



IEEE Guide for Protective Relay Applications to Power System Buses

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Developed by the

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of the
IEEE Power and Energy Society

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Abstract: Principles of power bus protection are discussed. The availability and location of breakers, current sensing devices, and disconnect switches are addressed, as well as bus configurations and switching schemes and their impact on the selection and application of bus protection. Bus protection schemes are presented, and their characteristics, strengths, and limitations are examined. Bus protection applications are presented.

Keywords: blocking zone-interlocked bus protection, breaker-and-a-half, breaker failure (BF) protection, breaker substitution, buses, check zone, CT saturation, current transformers, differential bus protection, double-bus double-breaker, double-bus single-breaker, dynamic bus replica, electric power substations, high-impedance differential, IEEE C37.234, main bus, partial differential, percentage-restrained differential, protective relaying, ring bus, single-bus single-breaker, stub bus, transfer bus, voltage trip supervision

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Introduction

This introduction is not part of IEEE Std C37.234-2021, IEEE Guide for Protective Relay Applications to Power System Buses.

Electric power system buses are points of common connection for source and load circuits. As such, buses are essential in maintaining power system integrity. Unnecessary isolation of a power bus by its protection system can considerably alter topology of the power grid and, even without other contingencies, can lead to system stability problems. Therefore, the security of bus protection schemes is of paramount importance. At the same time, the proximity and connection of various power apparatus within the perimeter of a substation and its exposure to secondary effects of a short circuit require fast isolation of all bus faults.

This document provides application guidelines for selecting and engineering bus protection schemes for a variety of bus configurations using several different protection philosophies to meet the requirements of security, dependability, and speed of operation.

The guide reviews many typical bus configurations and explains typical switching operations and their impact on the bus protection systems. This includes reconfigurable buses, such as double-bus single-breaker configuration, breaker substitution, main and transfer bus, etc., where the zones of protection change as the bus is switched, thus requiring the bus protection system to adapt accordingly for optimum selectivity.

The document reviews the most common bus protection schemes and presents their relative advantages given specific bus configuration and switching flexibility as well as performance requirements for the protection system. This includes schemes ranging from differentially connected overcurrent relays to microprocessor-based differential schemes with dynamic zone selection.

After reviewing relay input sources—current transformers (CTs), voltage transformers (VTs), and position sensing schemes for breakers and disconnect switches—the guide elaborates on each bus protection method in more detail by examining the operating principle, providing general setting guidelines, and listing general requirements for CTs.

The document also discusses specific related bus protection application issues including, but not limited to, partial differential protection, applications with paralleled CTs, CT column ground fault protection, voltage trip supervision, dynamic bus selection for double-bus single-breaker buses, bus protection under a breaker substitution configuration, stub bus configuration or configuration with paralleled buses, breaker failure (BF) application for reconfigurable buses, and treatment of in-zone out-of-service elements that provide a ground path for short-circuit currents.

A setting calculation example for a high-impedance bus differential scheme is given in [Annex A](#).

A protection logic design example is provided in [Annex B](#) to illustrate concepts of dynamic zone selection, dynamic BF trip selection, protection during a breaker substitution configuration, or circuit transfer leading to paralleling multiple buses via disconnect switches, voltage trip supervision, and the check zone. The example has been developed for a double-bus single-breaker configuration, but these advanced bus protection concepts are applicable to any reconfigurable bus.

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Applications to Power System Buses

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1. Overview

1.1 Scope

Concepts of power bus protection are discussed in this guide. Consideration is given to availability and location of breakers, current sensing devices ~~transformers (CTs)~~, and disconnect switches ~~disconnectors~~, as well as bus-switching scenarios, and their impact on the selection and application of bus protection. A number of bus protection schemes are presented; their adequacy, complexity, strengths, and limitations with respect to a variety of bus arrangements are discussed; specific application guidelines are provided. Breaker failure (BF) protection is discussed as pertaining to bus protection. Means of securing bus protection schemes against corrupted relay input signals are also included.

1.2 Purpose

The purpose of the guide is to assist utility engineers and industrial and commercial plant engineers in selecting and engineering proper bus protection.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{1,2}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

2. Normative references

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There are no normative references in this document.

