintenance problems. You will know the most important factors to be considered when designing an electric power substation. You will have learned the fundamentals of electric power system protection.

By completing this manual, you will also know what protective grounding is and why it is mandatory during maintenance operations, why interlocking is required between circuit breakers and disconnecting switches in electric power substations, why interlocking of incoming line circuit breakers is required in electric power substations, and the procedure to be followed when performing an on-load transfer.

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.

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 the 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.

Equipment installation

In order for students to be able to perform the exercises in the Student Manual, the Electric Power Technology Training Equipment must have been properly installed, according to the instructions given in the user guide Electric Power Technology Training Equipment, part number 38486-E.

Sample Exercise

Extracted from

the Student Manual

and the Instructor Guide

Single Bus Scheme

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with electric power substations using the single bus scheme with bus section circuit breakers. You will be introduced to the use of protective grounding when performing maintenance work in an electric power substation. You will know why interlocking is required between circuit breakers and disconnecting switches in electric power substations. You will also know why interlocking of incoming line circuit breakers is required in electric power substations.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- The single bus scheme
- The single bus scheme with bus section circuit breakers
- Reliability of substations using the single bus scheme with bus section circuit breakers
  Outgoing line fault. Incoming line fault. Bus fault. Outgoing line circuit-breaker fault. Incoming line circuit-breaker fault. Bus-section circuit-breaker fault. Reliability.
- Operating flexibility and maintenance of substations using the single bus scheme (with or without bus section circuit breakers)
- Protective grounding
- Summary of the advantages and disadvantages of the single bus scheme (with or without bus section circuit breakers)
- Interlocking a circuit breaker and the corresponding disconnecting switches in an electric power substation
- Interlocking incoming line circuit breakers in an electric power substation

DISCUSSION

The single bus scheme

Figure 25 shows a single-line diagram of an electric power substation using the single bus scheme. The single bus scheme is the most simple and economical way of arranging buses and switchgear in an electric power substation. With this scheme, all power lines reaching the substation are connected to the same bus, with each line being permanently connected to the bus through a circuit breaker and two disconnecting switches connected in series. Opening the two disconnecting switches in a line isolates the corresponding circuit breaker from the rest of the substation. This allows maintenance of the circuit breaker without affecting the rest of the substation.

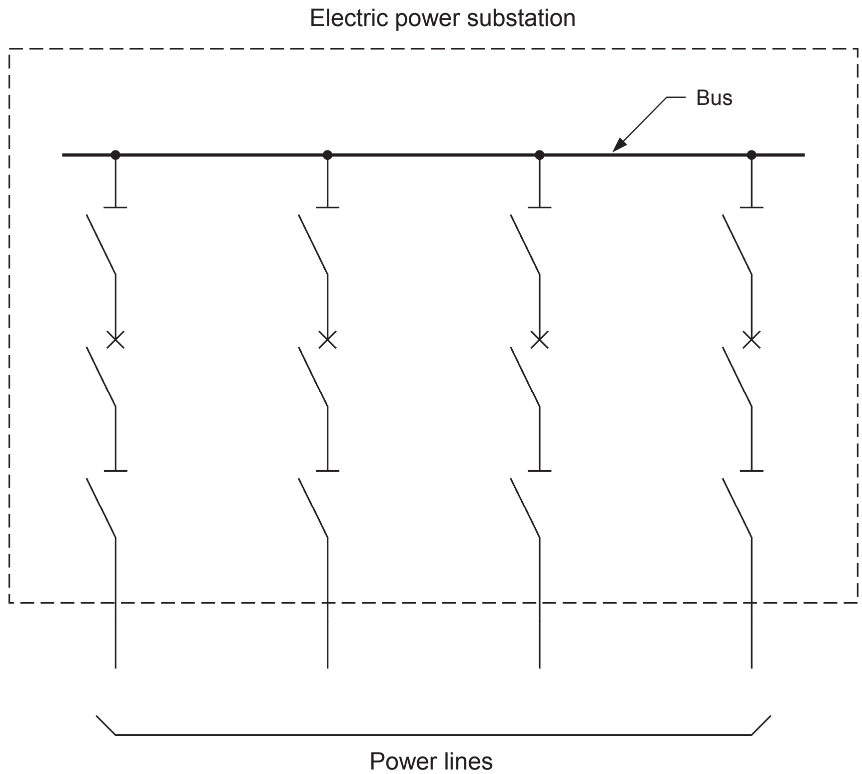


Figure 25. Single-line diagram of an electric power substation implemented using the single bus scheme.

The single bus scheme with bus section circuit breakers

The single bus scheme has an obvious weakness: any fault on the bus results in an outage of the entire electric power substation, i.e., power can no longer be routed to loads via the substation until the bus is repaired. To alleviate this drawback, it is common to provide the bus in a substation implemented using the single bus scheme with one or several **bus section circuit breaker**(s). Figure 26 shows the single-line diagram of an electric power substation in which the single bus can be separated into two sections using a bus section circuit breaker. The bus section circuit breaker is generally closed during normal operation. When a fault occurs on the bus, the bus section circuit breaker is opened to separate the bus into two sections. This allows the faulty bus section to be isolated, thereby limiting the number of loads that lose power. Ideally, the loads and ac power sources must be distributed evenly on the bus sections to ensure that the number of loads that lose power following a fault on a particular section of the bus is limited to minimum.

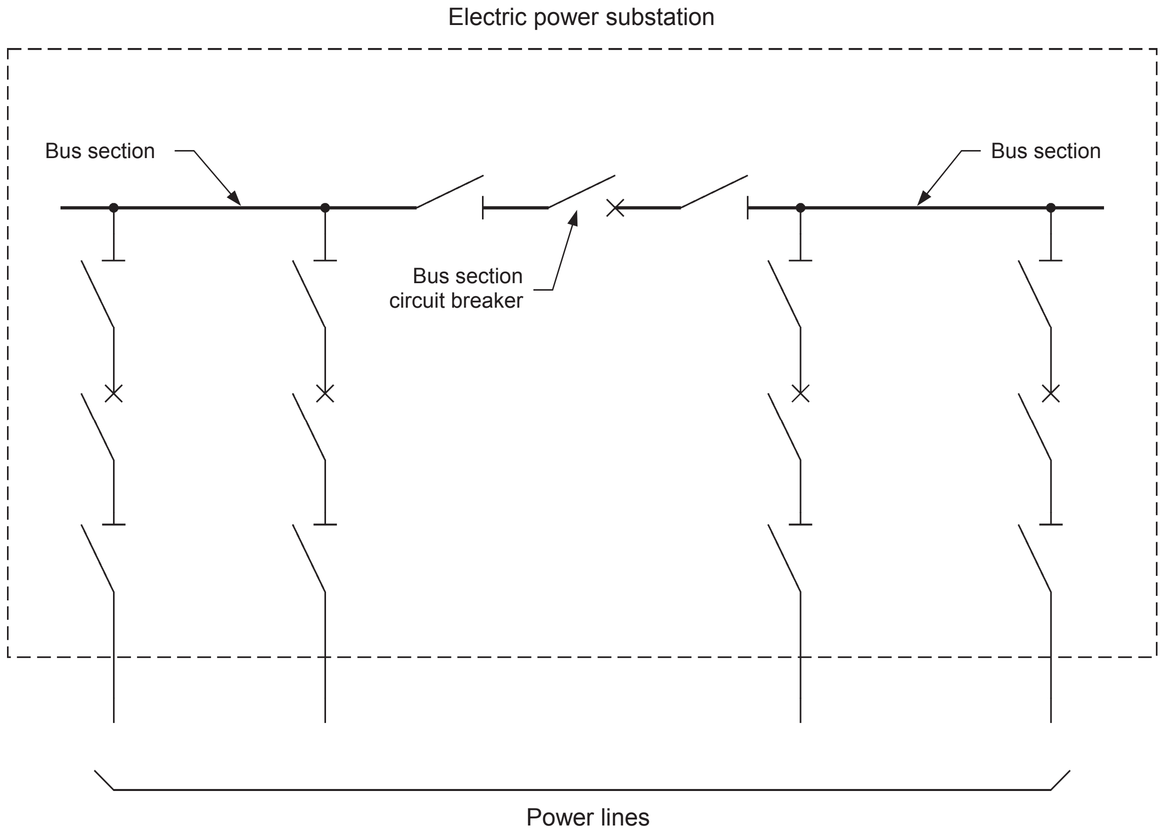


Figure 26. Single-line diagram of an electric power substation implemented using the single bus scheme with bus section circuit breakers.

Reliability of substations using the single bus scheme with bus section circuit breakers

This section of the discussion deals with the reliability of an electric power substation using the single bus scheme with bus section circuit breakers. The section starts with a series of subsections, each one describing how a fault at a particular location in the electric power substation affects the supply of power to loads. The section then concludes on the reliability of electric power substations using the single bus scheme with bus section circuit breakers.

Outgoing line fault

An **outgoing line** fault is a fault on a line where power exits the substation (see fault F1 in Figure 27). Opening the corresponding **line circuit breaker** isolates the faulty outgoing line and interrupts the fault current. Obviously, power is lost at the loads fed by this outgoing line. On the other hand, power is maintained in the rest of the substation. For instance, when outgoing line fault F1 occurs in Figure 27, opening line circuit breaker CB1 isolates the faulty outgoing line (outgoing line A) and power is lost at load 1. Power is maintained at load 2.

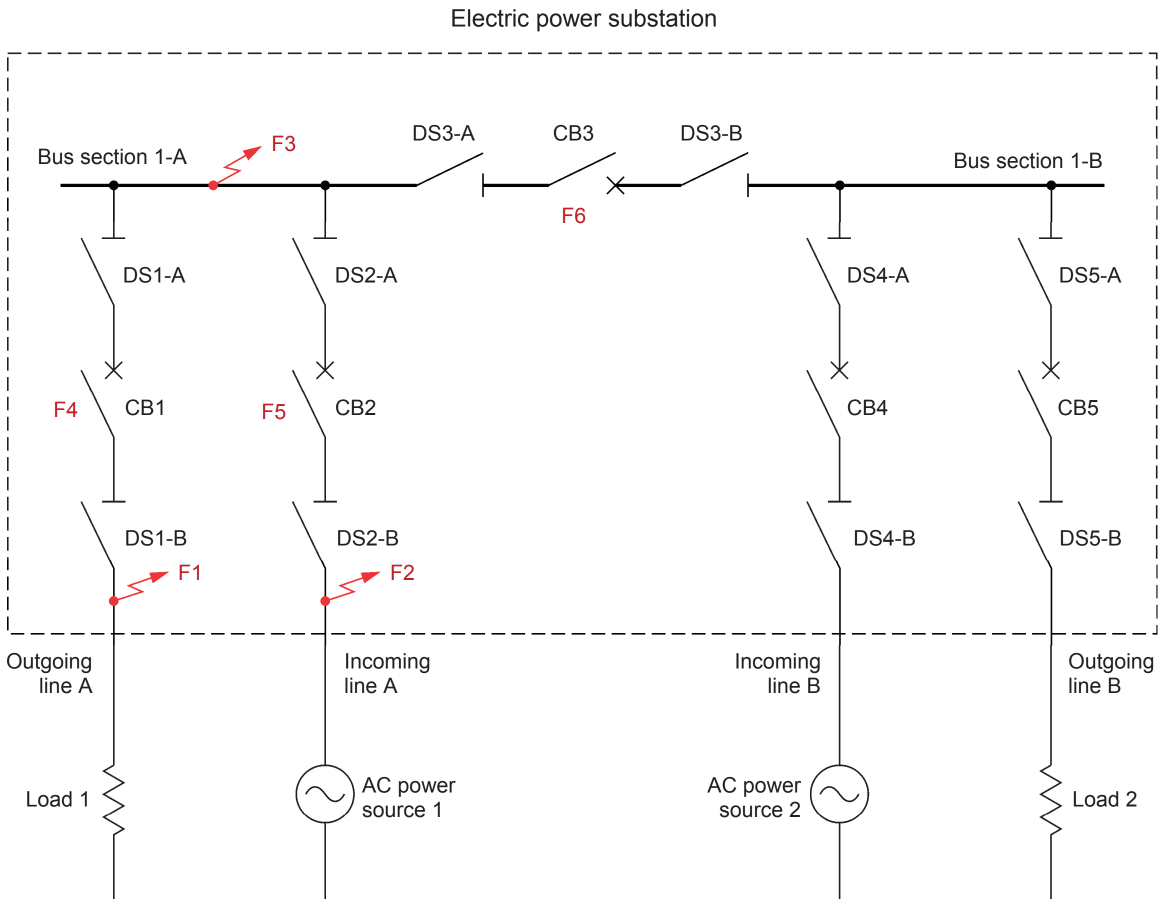


Figure 27. Faults at various locations in a substation implemented using the single bus scheme with bus section circuit breakers.

Incoming line fault

An **incoming line** fault is a fault on a line where power enters the substation (see fault F2 in Figure 27). Such a fault causes protection located outside the substation to open a circuit breaker that disconnects the ac power source from the faulty incoming line. This prevents the ac power source from feeding the fault. In the substation, the line circuit breaker associated with the faulty incoming line is also opened to isolate this line, and thereby prevent an ac power source connected to another incoming line (if any) from feeding the fault. When no other ac power source feeds the substation via another incoming line, power is lost at all loads fed by the outgoing lines of the substation. On the other hand, when a second ac power source feeds the substation via another incoming line, power is maintained at the loads fed by the outgoing lines of the substation.

For instance, when incoming line fault F2 occurs in Figure 27, protection located outside the substation opens a circuit breaker (not shown in Figure 27) that disconnects ac power source 1 from the faulty incoming line (incoming line A), thereby preventing this source from feeding the fault. Then, opening line circuit breaker CB2 isolates the faulty incoming line (incoming line A) and prevents ac power source 2 connected to incoming line B from feeding the fault. Power is maintained at loads 1 and 2 by ac power source 2 via incoming line B, bus sections 1-A and 1-B, and outgoing lines A and B.

Bus fault

A bus fault is a fault on any section of the bus (see fault F3 in Figure 27). The faulty section of the bus is isolated, and the fault current is interrupted, by opening all circuit breakers providing access to this section of the bus. Power is lost at the loads fed by any outgoing line connected to the faulty bus section. Also, power from any incoming line connected to the faulty bus section is no longer available (i.e., it cannot be routed to loads via the substation). Finally, power is maintained at the loads fed by outgoing lines connected to the other bus sections, provided that at least one incoming line feeds these bus sections.

For instance, when bus fault F3 occurs in Figure 27, opening circuit breakers CB1, CB2, and CB3 isolates the faulty bus section (bus section 1-A) and interrupts the fault current. Power is lost at load 1 since ac power source 1 and ac power source 2 can no longer supply this load. However, power is maintained at load 2 by ac power source 2 via incoming line B, bus section 1-B, and outgoing line B.

Outgoing line circuit-breaker fault

An outgoing line circuit-breaker fault occurs when a line circuit breaker fails to open following a fault on the outgoing line that it protects (see faults F1 and F4 in Figure 27). In this case, opening all circuit breakers providing access to the bus section affected by the faulty outgoing line circuit breaker isolates this bus section (consequently isolating the faulty line circuit breaker) and interrupts the fault current. Obviously, power is lost at the loads fed by the faulty outgoing line. Power is lost at the loads fed by any other outgoing line connected to the bus section affected by the faulty outgoing line circuit breaker. Also, power from any incoming line connected to the bus section affected by the faulty outgoing line circuit breaker is no longer available (i.e., it cannot be routed to loads via the substation). Finally, power is maintained at the loads fed by outgoing lines connected to the other bus sections, provided that at least one incoming line feeds these bus sections. Once the faulty outgoing line circuit breaker has been isolated by opening the proper disconnecting switches, the open circuit breakers can be reclosed to reconnect the corresponding bus section and lines to the rest of the substation. In certain cases, this allows power to be restored to some loads immediately.

For instance, when outgoing line circuit-breaker fault F4 occurs following outgoing line fault F1 in Figure 27, opening incoming line circuit breaker CB2 and bus section circuit breaker CB3 isolates the bus section (bus section 1-A) affected by the faulty outgoing line circuit breaker (CB1) and interrupts the fault current. Power is lost at load 1 and power from ac power source 1 is no longer available to supply loads. However, power is maintained at load 2 by ac power source 2 via incoming line B, bus section 1-B, and outgoing line B. Once outgoing line circuit breaker CB1 has been isolated by opening disconnecting switches DS1-A and DS1-B, incoming line circuit breaker CB2 and bus section circuit breaker CB3 can be reclosed to reconnect ac power source 1 to the rest of the electric power substation.

Incoming line circuit-breaker fault

An incoming line circuit-breaker fault occurs when a line circuit breaker fails to open following a fault on the incoming line that it protects (see faults F2 and F5 in Figure 27). In this case, opening all circuit breakers providing access to the bus section affected by the faulty incoming line circuit breaker isolates this bus section (consequently isolating the faulty line circuit breaker) and interrupts any fault current. Obviously, power from the faulty incoming line is no longer available (i.e., it cannot be routed to loads via the substation). Power is lost at the loads fed by any outgoing line connected to the bus section affected by the faulty incoming line circuit breaker. Also, power from any other incoming line connected to the bus section affected by the faulty incoming line circuit breaker is no longer available. Finally, power is maintained at the loads fed by outgoing lines connected to the other bus sections, provided that at least one incoming line feeds these bus sections. Once the faulty incoming line circuit breaker has been isolated by opening the proper disconnecting switches, the open circuit breakers can be reclosed to reconnect the corresponding bus section and lines to the rest of the substation. When a second ac power source feeds the substation via another incoming line, this allows power to be restored to loads immediately. Otherwise, power is lost at all loads fed by the outgoing lines of the substation.

For instance, when incoming line circuit-breaker fault F5 occurs following incoming line fault F2 in Figure 27, opening outgoing line circuit breaker CB1 and bus section circuit breaker CB3 isolates the bus section (bus section 1-A) affected by the faulty incoming line circuit breaker (CB2) and interrupts the fault current. Power is lost at load 1 and power from ac power source 1 is no longer available to supply loads. However, power is maintained at load 2 by ac power source 2 via incoming line B, bus section 1-B, and outgoing line B. Once incoming line circuit breaker CB2 has been isolated by opening disconnecting switches DS2-A and DS2-B, outgoing line circuit breaker CB1 and bus section circuit breaker CB3 can be reclosed to restore power at load 1 immediately.

Bus-section circuit-breaker fault

A bus-section circuit-breaker fault occurs when a bus section circuit breaker fails to open, following a fault on either of the two bus sections interconnected by this circuit breaker (see faults F3 and F6 in Figure 27). The faulty bus section circuit breaker is isolated, and the fault current is interrupted, by opening all circuit breakers providing access to the two bus sections interconnected by this circuit breaker. Power is lost at the loads fed by any outgoing lines connected to these two bus sections. Also, power from any incoming line connected to these two bus sections is no longer available (i.e., it cannot be routed to loads via the substation). Finally, power is maintained at the loads fed by outgoing lines connected to the other bus sections (if any), provided that at least one incoming line feeds these bus sections. Once the faulty bus section circuit breaker has been isolated by opening the proper disconnecting switches, some of the open circuit breakers can be reclosed to reconnect incoming and/or outgoing lines to the healthy bus section. This generally allows power to be restored to some loads immediately. An electric power substation operating in this situation is said to be split, i.e., the substation operates like two independent substations using the single bus scheme.

For instance, when bus-section circuit-breaker fault F6 occurs following bus fault F3 in Figure 27, opening line circuit breakers CB1, CB2, CB4, and CB5 isolates the faulty bus section circuit breaker (circuit breaker CB3) and interrupts the fault current. Power is lost at loads 1 and 2. Also, power from ac power sources 1 and 2 is no longer available to supply loads. Once bus section circuit breaker CB3 has been isolated by opening disconnecting switches DS3-A and DS3-B, line circuit breakers CB4 and CB5 can be reclosed to reconnect incoming line B and outgoing line B to the healthy bus section (bus section 1-B). This restores power at load 2 immediately.

Reliability

The effect of each of the aforementioned faults on the continuity of the supply of power is summarized in Table 3.

Table 3. Effect of various types of fault on the continuity of the supply of power.

Fault description	Effect of fault
– Outgoing line fault – Outgoing line circuit-breaker fault	Results in an interruption in the supply of power to the loads fed by the faulty outgoing line. The interruption in the supply of power lasts until the faulty equipment is repaired.
– Incoming line fault – Incoming line circuit-breaker fault	Results in an interruption in the supply of power to all loads fed by the outgoing lines of the substation when there is no other incoming line or when no ac power is available at another incoming line of the substation. The interruption in the supply of power lasts until the faulty equipment is repaired.
– Bus fault	Results in an interruption in the supply of power to the loads fed by any outgoing line connected to the faulty bus section. The interruption in the supply of power lasts until the faulty bus section is repaired.
– Bus-section circuit-breaker fault	Results in an interruption in the supply of power to the loads fed by any outgoing line connected to the two bus sections affected by the faulty bus section circuit breaker. The interruption in the supply of power to the loads fed by any outgoing line connected to the faulty bus section lasts until this bus section and the faulty bus section circuit breaker are repaired. Fortunately, however, the interruption in the supply of power to the loads fed by any outgoing line connected to the healthy bus section is likely to be of short duration. This is because power can generally be restored to these loads by reclosing some of the open circuit breakers.

In brief, an outgoing line fault or an outgoing line circuit-breaker fault in an electric power substation using the single bus scheme with bus section circuit breakers always causes an interruption in the supply of power to some loads that lasts until the faulty equipment is repaired. Similarly, a bus fault or a bus section circuit-breaker fault causes an interruption in the supply of power to some loads that lasts until the faulty equipment is repaired, when outgoing lines are connected to the faulty bus section. Finally, when there is no other incoming line or when no ac power is available at another incoming line of the substation, an incoming line fault or an incoming line circuit-breaker fault causes an interruption in the supply of power to all loads that lasts until the equipment is repaired. This demonstrates that electric power substations using the single bus scheme with bus section circuit breakers have a low reliability resulting in poor service continuity. Because of this, the use of the single bus scheme with bus section circuit breakers is often limited to substations supplying power to loads that can also be fed through other substations. This is generally the case for intermediate substations in a **meshed power network**, but not for substations that perform final distribution of electric power to consumers. For instance, an outgoing line fault in a substation performing final power distribution automatically results in an interruption in the supply of power to some loads that lasts until the faulty line is repaired.

The single bus scheme with bus section circuit breakers, despite its low reliability, is well suited to interconnect generator-transformer units to outgoing lines in large power generation stations (see single line diagram in Figure 28). This is because a fault on any bus section or outgoing line does not prevent the generation station from supplying power to the network via the remaining healthy bus sections and outgoing lines, thereby ensuring the continuity of service.

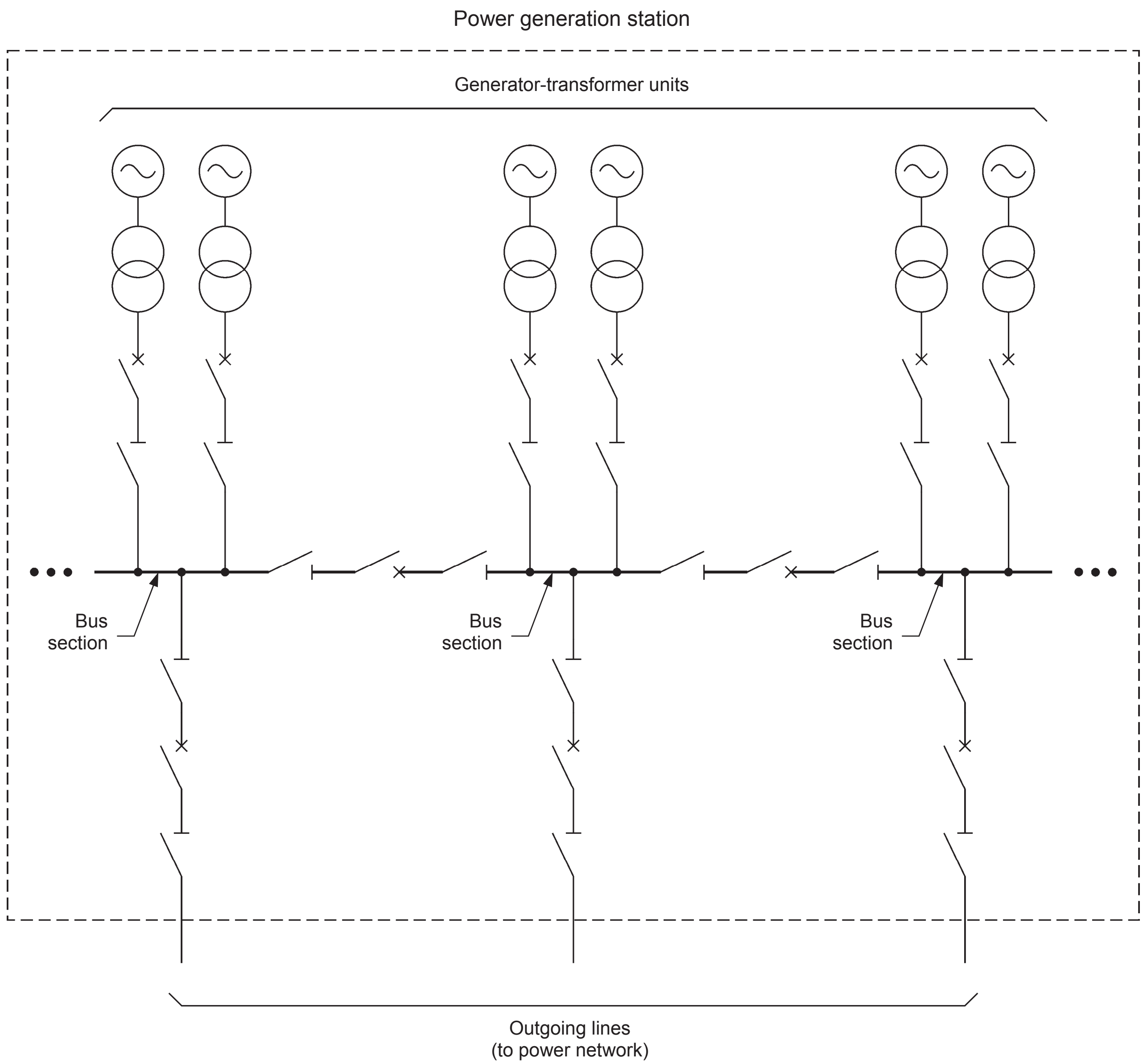


Figure 28. Single-line diagram of a large power generation station using the single bus scheme with bus section circuit breakers to interconnect generator-transformer units to the outgoing lines.