¹The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

²The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary* ~~Online: Glossary of Terms & Definitions~~ should be consulted ~~referenced~~ for terms not defined in this clause.³

~~Definitions of several terms used in this guide are provided in IEEE Std C37.100™ 1992 [B17].~~⁴

blind spot: In bus protection, the area between the circuit breaker and its associated current transformer(s) on network elements or bus tie breakers where the current transformers (CTs) have only been installed on one side of the circuit breaker; faults in such blind spots may ~~will~~ not be cleared ~~instantaneously~~ by the bus protection.

bus protection blind spot: The area between the circuit breaker and its associated current transformer(s) where the current transformers (CTs) have only been installed on one side of the circuit breaker, adjacent to the bus, and faults may not be detected by the bus protection.

breaker substitution: Temporary usage of a bus tie or transfer breaker in a multiple bus configuration to substitute for one of the network element's circuit breakers, typically for the maintenance of the latter; also known as *breaker transfer*.

breaker-and-a-half: A substation configuration wherein two main buses are bridged by two or more "diameters," each diameter consisting of three circuit breakers in series, with a circuit or other element tapped at each of the two junctions between the circuit breakers. ~~A variation has four circuit breakers and three circuits per diameter.~~

³ ~~The~~ *IEEE Standards Dictionary* Online is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page. ~~Glossary of Terms & Definitions is available at <http://shop.ieee.org/>.~~

⁴ ~~The numbers in brackets correspond to those of the bibliography in Annex D.~~

bus: A portion of a switchyard or a switchgear that electrically interconnects a number of circuit breakers and switches, and is protected as a separate entity from network elements. It may also directly connect other elements such as grounding transformers without breakers/switches.

bus section: A contiguous portion of a bus, able to be electrically disconnected from other sections of the bus.

bus-side CT: Current transformer [\(CT\)](#) located between the circuit breaker and the bus.

check zone: Nonselective part of a multi-zone bus protection system measuring current flows around the entire station and supervising selective tripping from individual bus zones of protection.

CT-column ground fault protection: A method of ground fault protection for a freestanding current transformer or a live-tank breaker.

CT trouble detection: A [current transformer \(CT\)](#) monitoring function of a bus protection system capable of detecting differential current that is not caused by a bus fault.

diameter: One of several connecting circuits between buses in a double bus-double breaker or breaker-and-a-half substation configuration; also referred to as a *bay* or *breaker bay*.

double-bus double-breaker: A substation configuration having two breakers per each circuit where each of the breakers is connected to a separate bus.

double-bus single-breaker: A substation configuration having one breaker per [circuit that can be switched via disconnect switches to connect to either of two buses](#). ~~each circuit where each of the breakers is connected to a separate bus via a disconnect switch.~~

dynamic bus replica: A mechanism of dynamically tracking connections to or within the protected bus by monitoring positions of disconnect switches, and in rare cases, circuit breakers; for example, maintaining optimum selectivity of protection by dynamically associating [current transformers \(CTs\)](#) and circuit breakers to a multitude of bus protection zones.

freestanding CT: Current transformer [\(CT\)](#) independent of other apparatus.

high-impedance scheme: A differential method of bus protection using [current transformers \(CTs\)](#) paralleled on a high-impedance load (a voltage [relay in parallel](#) or current relay in series with a stabilizing resistor).

line-side CT: A current transformer ([CT](#)) located on the far side of a breaker from the bus.

[low-impedance scheme: A differential method of protection using current transformers that does not use an added burden as a method of stabilization.](#)

network element: Any electrical device or set of electrical devices (e.g., a line, feeder, transformer, capacitor bank, generator), operated as a unit and connected to a bus ~~via a circuit breaker~~.

[NOTE—](#)In figures, a network element is indicated symbolically by a line with an arrowhead.⁴

over-tripping spot: In bus protection, an area within the bus protection measuring zone that is, or can be, electrically isolated from the bus by a circuit breaker or disconnect switch, such as where using a line-side [current transformer \(CT\)](#) for bus protection, [that can](#) ~~;~~~~will~~ result in unnecessary bus trip should a fault occur in such a location.

[partial differential scheme: A variation of a differential protection scheme in which some currents are not included in the summation, typically due to the unavailability of current transformers.](#)

[percentage-restrained differential: A method of protection where the differential \(operating\) current required for operation is increased according to some function of the through \(restraint\) current as its primary means of stabilization from false operation on current transformer \(CT\) error. Other common names for this type of scheme include restraint, multi-restraint, percentage with restraint, percent differential, percentage differential, and biased differential.](#)

ring bus: A substation configuration with a series connection of breakers or switches closing back on itself, to form a ring, with a circuit or other element tapped at each of the junctions between the circuit breakers/_switches.