Operating flexibility and maintenance of substations using the single bus scheme (with or without bus section circuit breakers)

In an electric power substation using the single bus scheme, with or without bus section circuit breakers, each line is permanently connected to the single bus, or to a bus section, through a circuit breaker and two disconnecting switches. Consequently, the operating flexibility of the single bus scheme is very limited since there is no alternate path available to route power to loads.

Maintenance in an electric power substation using the single bus scheme, with or without bus section circuit breakers, is problematic since it can rarely be performed without interrupting the supply of power to some or all of the loads connected to the substation. For instance, maintenance of any line circuit breaker or **line disconnecting switch** causes the corresponding line to be lost for a while. In the case of an outgoing line circuit breaker or disconnecting switch, this automatically results in an interruption in the supply of power to the loads fed by this line. Similarly, maintenance of any bus section or any disconnecting switch connected to a bus section causes all lines connected to this bus section to be lost and forces an interruption in the supply of power to the loads fed by any outgoing lines connected to this bus section. Finally, maintenance of the bus or any disconnecting switch connected to the bus in a substation using the single bus scheme without bus section circuit breakers requires shutdown of the entire substation, and thus, an interruption in the supply of power to all loads connected to the outgoing lines of the substation. In all these cases, any interruption in the supply of power lasts for the entire duration of maintenance. Note that in a meshed power network, any interruption in the supply of power to loads caused by maintenance in an electric power substation can be avoided when electric power can be routed to these loads via other substations in the network.

Protective grounding

Strict working practices must be observed when performing any maintenance work in an electric power substation to ensure the safety of the personnel. To begin, the equipment requiring maintenance (e.g., an incoming or outgoing line, a bus section, etc.) must be de-energized. This is generally achieved by opening circuit breakers and disconnecting switches. Then, voltage measurements must be carried out to ensure that the equipment requiring maintenance is effectively de-energized. Furthermore, the parts of the equipment requiring maintenance that are normally under high voltage must be connected to ground during the complete duration of the maintenance work. This is commonly referred to as **protective grounding**. Protective grounding ensures that absolutely no voltage can appear across the equipment during maintenance due to, for instance, inadvertent closure of a circuit breaker in the substation or to voltage induction produced by an adjacent circuit in the substation that is still in operation.

To assist in achieving proper protective grounding, a **grounding switch** can be added to the switchgear associated with a line in an electric power substation as shown in Figure 29. A grounding switch is simply a disconnecting switch with one contact bonded to ground. Therefore, when the grounding switch closes, the line is connected to ground.

Some interlocking is generally provided in the electric power substation to ensure that the grounding switch cannot be closed when the line disconnecting switch is closed. This prevents the grounding switch from making a ground fault in the substation.

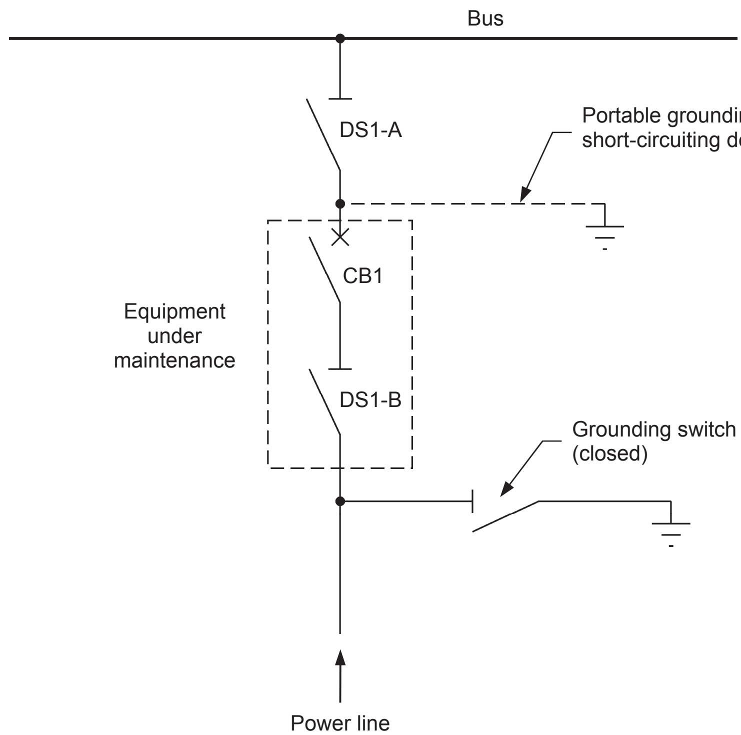


Figure 29. Grounding switch and portable grounding and short-circuiting device used to achieve protective grounding in an electric power substation.

For instance, when maintenance is required on the switchgear associated with a line, the line circuit breaker and disconnecting switches are first opened. Then, after making absolutely sure that the line is de-energized (through voltage measurement), the grounding switch is closed to connect one end of the line switchgear to ground, thereby ensuring that it cannot be inadvertently energized by the power line reaching the substation. This, however, does not prevent power coming from the substation bus from being applied to the line switchgear. To eliminate this possibility, a **portable grounding and short-circuiting device** (shown by the dotted line in Figure 29) is installed at the other end of the line switchgear that is under maintenance. Such a device is basically an arrangement of wires provided with connecting components specifically designed to facilitate the connection of these wires to a grounding point of the substation and high-voltage parts (e.g., the aluminum tubes of a three-phase bus) of the substation equipment (see Figure 30). Connecting the portable grounding and short-circuiting device at the location shown in Figure 29 ensures that the circuit breaker and line-side disconnecting switch (DS1-B) remain de-energized throughout the maintenance work. When the bus-side disconnecting switch (DS1-A) of the line also requires maintenance, the bus must be de-energized and the portable grounding and short-circuiting device must be connected to the bus.

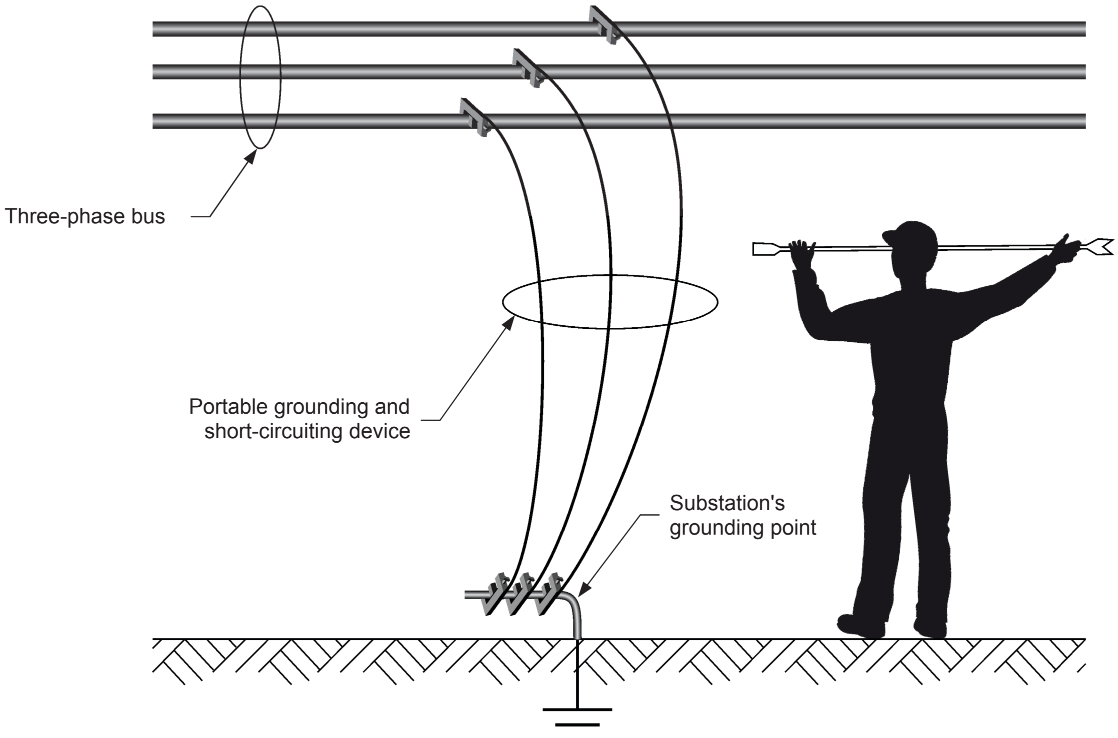


Figure 30. A portable grounding and short-circuiting device installed on a bus in an electric power substation.

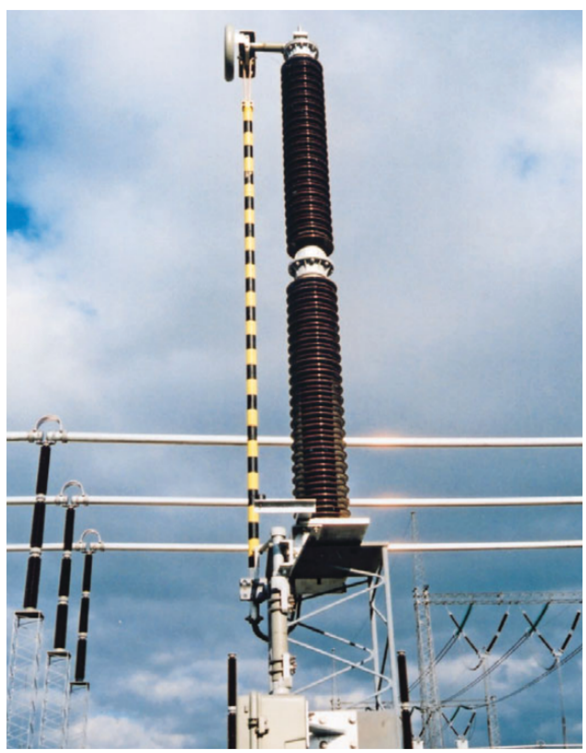


Figure 31. A grounding switch in the closed state. The black and yellow arm of the switch is bonded to ground (© Siemens AG 2014, all rights reserved).

Summary of the advantages and disadvantages of the single bus scheme (with or without bus section circuit breakers)

The single bus scheme (with or without bus section circuit breakers) is a low cost alternative that is easy to operate due to its simplicity. Also, protection arrangement in a substation using the single bus scheme is relatively simple. Finally, substation expansion (e.g., addition of a line to the existing bus or addition of a bus section and lines) is generally easy, especially when extra disconnecting switches have been installed on the bus from the outset. However, the single bus scheme has a low reliability which is likely to result in a poor continuity of service. Also, the operating flexibility of the single bus scheme is very limited since there is no alternate path available to route power to loads. Finally, maintenance of the bus or any section of the bus, maintenance of a disconnecting switch connected to the bus or a bus section, maintenance of an outgoing line circuit breaker, or maintenance of an outgoing line disconnecting switch cannot be performed without interrupting power to loads fed via this bus, bus section or outgoing line. Table 4 summarizes the main advantages and disadvantages of the single bus scheme (with or without bus section circuit breakers).