⁴[Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.](#)

stub bus: Area of a bus or line that becomes isolated from the original zone of protection or an area that loses protection due to the loss of sensing to zone protection relays.

bus tie breaker: A circuit breaker connecting two buses. [In double-bus single-breaker arrangements, a bus tie breaker can be further designated](#) ~~;-also-known~~ as a bus coupler or a [bus sectionalizer sectionalizing breaker](#).

voltage trip supervision: A supervisory function that responds to undervoltage or voltage unbalance conditions, which is used to secure current-based bus protection schemes from problems associated with temporary or permanent abnormal current readings.

4. Buses in various station arrangements

[4.1 Overview](#)

There are [several](#) ~~a-number-of~~ considerations in designing a bus, [some of which are as follows](#):

- Reliability requirements in terms of continuity of service for the bus as a whole or for an essential network element supplied from the bus.
- Operational considerations in terms of equipment maintainability and network switching flexibility.
- Economical and footprint constraints.
- Sectionalizing requirements to avoid exceeding breaker fault duty and operational cycles. [There are other options to reduce the bus fault current, as an example, by adding series reactors.](#)
- Ease of future bus expansion.

[For further details on bus design considerations, refer to IEEE Std 605™-2008 \[B28\].](#)

It is essential to understand the various bus arrangements before selecting an adequate protection scheme for a given bus configuration.

There are six major bus configurations in common use, as follows:

- a) Single bus
- b) Main and transfer bus
- c) Double-bus double-breaker
- d) Double-bus single-breaker
- e) Breaker-and-a-half
- f) Ring bus

These classical bus arrangements are described and discussed in the following [subclauses](#) ~~subsections~~. In the included figures, not all [current transformers \(CTs\)](#) and disconnect switches are depicted; only those that pertain to bus protection. [For the most part, CT polarities are not shown in figures in this guide. It is very important to verify that the CT secondary currents flow correctly for the scheme that is used.](#)

Note that this document depicts CTs, wiring, and relay devices in a simplified manner; for explanation of bus protection methods and applications. Refer to IEEE Std C57.13.3TM [B41] for rules of grounding secondary CT and relay circuits.⁵

4.2 Single bus

With reference to Figure 1, the single bus configuration (also known as *straight bus* or *single-bus single-breaker*) consists of a single bus with all network elements connected directly with breakers. This configuration is simple and [generally more](#) economical ~~as it requires less equipment and space~~. However, from the system point of view, it is the least reliable and least flexible in terms of network switching and equipment maintenance.

⁵ ~~Information on references can be found in Clause 2.~~

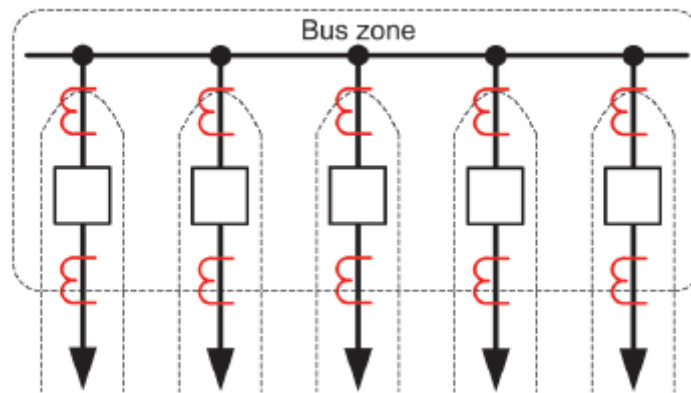


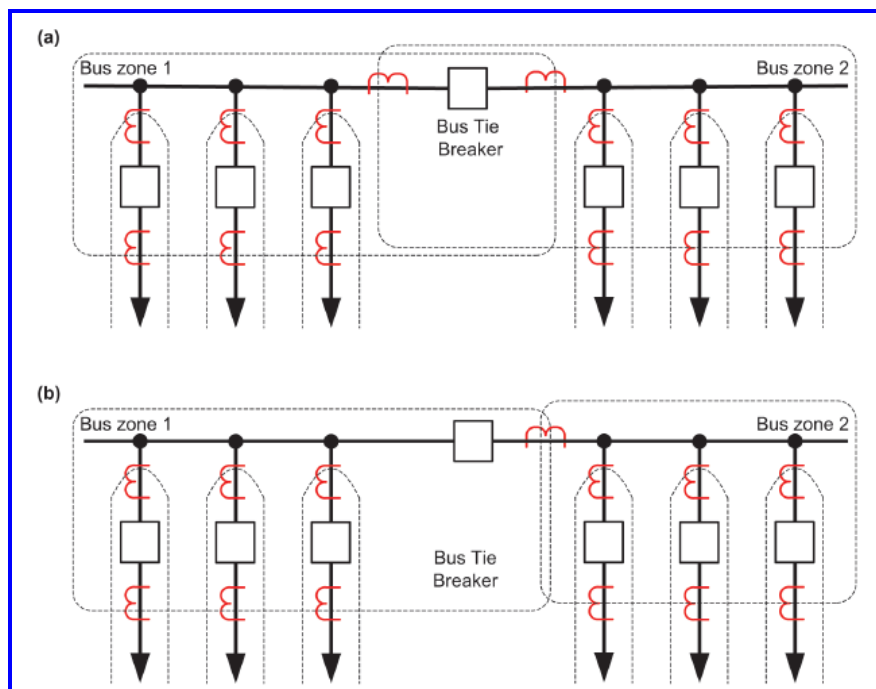
Figure 1—Single bus configuration

All network elements in the single bus configuration are disconnected from a bus ~~taken out of service~~ upon a bus fault or for bus maintenance. Maintenance or problems with a given breaker call for disconnecting ~~taking~~ its associated network element ~~out of service~~. Under a breaker failure (BF) condition, the entire bus is cleared.

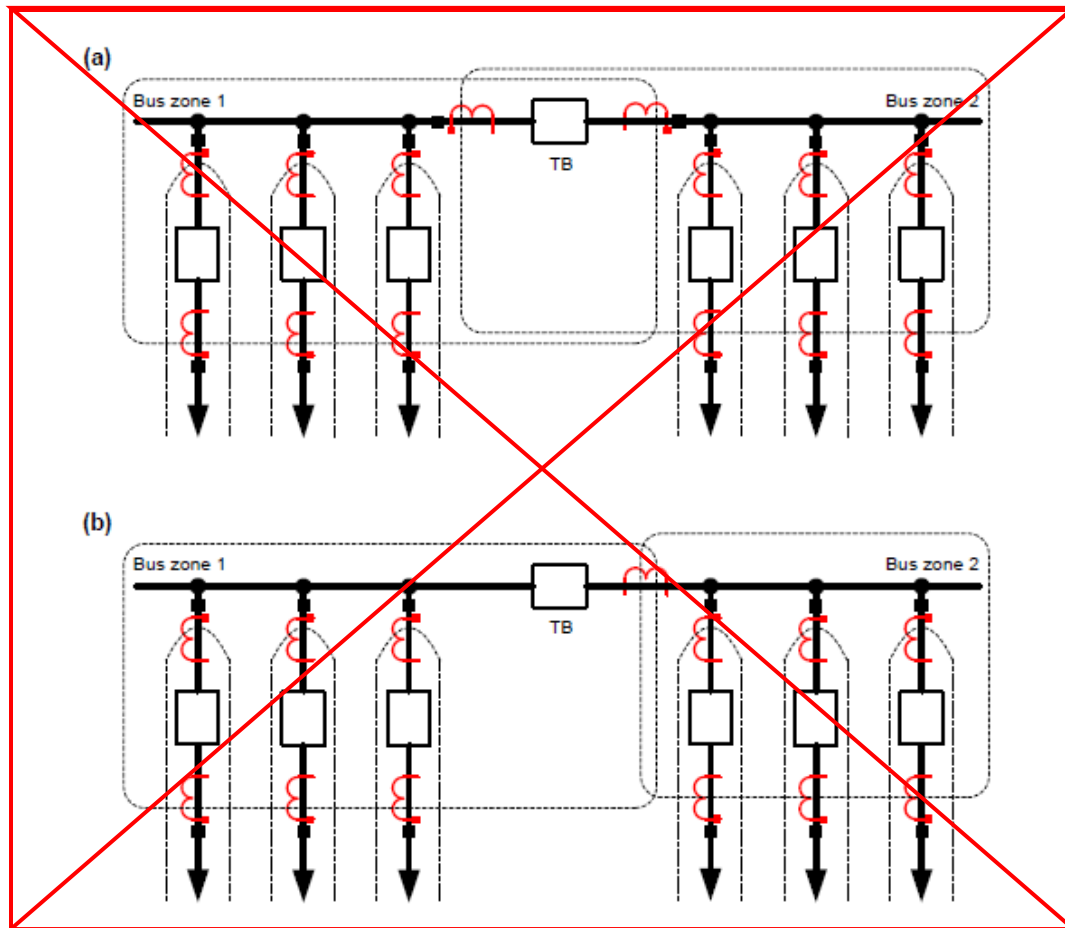
From the protection point of view, the measurement zone of protection for the single bus configuration is bounded by CTs on all the connected network elements, and all the connected breakers are tripped upon a bus fault. Figure 1 shows a desired situation with CTs available on both sides of each breaker, allowing the bus measurement zone and the measurement zones of protection of the network elements to overlap, thus eliminating any blind spots. Live tank breakers with freestanding CTs located on only one side do not provide for such overlap and, therefore, are treated with extra considerations, as described in 8.13 12.