Table 4. Main advantages and disadvantages of the single bus scheme (with or without bus section circuit breakers).

Advantages	Disadvantages
– Low cost – Simple – Easy to operate – Protection arrangement is relatively simple – Easy to expand	– Low reliability – Limited operating flexibility – Maintenance of the bus, a bus section, or a disconnecting switch connected to the bus (or a bus section) interrupts supply of power to corresponding loads – Maintenance of any outgoing line circuit breaker or disconnecting switch interrupts supply of power to corresponding loads

Interlocking a circuit breaker and the corresponding disconnecting switches in an electric power substation

A disconnecting switch is not designed to make or break any significant load current in a circuit, as mentioned in Exercise 1. For instance, closing disconnecting switch DS1-A in the electric power substation shown in Figure 32 makes current flow in the load connected to outgoing line A. Of course, such an operation should be avoided since it is likely to damage disconnecting switch DS1-A. In the case damage effectively occurs, the bus or bus section to which disconnecting switch DS1-A is connected has to be put out of service during repair or replacement of this disconnecting switch, thereby resulting in an interruption in the supply of power to some loads.

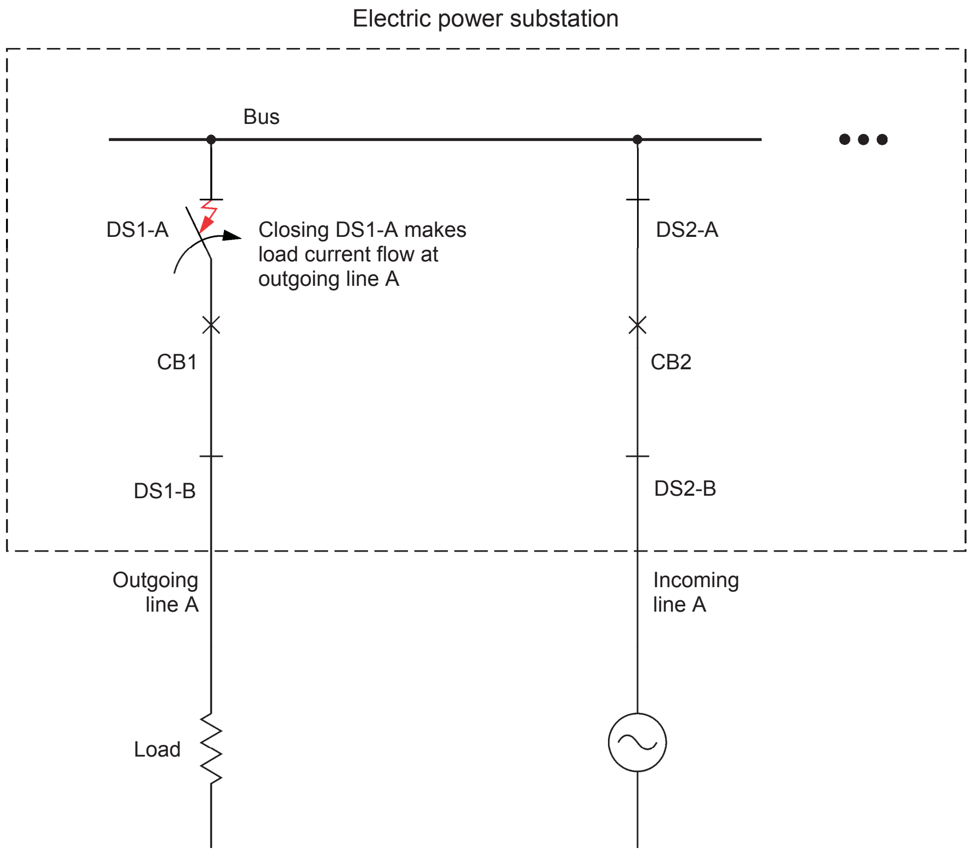


Figure 32. Closing a disconnecting switch while the corresponding circuit breaker is closed should be avoided.

The above example demonstrates that some **interlocking** is required between each circuit breaker and the corresponding disconnecting switches to prevent errors in the operation of the switchgear in an electric power substation from causing damage to the disconnecting switches and a long interruption in the supply of power to some loads. To be effective, interlocking simply has to prevent the disconnecting switches connected in series with a circuit breaker from being opened or closed when the circuit breaker is closed. Interlocking can be mechanical or electrical (logical).

Mechanical interlocking is generally based on a system of trapped keys. In such a system, a key is required to open or close a disconnecting switch. This key is trapped and can only be obtained when the circuit breaker that is connected in series with the disconnecting switch is open. This makes it impossible to operate the disconnecting switch when the circuit breaker is closed.

Electrical interlocking relies on electrical signals and is generally implemented in a programmable logic controller (PLC) programmed to control switchgear operation in an automated electric power substation. This dedicated PLC is often referred to as a bay control unit. In brief, the auxiliary contacts indicating the state of each disconnecting switch and circuit breaker in the substation are all routed to binary inputs of the PLC. The PLC uses this information to prevent any disconnecting switch from opening or closing when the circuit breaker that is connected in series with this disconnecting switch is closed.

Interlocking incoming line circuit breakers in an electric power substation

When connecting an incoming line to a bus in an electric power substation that is already fed by another incoming line or several other incoming lines, synchronism between the bus voltage and the voltage of the ac power source at the incoming line to be connected must be checked before closing the corresponding incoming line circuit breaker. Closure of this circuit breaker is allowed only when both voltages are within tight synchronizing limits to prevent excessive currents at synchronization (i.e., at the circuit breaker closure) that could trip overcurrent protections and open circuit breakers. Checking synchronism before allowing closure of an incoming line circuit breaker is another form of interlocking that prevents errors in the operation of the switchgear in an electric power substation that could affect the supply of power to loads.

Checking the synchronism of ac power sources before allowing closure of an incoming line circuit breaker is generally performed using a **synchro-check relay** connected as shown in Figure 33. Initially, incoming line A is connected to the substation bus since line circuit breaker CB1 and disconnecting switches DS1-A and DS1-B are closed. The synchro-check relay senses the bus voltage, i.e., the voltage of ac power source 1 connected to incoming line A, and the voltage of ac power source 2 connected to incoming line B via two **voltage transformers**. Voltage transformers are required to lower the sensed voltages to levels (generally around 100 V) suitable for the voltage inputs of the synchro-check relay. The synchro-check relay analyzes these two voltages and allows closure of line circuit breaker CB2 only when they are within tight synchronization limits, thereby ensuring that the connection of incoming line B does not disturb the operation of the substation.

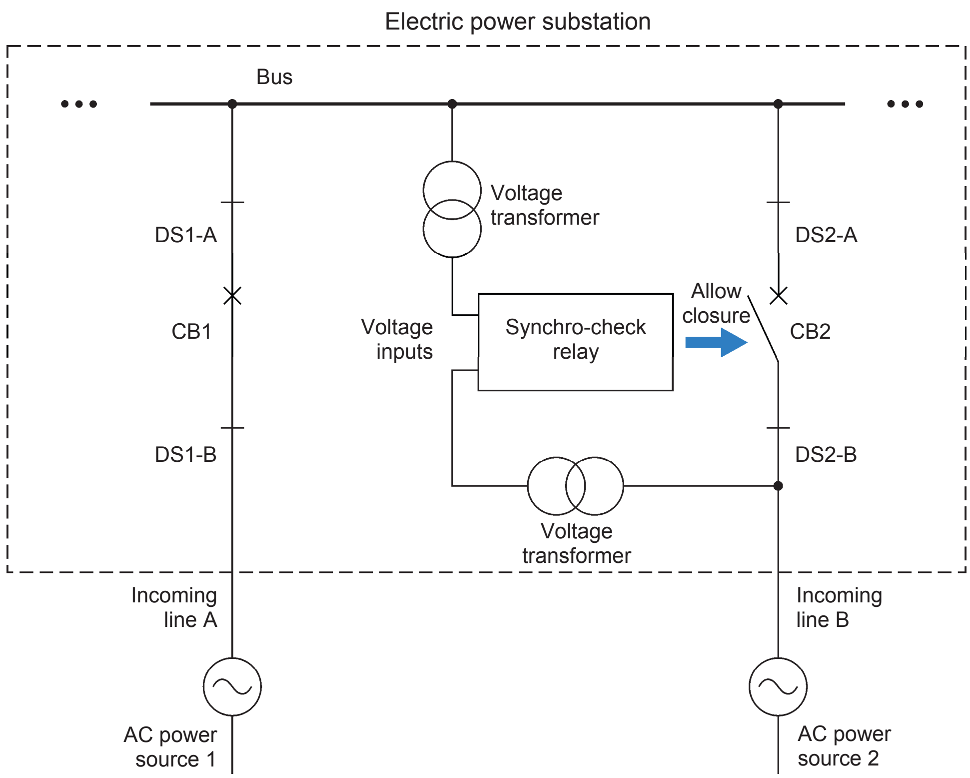


Figure 33. A synchro-check relay is used to check the synchronism of ac power sources before allowing closure of an incoming line circuit breaker.

Note that each incoming line in an electric power substation is normally provided with a synchro-check relay and voltage transformers connected as shown in Figure 33 to check the synchronism of the ac power sources before allowing closure of the corresponding line circuit breaker. Also note that when a first incoming line has to be connected to a substation bus, i.e., when the substation bus has not yet been powered (this is referred to as a dead bus condition), the synchro-check relay automatically allows the corresponding line circuit breaker to close since this causes no problems.

Figure 34. Gas-insulated 400 kV high-voltage switchgear at a substation in Abu Dhabi, in the United Arab Emirates. This substation contains 24 switchgear bays at 400 kV and 28 at 132 kV, making it one of the largest in the world (© Siemens AG 2014, all rights reserved).

Procedure Outline

The Procedure is divided into the following sections:

- Set up and connections
- Familiarization with the SCADA window of the electric power substation
- Interlocking between a circuit breaker and the corresponding disconnecting switches
- Interlocking between two incoming line circuit breakers
- Outgoing line fault
- Incoming line fault
- Bus fault
- Outgoing line circuit-breaker fault
- Incoming line circuit-breaker fault
- Bus-section circuit-breaker fault

PROCEDURE

Set up and connections

In this section, you will set up a circuit representing one phase of an electric power substation using the single bus scheme with bus section circuit breaker.

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

   Install the required equipment in the Workstation.

2. Make sure that the ac and dc power switches on the Power Supply are set to the O (off) position, then connect the Power Supply to a three-phase ac power outlet.

   Make sure that the power switch on the DC Power Supply/Ethernet Switch is set to the O (off) position, then connect the *Power Input* to an ac power outlet.

   Connect the *Power Input* of the Data Acquisition and Control Interface to a 24 V ac power supply. Turn the 24 V ac power supply on.