Often to increase reliability and reduce breaker fault duty requirements, a single bus is split into—typically two—sections with a switching device (tie) between them. The multiple sections include sources that can adequately serve the connected loads. The fault duty of each bus section is reduced when the switching device is open ~~are preferably supplied from multiple sources with some degree of independence~~.

With reference to Figure 2(a), the tie can be a breaker rated for fault current interruption. In this case, a preferable arrangement is to install CTs on both sides of the bus tie breaker (TB) so that two independent zones of bus protection can be applied to protect and trip both ~~the~~ bus sections independently. Upon a fault in ~~on~~ zone 1, all network elements connected to zone 1 and the tie breaker are tripped. Upon a fault in zone 2, all ~~its~~ network elements connected to zone 2 and ~~are tripped as well as~~ the bus tie breaker are tripped. For faults between the bus tie breaker and its CTs, both buses are tripped unless special means are deployed to pinpoint the fault ~~better~~ and save one of the bus sections. Typically, these methods are based on intentionally delayed tripping and are ~~better~~ described in more detail in 8.13 ~~8.12~~.



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Figure 2—Single bus sectionalized with a tie breaker: current transformers on (a) both sides, and (b) on one side of the tie breaker only

Under BF conditions upon a fault on any network element, only the [breakers associated with the](#) connected bus section [are](#) ~~is~~ tripped including the [bus](#) tie breaker. This allows uninterrupted service of network elements connected to the other section.

In some configurations, the [bus](#) tie breaker is equipped with CTs on one side only [Figure 2(b)]. This case requires careful protection engineering to deal with the blind spot between the [bus tie breaker](#) ~~TB~~ and the CT. Detailed solutions to this problem are presented in 8. [13](#) ~~12~~.

When the bus tie is not a properly rated breaker, but a disconnect, the bus may be operated with the disconnect open (typically) or closed (occasionally) as shown in Figure 3(a) and Figure 3(b), respectively.

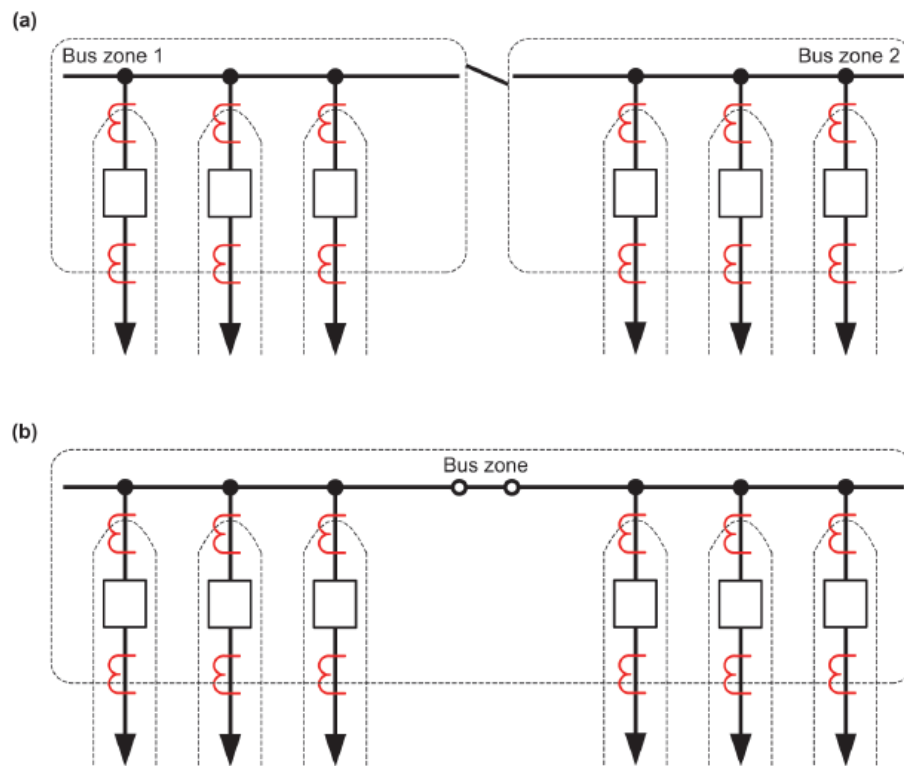


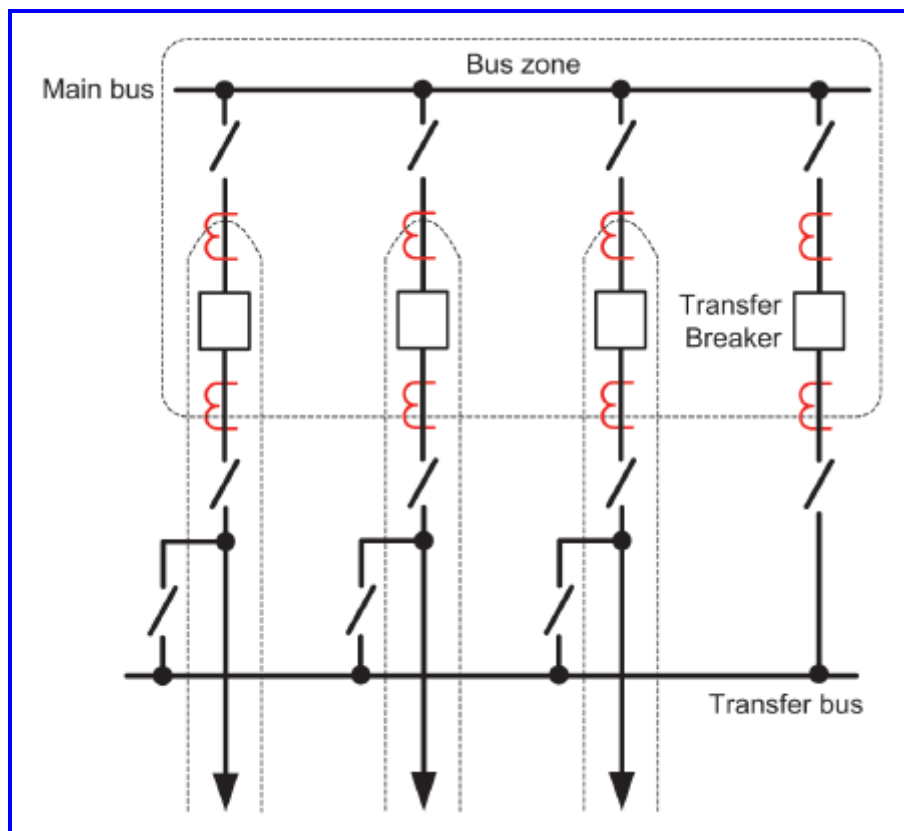
Figure 3—Single bus sectionalized with a disconnect switch: (a) bus protection with the disconnect open and (b) closed

With the disconnect open, this bus configuration becomes two independent single buses and is protected as such with two independent bus protection schemes. When the disconnect switch is closed, the two bus sections cannot be separated under a bus fault condition as the tie switch does not have sufficient fault interrupting capabilities. Therefore, the entire bus structure is protected as a single bus.

When the bus tie is a disconnect switch, there is no need for current measurement at the tie, and, therefore, no CTs are typically installed. Instead, the disconnect position becomes an important [status](#) input to the bus protection scheme controlling which currents are included in the zones of protection [and](#), which breakers are tripped under bus faults and under BF conditions.

4.3 Main and transfer bus

This bus configuration is an extension of the single bus arrangement and is aimed at [improving network element availability during bringing extra](#) equipment maintenance [through and](#) switching flexibility, [possibly with the addition of a single shared breaker without adding extra breakers](#). In reference to Figure 4, a second bus, called a *transfer bus* or an *auxiliary bus*, is added to the single bus configuration. Each network element is connected to the main bus via a breaker, and to the transfer bus via a disconnect switch. An extra breaker, called a [transfer breaker bus tie \(TB\)](#), or a bus coupler is inserted between the main and transfer buses.