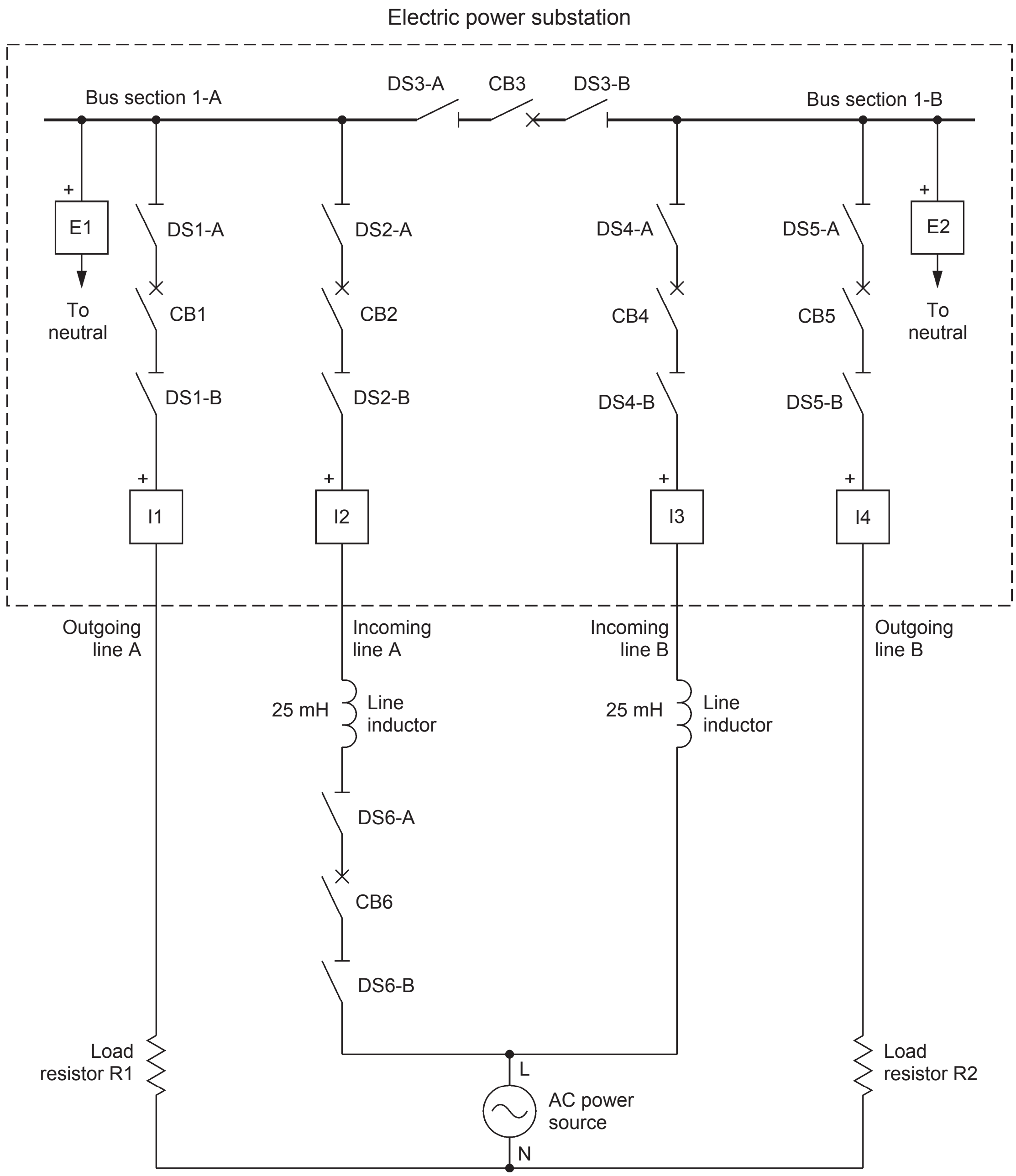
3. Connect the equipment as shown in Figure 35 to set up one phase of an electric power substation using the single bus scheme with bus section circuit breaker.

   Connecting the equipment to set up only one of the three phases of the electric power substation reduces the amount of equipment required and makes equipment connections easier and faster. However, this does not affect study of the substation operation since all three phases have the same behavior.

   Use modules Circuit Breakers and Disconnecting Switches 1 and Circuit Breakers and Disconnecting Switches 2 to implement the electric power substation. Use the Line Inductors module to implement the two line inductors at incoming lines A and B. These line inductors emulate short (about 20 km [12.4 miles]) power lines between the ac power source and the electric power substation. *E1*, *E2*, *I1*, *I2*, *I3*, and *I4* are voltage and current inputs of the Data Acquisition and Control Interface (DACI). Load resistors R1 and R2 are implemented with the Resistive Load module.

   The resistance value to be used for resistors R1 and R2 depends on your local ac power network voltage. A table below the circuit diagram in Figure 35 indicates the resistance value to be used for ac power network voltages of 120 V, 220 V, and 240 V. Make sure to use the resistance value corresponding to your local ac power network voltage. Appendix C of this manual lists the switch settings and connections to perform on the Resistive Load module in order to obtain various resistance values.

   Notice that in the circuit of Figure 35, circuit breaker CB6 and disconnecting switches DS6-A and DS6-B in Circuit Breakers and Disconnecting Switches 2 are used to implement protection located outside the electric power substation that disconnects the ac power source from incoming line A when a fault occurs on this line.



Local ac power network		Load resistors R1, R2 (Ω)
Voltage (V)	Frequency (Hz)	
120	60	240
220	50	880
240	50	960
220	60	880

Figure 35. Electric power substation using the single bus scheme with bus section circuit breaker (one phase only).

4. Connect the USB port of the Data Acquisition and Control Interface to a USB port of the host computer.

5. Connect the *Power Input* of each of the two Circuit Breakers and Disconnecting Switches modules to the 120 V output of the DC Power Supply/Ethernet Switch.

6. Connect the Ethernet port of each of the two Circuit Breakers and Disconnecting Switches modules to one of the ports on the DC Power Supply/Ethernet Switch.

7. Connect a USB port of the host computer to one of the ports on the DC Power Supply/Ethernet Switch via the USB-to-Ethernet adapter (included with the DC Power Supply/Ethernet Switch).

8. Turn the DC Power Supply/Ethernet Switch on. Wait a few seconds, then notice that all open (O) LEDs on the front panels of the two Circuit Breakers and Disconnecting Switches modules are lit, thereby indicating that all circuit breakers and disconnecting switches in the electric power substation are open.

   – On the Circuit Breakers and Disconnecting Switches 2, momentarily depress the DS6-A close (I) push button and DS6-B close (I) push button in the *Circuit Breaker and Disconnecting Switch Control* section to close disconnecting switches DS6-A and DS6-B.

   – On the Circuit Breakers and Disconnecting Switches 2, momentarily depress the CB6 close (I) push button in the *Circuit Breaker and Disconnecting Switch Control* section to close circuit breaker CB6.

Familiarization with the SCADA window of the electric power substation

In this section, you will familiarize yourself with the SCADA window of the electric power substation.

9. Turn the host computer on, then start the Electric Power Substation SCADA Application by performing the following two steps.

   – Start the Electric Power Substation SCADA Application Launcher by double-clicking the corresponding icon on the host computer desktop.

   – Launch the Electric Power Substation SCADA Application by clicking the *Launch Application* button in the Electric Power Substation SCADA Application Launcher. The Electric Power Substation SCADA Application Launcher should disappear (in fact, the corresponding window is minimized) and the Electric Power Substation SCADA Application window should appear.

10. In the Electric Power Substation SCADA Application window, click the *Single Bus With Bus Section Circuit Breaker* button to select this substation switching scheme. The single-line diagram of the corresponding electric power substation should appear on your host computer screen.

For the remainder of this exercise procedure, the Electric Power Substation SCADA Application window is simply referred to as the SCADA window.

Observe that the single-line diagram of the electric power substation displayed in the SCADA window corresponds to the electric power substation (see diagram in Figure 35) that you set up using the two Circuit Breakers and Disconnecting Switches modules.

Observe that each circuit breaker symbol in the SCADA window indicates the current state (open) of the corresponding circuit breaker in the electric power substation. Similarly, each disconnecting switch symbol in the SCADA window indicates the current state (open) of the corresponding disconnecting switch in the electric power substation.

Observe that the letter "R" appears next to each circuit breaker symbol in the SCADA window to indicate that the corresponding circuit breaker in the electric power substation is ready to close.

Finally, observe that displays in the SCADA window indicate the values of voltage at bus section 1-A and bus section 1-B, the values of current at incoming lines A and B, and the values of current at outgoing lines A and B.

11. Click the symbol of circuit breaker CB2 in the SCADA window. A dialog box should appear in the SCADA window. Click the *Close* button in this dialog box, then observe that circuit breaker CB2 in the electric power substation closes and that the letter "R" next to the symbol of circuit breaker CB2 in the SCADA window disappears for a few seconds to indicate that circuit breaker CB2 is no longer ready to close (because the closing spring in its operating mechanism needs to be recharged). Also, observe that the symbol of circuit breaker CB2 in the SCADA window is now shown in the closed state and that the background color of the symbol has passed from red to green. This provides a clear indication that circuit breaker CB2 is closed.

Click the symbol of circuit breaker CB2 in the SCADA window again. Click the *Open* button in the dialog box. Observe that circuit breaker CB2 in the electric power substation opens. Also, observe that the symbol of circuit breaker CB2 in the SCADA window is now shown in the open state and that the background color of the symbol has reverted to red. This provides a clear indication that circuit breaker CB2 is open.

Clicking any of the symbols in the SCADA window opens a switchgear control dialog box that allows remote control of the corresponding switchgear element (circuit breaker or disconnecting switch).

Interlocking between a circuit breaker and the corresponding disconnecting switches

In this section, you will close a circuit breaker in the electric power substation and then try to close one of the corresponding disconnecting switches. This will allow you to observe that interlocking between the circuit breaker and the corresponding disconnecting switches prevents such an operation.

12. On the Power Supply, turn the ac power source on.

13. Close circuit breaker CB2 in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

⚠ WARNING

The next manipulation requires that you make a connection while the equipment is powered. To minimize the risk of electric shocks, make sure to use a safety banana plug lead to make the connection.

14. Try to close disconnecting switch DS2-A in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Also, try to close disconnecting switch DS2-A by momentarily depressing the DS2-A close (**I**) push button on the Circuit Breakers and Disconnecting Switches 1 or by applying a voltage pulse to the DS2-A close (**I**) control input on the Circuit Breakers and Disconnecting Switches 1. Observe that this switching operation is not allowed. This is because circuit breaker CB2 is closed.

Explain why interlocking implemented in the electric power substation prevents a disconnecting switch from being operated when the corresponding circuit breaker (i.e., the circuit breaker connected in series with the disconnecting switch) is closed.

To ensure that the disconnecting switch does not make or break current when it changes state, thereby preventing possible damage to the disconnecting switch that could force an interruption in the supply of power to loads.

15. Open circuit breaker CB2 in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box.

16. Successively close disconnecting switches DS2-A and DS2-B in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Close circuit breaker CB2 in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Observe that bus section 1-A is now energized by the ac power source connected to incoming line A. The value of the voltage at bus section 1-A (i.e., the ac power source voltage) is indicated in the SCADA window.

17. Successively close disconnecting switches DS1-A and DS1-B in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Close circuit breaker CB1 in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Observe that power is now routed to load resistor R1 via incoming line A, bus section 1-A, and outgoing line A. The value of the current flowing through incoming line A and outgoing line A is indicated in the SCADA window.

Interlocking between two incoming line circuit breakers

In this section, you will connect a second incoming line to the bus in the electric power substation. This will allow you to observe that interlocking between incoming line circuit breakers requires you to confirm that the voltage at the incoming line to be connected is synchronous with the bus voltage before allowing closure of the corresponding incoming line circuit breaker.

18. Successively close disconnecting switches DS3-A and DS3-B in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Close circuit breaker CB3 (bus section circuit breaker) in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Observe that bus section 1-B is now energized by the ac power source connected to incoming line A. The value of the voltage at bus section 1-B (i.e., the ac power source voltage) is indicated in the SCADA window.

19. Successively close disconnecting switches DS4-A and DS4-B in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Close circuit breaker CB4 in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Observe that circuit breaker CB4 does not close immediately. Instead, another dialog box appears in the SCADA window. This dialog box requires you to confirm that the voltage at the incoming line to be connected (i.e., incoming line B) is synchronous with the bus voltage before allowing closure of circuit breaker CB4. In this case, the voltage at incoming line B and the bus voltage both come from the same ac power source, so they are in phase (i.e., they are synchronous).

Click the *Yes* button in the dialog box. Observe that circuit breaker CB4 closes and that the dialog box closes. Observe that power is now routed to load resistor R1 via outgoing line A, bus sections 1-A and 1-B, and incoming lines A and B. The values of the currents flowing through outgoing line A and incoming lines A and B are indicated in the SCADA window.

20. Successively close disconnecting switches DS5-A and DS5-B in the electric power substation by clicking the corresponding symbols in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Close circuit breaker CB5 in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Observe that power is now routed to load resistor R2 via bus section 1-B and outgoing line B. The value of the current flowing through load resistor R2 via outgoing line B is indicated in the SCADA window.

The electric power substation is now fully operational, i.e., all incoming and outgoing lines are connected to the substation bus and all loads connected to the substation are fed with power.

Outgoing line fault

In this section, you will insert a fault at outgoing line A of the electric power substation and observe the effect that this fault has on the currents flowing through the incoming and outgoing lines. You will then open a circuit breaker in the electric power substation to isolate the faulty line, observe what happens to the currents flowing through the incoming and outgoing lines, and assess the effect on the supply of power to the loads.

21. On the Power Supply, turn the ac power source off.

On the Fault Module, make sure that the *Fault* switch is set to the open (O) position, then connect the *Power Input* to the ac power source. Connect fault contact *K1-A* and the *Current-Limiting Resistor* of the Fault Module to outgoing line A as shown in Figure 36. This allows a fault to be inserted at outgoing line A. The *Current-Limiting Resistor* is connected in series with fault contact *K1-A* to limit the value of the fault current.

On the Power Supply, turn the ac power source on.

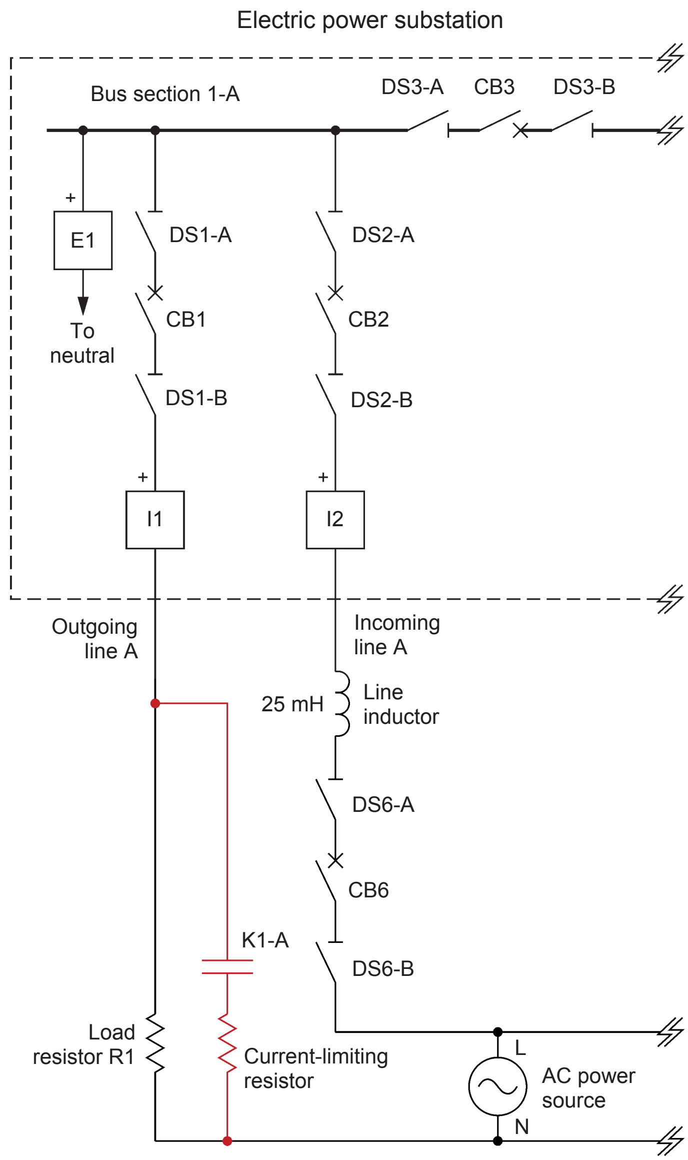


Figure 36. Connection of the Fault Module required to insert a fault at outgoing line A of the electric power substation.

22. On the Fault Module, set the *Fault* switch to the closed (I) position to insert a fault at outgoing line A. Observe that the values of the currents flowing through outgoing line A and incoming lines A and B increase considerably.

Which circuit breaker in the electric power substation must be opened to isolate outgoing line A and interrupt the fault current flowing through this line and incoming lines A and B?

Outgoing line circuit breaker CB1.

Open the circuit breaker that you mentioned above by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box.

Has the fault current flowing through outgoing line A and incoming lines A and B been interrupted?

Yes, opening outgoing line circuit breaker CB1 in the electric power substation isolates outgoing line A (faulty outgoing line) and interrupts the fault current flowing through this line and incoming lines A and B.

What are the consequences of opening this circuit breaker?

Power at load resistor R1 is lost (the current at outgoing line A is zero) until the fault affecting outgoing line A is removed and outgoing line circuit breaker CB1 is reclosed. On the other hand, power is maintained in the rest of the substation.

23. On the Fault Module, set the *Fault* switch to the open (O) position to remove the fault at outgoing line A (as when repair of a faulty line is completed). Consequently, outgoing line A can be reconnected to the electric power substation.

Reclose the open circuit breaker by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Observe that electric power is recovered at load resistor R1 and that the current flowing through outgoing line A has a normal value.

Incoming line fault

In this section, you will insert a fault at incoming line A of the electric power substation and observe the effect that this fault has on the currents flowing through the incoming and outgoing lines. You will then open circuit breakers to isolate the faulty line, observe what happens to the currents flowing through the incoming and outgoing lines, and assess the effect on the supply of power fed to loads.

24. On the Power Supply, turn the ac power source off.

On the Fault Module, make sure that the *Fault* switch is set to the open (O) position, then connect fault contact *K1-A* and the *Current-Limiting Resistor* of the Fault Module to incoming line A as shown in Figure 37. This allows a fault to be inserted at incoming line A. The *Current-Limiting Resistor* is connected in series with fault contact *K1-A* to limit the value of the fault current.

On the Power Supply, turn the ac power source on.

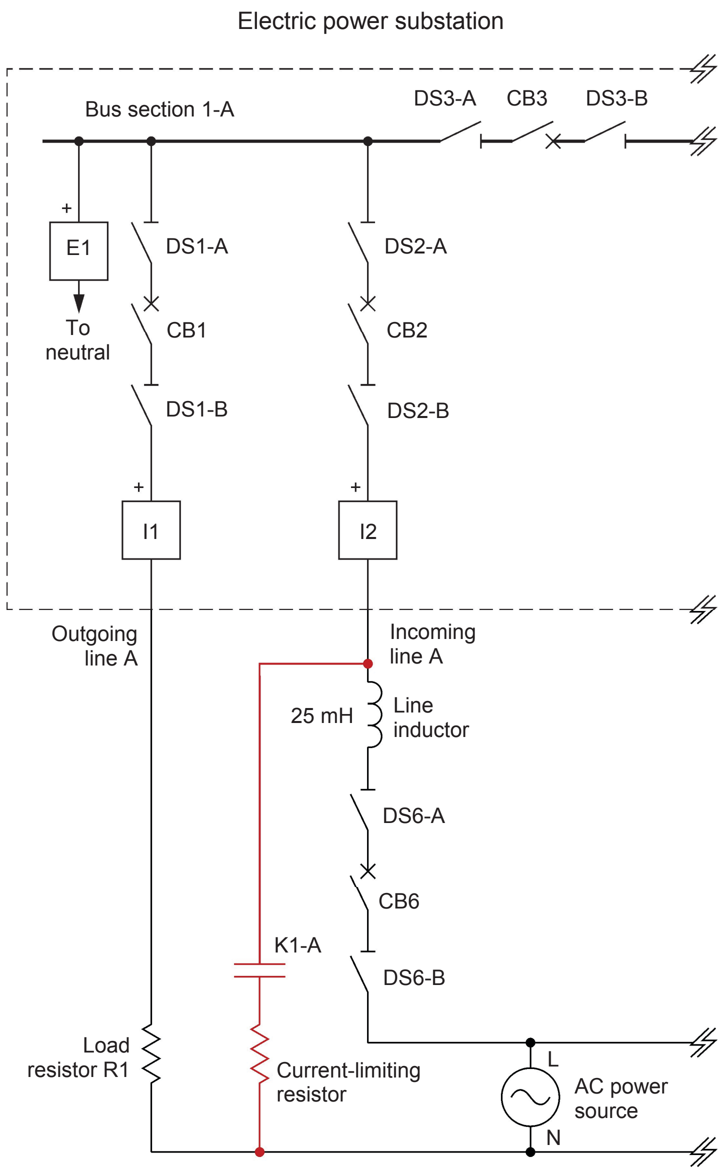


Figure 37. Connection of the Fault Module required to insert a fault at incoming line A of the electric power substation.

CAUTION

If your local ac power network voltage is 120 V, the nominal current of the line inductors will be exceeded significantly during the course of the following manipulation. Proceed rapidly when performing this manipulation to prevent excessive overheating from causing damage to the line inductors.

25. On the Fault Module, set the *Fault* switch to the closed (*I*) position to insert a fault at incoming line A. Observe that the value of the current flowing through incoming line B of the electric power substation increases considerably because the sum of the currents flowing through load resistors R1 and R2 plus a part of the fault current now flows through this line.

On the Circuit Breakers and Disconnecting Switches 2, momentarily depress the CB6 open (O) push button in the *Circuit Breaker and Disconnecting Switch Control* section to open circuit breaker CB6. This emulates tripping of the protection located outside the electric power substation and disconnects the ac power source from the faulty incoming line (incoming line A).

Observe that the values of the currents flowing through incoming lines A and B increase considerably because the ac power source now feeds the fault via the electric power substation only. In other words, the total fault current now flows through incoming lines A and B.

Which circuit breaker in the electric power substation must be opened to isolate incoming line A and interrupt the fault current flowing through incoming lines A and B?

Incoming line circuit breaker CB2.

Open the circuit breaker that you mentioned above by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box.

Has the fault current flowing through incoming lines A and B been interrupted?

Yes, opening incoming line circuit breaker CB2 in the electric power substation isolates incoming line A (faulty incoming line) and interrupts the fault current flowing through incoming lines A and B.

What are the consequences of opening this circuit breaker?

Electric power from the ac power source can no longer be routed to loads via incoming line A (the current entering the electric power substation via incoming line A is zero) until the fault affecting incoming line A is removed, circuit breaker CB6 is reclosed, and incoming line circuit breaker CB2 is reclosed. Power is maintained at load resistors R1 and R2 via incoming line B, bus sections 1-A and 1-B, and outgoing lines A and B. Consequently, the current flowing through incoming line B is twice the usual value because load resistors R1 and R2 are both supplied via this line.

26. On the Fault Module, set the *Fault* switch to the open (O) position to remove the fault at incoming line A (as when repair of a faulty line is completed). Consequently, incoming line A can be reconnected to the ac power source and the electric power substation.

On the Circuit Breakers and Disconnecting Switches 2, momentarily depress the CB6 close (I) push button in the *Circuit Breaker and Disconnecting Switch Control* section to reclose circuit breaker CB6. This resets the protection located outside the electric power substation and reconnects the ac power source to incoming line A.

Reclose the open circuit breaker by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. A dialog box appears, requiring you to confirm that the voltage at the incoming line to be connected (i.e., incoming line A) is synchronous with the bus voltage before allowing closure of the circuit breaker. Since the voltage at incoming line A and the bus voltage both come from the same ac power source, they are in phase (i.e., they are synchronous). Click the *Yes* button in the dialog box to close the circuit breaker and the dialog box.

Observe that this allows electric power to be routed to loads via incoming line A and that the current flowing through incoming line A has a normal value. Also, observe that the current flowing through incoming line B also returns to a normal value.

Bus fault

In this section, you will insert a fault at bus section 1-A of the electric power substation and observe the effect that this fault has on the currents flowing through the incoming lines. You will then open circuit breakers in the electric power substation to isolate the faulty bus section, observe what happens to the currents flowing through the incoming and outgoing lines, and assess the effect on the supply of power to the loads.

27. On the Power Supply, turn the ac power source off.

On the Fault Module, make sure that the *Fault* switch is set to the open (O) position, then connect fault contact *K1-A* and the *Current-Limiting Resistor* of the Fault Module to bus section 1-A, as shown in Figure 38. This allows a fault to be inserted at bus section 1-A. The *Current-Limiting Resistor* is connected in series with fault contact *K1-A* to limit the value of the fault current.

On the Power Supply, turn the ac power source on.

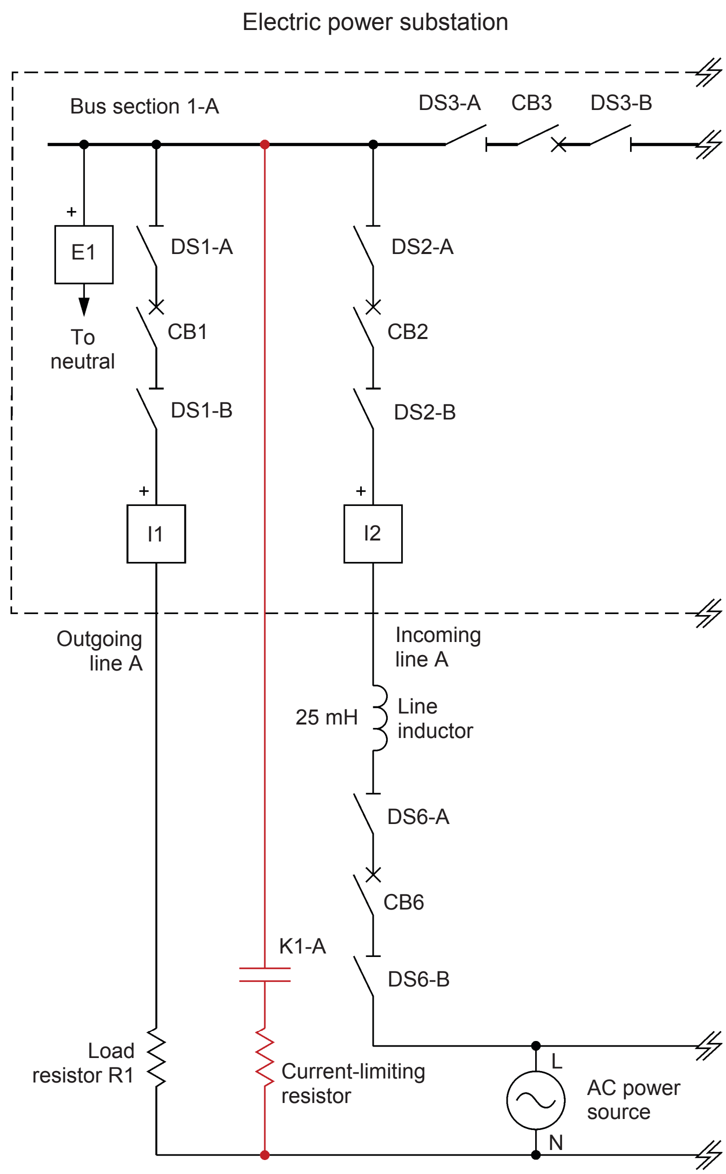


Figure 38. Connection of the Fault Module required to insert a fault at bus section 1-A of the electric power substation.