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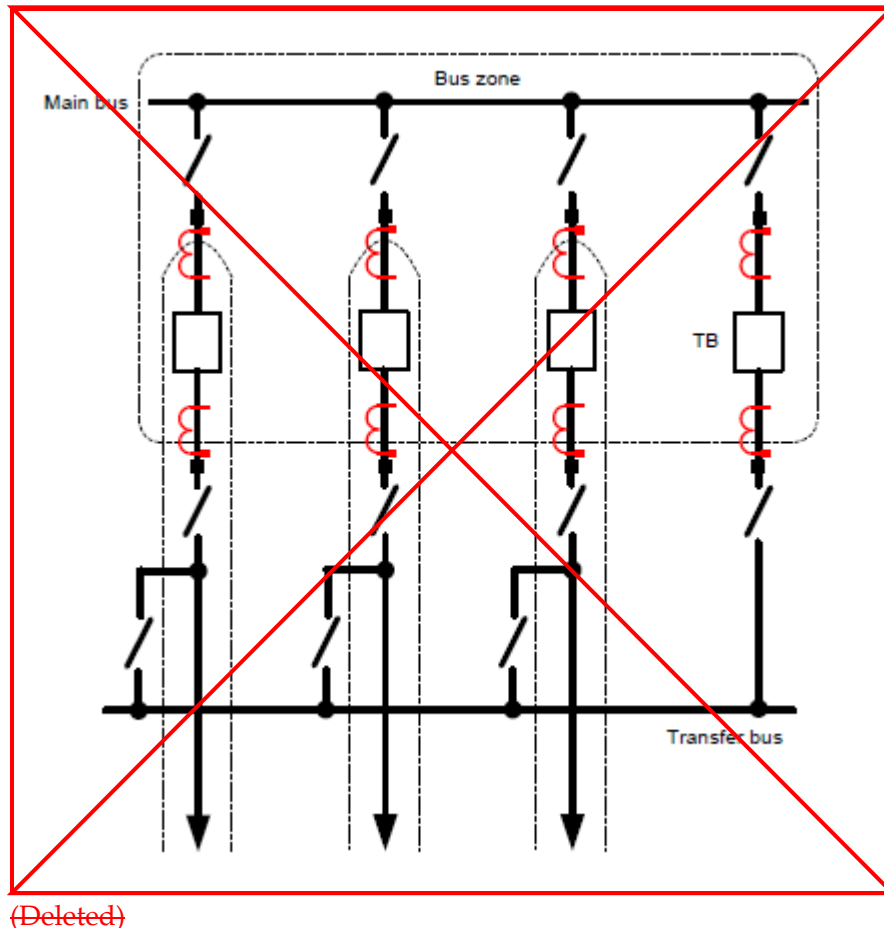
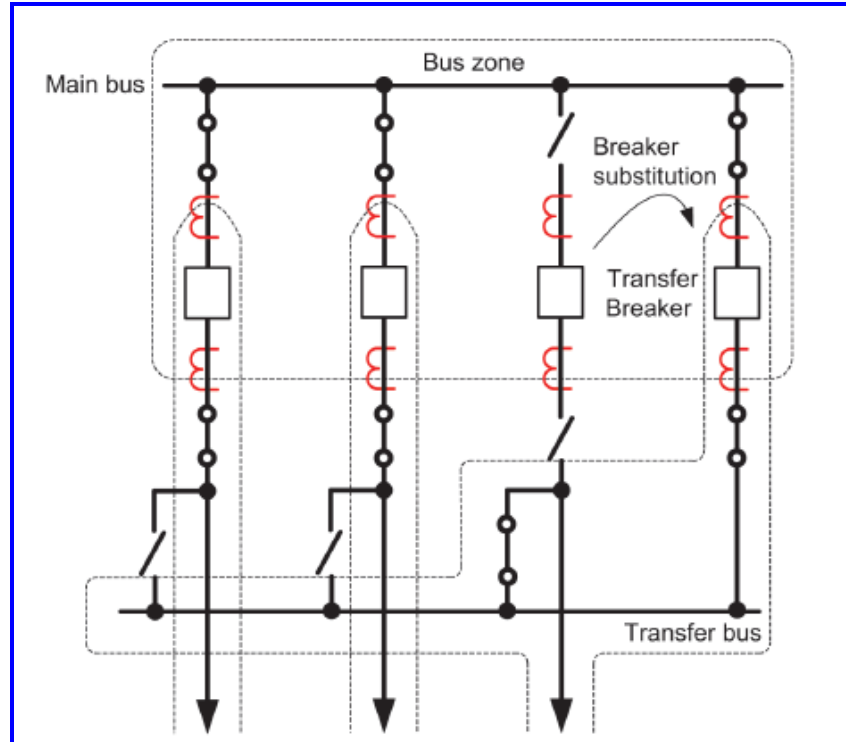