28. On the Fault Module, set the *Fault* switch to the closed (I) position to insert a fault at bus section 1-A. Observe that the values of the currents flowing through incoming lines A and B increase considerably.

Which circuit breakers in the electric power substation must be opened to isolate bus section 1-A and interrupt the fault currents flowing through incoming lines A and B?

Outgoing line circuit breaker CB1, incoming line circuit breaker CB2, and bus section circuit breaker CB3.

Successively open the circuit breakers that you mentioned above by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box.

Have the fault currents flowing through incoming lines A and B been interrupted?

Yes, opening outgoing line circuit breaker CB1, incoming line circuit breaker CB2, and bus section circuit breaker CB3 in the electric power substation isolates bus section 1-A (faulty bus section) and interrupts the fault currents flowing through incoming lines A and B.

What are the consequences of opening these circuit breakers?

Power at load resistor R1 is lost (the current at outgoing line A is zero) and electric power from the ac power source can no longer be routed to loads via incoming line A (the current entering the electric power substation via incoming line A is zero). This situation lasts until the fault affecting bus section 1-A is removed and the open circuit breakers (CB1, CB2, and CB3) are reclosed. On the other hand, power is maintained at load resistor R2 via incoming line B, bus section 1-B, and outgoing line B.

29. On the Fault Module, set the *Fault* switch to the open (O) position to remove the fault at bus section 1-A (as when repair of a faulty bus section is completed). Consequently, bus section 1-A can be reconnected to the electric power substation.

Successively reclose the open circuit breakers by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Observe that electric power is recovered at load resistor R1 and that the current flowing through outgoing line A has a normal value. Also observe that this allows electric power to be routed to loads via incoming line A and that the current flowing through incoming line A has a normal value.

At some point when reclosing the circuit breakers, a dialog box will appear requiring a confirmation that the voltage at the incoming line to be connected (i.e., incoming line A) is synchronous with the bus voltage before allowing closure of the circuit breaker. Since the voltage at incoming line A and the bus voltage both come from the same ac power source, they are in phase (i.e., they are synchronous). At this point, click the Yes *button in the dialog box to close the circuit breaker and the dialog box.*

Outgoing line circuit-breaker fault

In this section, you will produce a circuit-breaker fault at outgoing line A of the electric power substation and observe the effect that this fault has on the currents flowing through the incoming and outgoing lines. You will then open other circuit breakers in the electric power substation to isolate the faulty outgoing-line circuit breaker, observe what happens to the currents flowing through the incoming and outgoing lines, and assess the effect on the supply of power to the loads. Finally, you will determine what operations can be performed immediately to limit the consequences of the fault.

30. On the Power Supply, turn the ac power source off.

On the Fault Module, make sure that the *Fault* switch is set to the open (O) position, then connect fault contact *K1-A* and the *Current-Limiting Resistor* of the Fault Module to outgoing line A, as shown in Figure 36. This allows a fault to be inserted at outgoing line A. The *Current-Limiting Resistor* is connected in series with fault contact *K1-A* to limit the value of the fault current.

On the Power Supply, turn the ac power source on.

In the SCADA window, click the symbol of circuit breaker CB1, then click the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. Clicking this check box emulates a faulty circuit breaker, i.e., it makes circuit breaker CB1 ignore open commands and close commands. It also disables interlocking between circuit breaker CB1 and the corresponding disconnecting switches (DS1-A and DS1-B).

Make sure that a blinking "X" appears in the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. This confirms that the fault is inserted in the circuit breaker and interlocking is disabled.

Click the *Open* button in the switchgear control dialog box. Observe that circuit breaker CB1 fails to open.

31. On the Fault Module, set the *Fault* switch to the closed (I) position to insert a fault at outgoing line A. Observe that the values of the currents flowing through outgoing line A and incoming lines A and B increase considerably.

Which circuit breaker in the electric power substation must be opened to isolate outgoing line A and interrupt the fault current flowing through this line and incoming lines A and B?

Outgoing line circuit breaker CB1.

Open the circuit breaker that you mentioned above by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box. Observe that the circuit breaker fails to open and that, consequently, fault current continues to flow through outgoing line A and incoming lines A and B. This results in an outgoing line circuit-breaker fault.

In this situation, which other circuit breakers in the electric power substation must be opened to isolate the faulty outgoing line circuit breaker and interrupt the fault current flowing through outgoing line A and incoming lines A and B?

Incoming line circuit breaker CB2 and bus section circuit breaker CB3.

32. Successively open the circuit breakers that you mentioned above by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box.

Has the fault current flowing through outgoing line A and incoming lines A and B been interrupted?

Yes, opening incoming line circuit breaker CB2 and bus section circuit breaker CB3 in the electric power substation isolates the faulty outgoing line circuit breaker (CB1) and interrupts the fault current flowing through outgoing line A and incoming lines A and B.

What are the consequences of opening these circuit breakers?

Power at load resistor R1 is lost (the current at outgoing line A is zero) and electric power from the ac power source can no longer be routed to loads via incoming line A (the current entering the electric power substation via incoming line A is zero). On the other hand, power is maintained at load resistor R2 via incoming line B, bus section 1-B, and outgoing line B.

What operations can be performed immediately to limit the consequences of this fault while the faulty outgoing line and circuit breaker (outgoing line A and circuit breaker CB1) are being repaired?

Disconnecting switches DS1-A and DS1-B can be opened to disconnect the faulty outgoing line circuit breaker (CB1) from the electric power substation. Then, bus section circuit breaker CB3 and incoming line circuit breaker CB2 can be reclosed to reconnect incoming line A to the electric power substation. This allows electric power to be routed to loads via incoming line A while the faulty outgoing line and circuit breaker (outgoing line A and circuit breaker CB1) are isolated from the electric power substation for repair.

33. Successively open disconnecting switches DS1-A and DS1-B in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box. This isolates the faulty outgoing line circuit breaker (CB1) from the electric power substation.

Reclose bus section circuit breaker CB3 by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Reclose incoming line circuit breaker CB2 by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Incoming line circuit breaker CB2 does not close immediately. Instead, another dialog box appears in the SCADA window, requiring you to confirm that the voltage at the incoming line to be connected (i.e., incoming line A) is synchronous with the bus voltage before allowing closure of the circuit breaker. Since the voltage at incoming line A and the bus voltage both come from the same ac power source, they are in phase (i.e., they are synchronous). Click the *Yes* button in the dialog box to allow closure of incoming line circuit breaker CB2.

Observe that these operations allow electric power to be routed to loads via incoming line A while the faulty outgoing line and circuit breaker (outgoing line A and circuit breaker CB1) are isolated from the electric power substation for repair. Also, observe that the current flowing through incoming line A has a normal value.

34. On the Fault Module, set the *Fault* switch to the open (O) position to remove the fault at outgoing line A.

In the SCADA window, click the symbol of circuit breaker CB1, then click the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. Clicking this check box makes the circuit breaker operate normally, i.e., it makes circuit breaker CB1 respond normally to open commands and close commands. It also enables interlocking between circuit breaker CB1 and the corresponding disconnecting switches (DS1-A and DS1-B).

Make sure that no blinking "X" appears in the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. This confirms that no fault is inserted in the circuit breaker and interlocking is enabled.

Open outgoing line circuit breaker CB1 by clicking the *Open* button in the switchgear control dialog box.

The faults affecting outgoing line A and circuit breaker CB1 have been removed (as when repair of the faulty equipment is completed). Consequently, outgoing line A can be reconnected to the electric power substation.

35. Successively close disconnecting switches DS1-A and DS1-B in the electric power substation by clicking the corresponding symbol in the SCADA window then clicking the *Close* button in the switchgear control dialog box.

Close outgoing line circuit breaker CB1 by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Observe that electric power is recovered at load resistor R1 and that the current flowing through outgoing line A has a normal value.

Incoming line circuit-breaker fault

In this section, you will produce a circuit-breaker fault at incoming line A of the electric power substation and observe the effect that this fault has on the currents flowing through the incoming and outgoing lines. You will then open other circuit breakers in the electric power substation to isolate the faulty incoming line circuit breaker, observe what happens to the currents flowing through the incoming and outgoing lines, and assess the effect on the supply of power to loads. Finally, you will determine what operations can be performed immediately to limit the consequences of the fault.

36. On the Power Supply, turn the ac power source off.

On the Fault Module, make sure that the *Fault* switch is set to the open (O) position, then connect fault contact *K1-A* and the *Current-Limiting Resistor* of the Fault Module to incoming line A as shown in Figure 37. This allows a fault to be inserted at incoming line A. The *Current-Limiting Resistor* is connected in series with fault contact *K1-A* to limit the value of the fault current.

On the Power Supply, turn the ac power source on.

In the SCADA window, click the symbol of circuit breaker CB2, then click the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. Clicking this check box emulates a faulty circuit breaker, i.e., it makes circuit breaker CB2 ignore open commands and close commands. It also disables interlocking between circuit breaker CB2 and the corresponding disconnecting switches (DS2-A and DS2-B).

Make sure that a blinking "X" appears in the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. This confirms that the fault is inserted in the circuit breaker and interlocking is disabled.

Click the *Open* button in the switchgear control dialog box. Observe that circuit breaker CB2 fails to open.

CAUTION

If your local ac power network voltage is 120 V, the nominal current of the line inductors will be exceeded significantly during the course of the following two manipulations. Proceed rapidly when performing these manipulations to prevent excessive overheating from causing damages to the line inductors.

37. On the Fault Module, set the *Fault* switch to the closed (I) position to insert a fault at incoming line A. Observe that the value of the current flowing through incoming line B of the electric power substation increases considerably because the sum of the currents flowing through load resistors R1 and R2 plus some of the fault current now flows through this line.

On the Circuit Breakers and Disconnecting Switches 2, momentarily depress the CB6 open (O) push button in the *Circuit Breaker and Disconnecting Switch Control* section to open circuit breaker CB6. This emulates tripping of the protection located outside the electric power substation and disconnects the ac power source from the faulty incoming line (incoming line A).

Observe that the values of the currents flowing through incoming lines A and B increase considerably because the ac power source now feeds the fault via the electric power substation only. In other words, the total fault current now flows through incoming lines A and B.

Which circuit breaker in the electric power substation must be opened to isolate incoming line A and interrupt the fault current flowing through incoming lines A and B?

Incoming line circuit breaker CB2.

Open the circuit breaker that you mentioned above by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box. Observe that the circuit breaker fails to open and that, consequently, fault current continues to flow through incoming lines A and B. This results in an incoming line circuit-breaker fault.

In this situation, which other circuit breakers in the electric power substation must be opened to isolate the faulty incoming line circuit breaker and interrupt the fault current flowing through incoming lines A and B?

Outgoing line circuit breaker CB1 and bus section circuit breaker CB3.

38. Successively open the circuit breakers that you mentioned above by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box.

Has the fault current flowing through incoming lines A and B been interrupted?

Yes, opening outgoing line circuit breaker CB1 and bus section circuit breaker CB3 in the electric power substation isolates the faulty incoming line circuit breaker (CB2) and interrupts the fault current flowing through incoming lines A and B.

What are the consequences of opening these circuit breakers?

Electric power from the ac power source can no longer be routed to loads via incoming line A (the current entering the electric power substation via incoming line A is zero) and power at load resistor R1 is lost (the current at outgoing line A is zero). On the other hand, power is maintained at load resistor R2 via incoming line B, bus section 1-B, and outgoing line B.

What operations can be performed immediately to limit the consequences of this fault while the faulty incoming line and circuit breaker (incoming line A and circuit breaker CB2) are being repaired?

Disconnecting switches DS2-A and DS2-B can be opened to disconnect the faulty incoming line circuit breaker (CB2) from the electric power substation. Then, bus section circuit breaker CB3 and outgoing line circuit breaker CB1 can be reclosed to reconnect outgoing line A to the electric power substation. This allows electric power to be recovered rapidly at load resistor R1 while the faulty incoming line and circuit breaker (incoming line A and circuit breaker CB2) are isolated from the electric power substation for repair.

39. Successively open disconnecting switches DS2-A and DS2-B in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box. This isolates the faulty incoming line circuit breaker (CB2) from the electric power substation.

Reclose bus section circuit breaker CB3 by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Reclose outgoing line circuit breaker CB1` by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Observe that these operations allow electric power to be recovered at load resistor R1 while the faulty incoming line and circuit breaker (incoming line A and circuit breaker CB2) are isolated from the electric power substation for repair. Also observe that the current flowing through outgoing line A has a normal value and that the current flowing through incoming line B is twice the usual value because load resistors R1 and R2 are both supplied via this line.

40. On the Fault Module, set the *Fault* switch to the open (O) position to remove the fault at incoming line A.

In the SCADA window, click the symbol of circuit breaker CB2, then click the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. Clicking this check box makes the circuit breaker operate normally, i.e., it makes circuit breaker CB2 respond normally to open commands and close commands. It also enables interlocking between circuit breaker CB2 and the corresponding disconnecting switches (DS2-A and DS2-B).

Make sure that no blinking "X" appears in the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. This confirms that no fault is inserted in the circuit breaker and interlocking is enabled.

Open incoming line circuit breaker CB2 by clicking the *Open* button in the switchgear control dialog box.

The faults affecting incoming line A and circuit breaker CB2 have been removed (as when repair of the faulty equipment is completed). Consequently, incoming line A can be reconnected to the ac power source and the electric power substation.

41. On the Circuit Breakers and Disconnecting Switches 2, momentarily depress the CB6 close (I) push button in the *Circuit Breaker and Disconnecting Switch Control* section to close circuit breaker CB6. This resets the protection located outside the electric power substation and reconnects the ac power source to incoming line A.

Successively close disconnecting switches DS2-A and DS2-B in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Close incoming line circuit breaker CB2 by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Incoming line circuit breaker CB2 does not close immediately. Instead, another dialog box appears in the SCADA window, requiring you to confirm that the voltage at the incoming line to be connected (i.e., incoming line A) is synchronous with the bus voltage before allowing closure of the circuit breaker. Since the voltage at incoming line A and the bus voltage both come from the same ac power source, they are in phase (i.e., they are synchronous). Click the *Yes* button in the dialog box to allow closure of incoming line circuit breaker CB2.

Observe that this allows electric power to be routed to loads via incoming line A and that the current flowing through incoming line A has a normal value. Also, observe that the current flowing through incoming line B also returns to a normal value.

Bus-section circuit-breaker fault

In this section, you will produce a bus-section circuit-breaker fault in the electric power substation and observe the effect that this fault has on the currents flowing through the incoming lines. You will then open other circuit breakers in the electric power substation to isolate the faulty bus-section breaker, observe what happens to the currents flowing through the incoming and outgoing lines, and assess the effect on the supply of power to loads. Finally, you will determine what operations can be performed immediately to limit the consequences of the fault.

42. On the Power Supply, turn the ac power source off.

On the Fault Module, make sure that the *Fault* switch is set to the open (O) position, then connect fault contact *K1-A* and the *Current-Limiting Resistor* of the Fault Module to bus section 1-A, as shown in Figure 38. This allows a fault to be inserted at bus section 1-A. The *Current-Limiting Resistor* is connected in series with fault contact *K1-A* to limit the value of the fault current.

On the Power Supply, turn the ac power source on.

In the SCADA window, click the symbol of circuit breaker CB3, then click the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. Clicking this check box emulates a faulty circuit breaker, i.e., it makes circuit breaker CB3 ignore open commands and close commands. It also disables interlocking between circuit breaker CB3 and the corresponding disconnecting switches (DS3-A and DS3-B).

Make sure that a blinking "X" appears in the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. This confirms that the fault is inserted in the circuit breaker and interlocking is disabled.

Click the *Open* button in the switchgear control dialog box. Observe that circuit breaker CB3 fails to open.

CAUTION

If your local ac power network voltage is 120 V, the nominal current of the line inductors will be exceeded significantly during the course of the following two manipulations. Proceed rapidly when performing these manipulations to prevent excessive overheating from causing damages to one of the two line inductors in the circuit.

43. On the Fault Module, set the *Fault* switch to the closed (I) position to insert a fault at bus section 1-A. Observe that the values of the currents flowing through incoming lines A and B increase considerably.

Which circuit breakers in the electric power substation must be opened to isolate bus section 1-A and interrupt the fault currents flowing through incoming lines A and B?

Outgoing line circuit breaker CB1, incoming line circuit breaker CB2, and bus section circuit breaker CB3.

Successively open the circuit breakers that you mentioned above by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box. Observe that fault current no longer flows through incoming line A. Also observe that bus section circuit breaker CB3 fails to open and that, consequently, fault current continues to flow through incoming line B. This results in a bus-section circuit-breaker fault.

In this situation, which other circuit breakers in the electric power substation must be opened to isolate the faulty bus section circuit breaker and interrupt the fault current flowing through incoming line B?

Incoming line circuit breaker CB4 and outgoing line circuit breaker CB5.

44. Successively open the circuit breakers that you mentioned in step 43 by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box.

Has the fault current flowing through incoming line B been interrupted?

Yes, opening incoming line circuit breaker CB4 and outgoing line circuit breaker CB5 in the electric power substation isolates the faulty bus section circuit breaker (CB3) and interrupts the fault current flowing through incoming line B.

What are the consequences of opening these circuit breakers?

Power at load resistors R1 and R2 is lost (the current at outgoing line A and outgoing line B is zero) and electric power from the ac power source can no longer be routed to loads via incoming lines A and B (the current entering the electric power substation via incoming line A and incoming line B is zero). In other words, the entire electric power substation is shut down.

What operations can be performed immediately to limit the consequences of this fault while the faulty bus section and bus section circuit breaker (bus section 1-A and circuit breaker CB3) are being repaired?

Disconnecting switches DS3-A and DS3-B can be opened to disconnect the faulty bus section circuit breaker (CB3) from the electric power substation. Then, incoming line circuit breaker CB4 and outgoing line circuit breaker CB5 can be reclosed to reconnect incoming line B and outgoing line B to bus section 1-B, which is healthy. This allows electric power to be routed to resistive load R2 while the faulty bus section and bus section circuit breaker (bus section 1-A and circuit breaker CB3) are isolated from the electric power substation for repair.

45. Successively open disconnecting switches DS3-A and DS3-B in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Open* button in the switchgear control dialog box. This isolates the faulty bus section circuit breaker (CB3) from the electric power substation.

Reclose incoming line circuit breaker CB4 by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Reclose outgoing line circuit breaker CB5 by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Observe that these operations allow electric power to be recovered at load resistor R2 while the faulty bus section and bus section circuit breaker (bus section 1-A and circuit breaker CB3) are isolated from the electric power substation for repair. Also, observe that the current flowing through incoming line B and outgoing line B has a normal value.

46. On the Fault Module, set the *Fault* switch to the open (O) position to remove the fault at bus section 1-A.

In the SCADA window, click the symbol of circuit breaker CB3, then click the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. Clicking this check box makes the circuit breaker operate normally, i.e., it makes circuit breaker CB3 respond normally to open commands and close commands. It also enables interlocking between circuit breaker CB3 and the corresponding disconnecting switches (DS3-A and DS3-B).

Make sure that no blinking "X" appears in the check box next to the *Insert fault and disable interlocking* option in the switchgear control dialog box. This confirms that no fault is inserted in the circuit breaker and interlocking is enabled.

Open bus section circuit breaker CB3 by clicking the *Open* button in the switchgear control dialog box.

The faults affecting bus section 1-A and circuit breaker CB3 have been removed (as when repair of the faulty equipment is completed). Consequently, incoming line A and outgoing line A can be reconnected to the electric power substation.

47. Successively close disconnecting switches DS3-A and DS3-B in the electric power substation by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Close bus section circuit breaker CB3 by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Reclose incoming line circuit breaker CB2 by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box. Incoming line circuit breaker CB2 does not close immediately. Instead, another dialog box appears in the SCADA window, requiring you to confirm that the voltage at the incoming line to be connected (i.e., incoming line A) is synchronous with the bus voltage before allowing closure of the circuit breaker. Since the voltage at incoming line A and the bus voltage both come from the same ac power source, they are in phase (i.e., they are synchronous). Click the *Yes* button in the dialog box to allow closure of incoming line circuit breaker CB2.

Reclose outgoing line circuit breaker CB1 by clicking the corresponding symbol in the SCADA window, then clicking the *Close* button in the switchgear control dialog box.

Observe that electric power is recovered at load resistor R1 and that the current flowing through outgoing line A has a normal value. Also, observe that this allows electric power to be routed to loads via incoming line A and that the current flowing through incoming line A has a normal value.

48. On the Power Supply, turn the ac power source off.

On the DC Power Supply/Ethernet Switch, turn the 120 V dc power source off.

49. Close the Electric Power Substation SCADA Application by closing the corresponding window.

Conclusion

In this exercise, you were introduced to the operation of electric power substations using the single bus scheme. You learned that with this scheme, all power lines reaching the substation are connected to the same bus, with each line being permanently connected to the bus through a circuit breaker and two disconnecting switches connected in series. You learned that the bus in this type of substation is generally provided with one or several bus section circuit breakers to prevent any fault on the bus from resulting in an outage of the entire electric power substation. You studied the effects of faults at various locations of a substation using the single bus scheme with bus section circuit breakers, and determined how these faults affect the supply of power to loads and the reliability of the substation.

Review Questions

1. Describe an electric power substation implemented using the single bus scheme with bus section circuit breakers.

   In an electric power substation implemented using the single bus scheme with bus section circuit breakers, the power lines reaching the substation are connected to the same bus, with each line being permanently connected to the bus through a circuit breaker and two disconnecting switches connected in series. The bus is separated into sections by at least one bus section circuit breaker to prevent any fault on the bus from resulting in an outage of the entire electric power substation. Ideally, the loads and ac power sources must be distributed evenly on the bus sections to ensure that the number of loads that lose power following a fault on a particular section of the bus is limited to minimum.

2. In an electric power substation implemented using the single bus scheme with bus section circuit breakers, what effect does an incoming line fault have on the continuity of the supply of power to loads? Explain.

   When no other ac power source feeds the substation via another incoming line, power is lost at all loads fed by the outgoing lines of the substation. On the other hand, when a second ac power source feeds the substation via another incoming line, power is maintained at the loads fed by the outgoing lines of the substation.

3. Explain what protective grounding is and why it is mandatory during maintenance operations.

   Protective grounding is the set of means used to ensure that all parts of equipment in an electric power substation that require maintenance, and that are normally under high voltage, are connected to ground during the complete duration of the maintenance work. Protective grounding is mandatory during maintenance operation because it ensures that absolutely no voltage can appear across the equipment during maintenance due to, for instance, inadvertent closure of a circuit breaker in the substation or to voltage induction produced by an adjacent circuit in the substation that is still in operation.

4. What are the advantages and disadvantages of the single bus scheme (with or without bus section circuit breakers)?

The single bus scheme (with or without bus section circuit breakers) is a low cost alternative that is easy to operate due to its simplicity. Also, protection arrangement in a substation using the single bus scheme is relatively simple. Finally, substation expansion (e.g., addition of a line to the existing bus or addition of a bus section and lines) is generally easy. However, the single bus scheme has a low reliability which is likely to result in a poor continuity of service. Also, the operating flexibility of the single bus scheme is very limited since there is no alternate path available to route power to loads. Finally, maintenance of the bus or any section of the bus, maintenance of a disconnecting switch connected to the bus or a bus section, maintenance of an outgoing line circuit breaker or maintenance of an outgoing line disconnecting switch cannot be performed without interrupting power to loads fed via this bus, bus section, or outgoing line.

5. Explain why interlocking is required between each circuit breaker and the corresponding disconnecting switches in an electric power substation.

Interlocking is required between each circuit breaker and the corresponding disconnecting switches to prevent errors in the operation of the switchgear in an electric power substation from causing damage to the disconnecting switches and a long interruption in the supply of power to some loads. To be effective, interlocking simply has to prevent the disconnecting switches connected in series with a circuit breaker from being opened or closed when the circuit breaker is closed. Interlocking can be mechanical or electrical (logical).

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