Figure 4—Main and transfer bus configuration

Normally, all network elements in this configuration are supplied from the main bus, and the **bus-tie transfer breaker** is **open**, **opened** leaving the transfer bus de-energized. When a breaker is **taken out of service for maintenance to-be-maintained**, the associated network element is supplied from the transfer bus via the disconnect switch, while the transfer bus is fed via the **transfer breaker bus-tie**. In this way, the network element is transferred to the **transfer bus-tie** breaker, hence the “transfer bus” designation. During the transfer, the network element is protected by the transfer breaker. As a result, the **transfer breaker bus-tie** acts as a substituting breaker, and the transfer bus is temporarily included in the zone of protection of the transferred network element (Figure 5).



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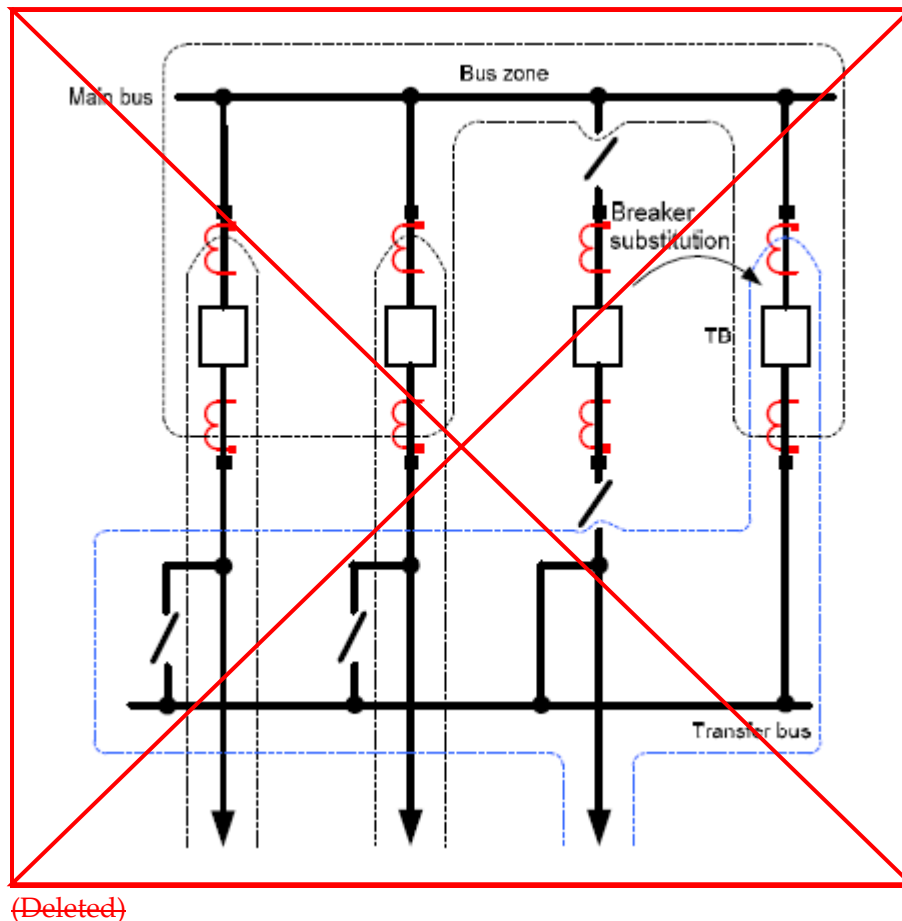


Figure 5— An example of a network element transferred to the transfer
bus-tie breaker

From the bus protection point of view, this arrangement is as simple as the single bus. Only one bus
protection zone ~~of bus protection~~ is required and is bounded by the spans CTs on the ~~and~~ breakers
of all network elements and the transfer **bus-tie** breaker.

From the point of view of protecting the network elements, extra complexity arises from the requirement of routing the current and trip signal paths from the main breaker to the substituting [transfer bus-tie](#) breaker. This may be accomplished by manually switching the signal paths, or by using an extra relay at the [transfer breaker tie](#) and temporarily reprogramming it to serve as the main protection for the transferred network element. [A detailed discussion of the protection of a network element when fed from the transfer bus is outside the scope of this guide.](#)

4.4 Double-bus double-breaker

This bus configuration provides for both reliability and operational flexibility at the expense of using two circuit breakers per each network element, hence the designation *double-breaker*. Two bus sections are set up and connected via diameters of two breakers [each](#). Each of the network elements is supplied from two breakers in each diameter, as shown in Figure 6.

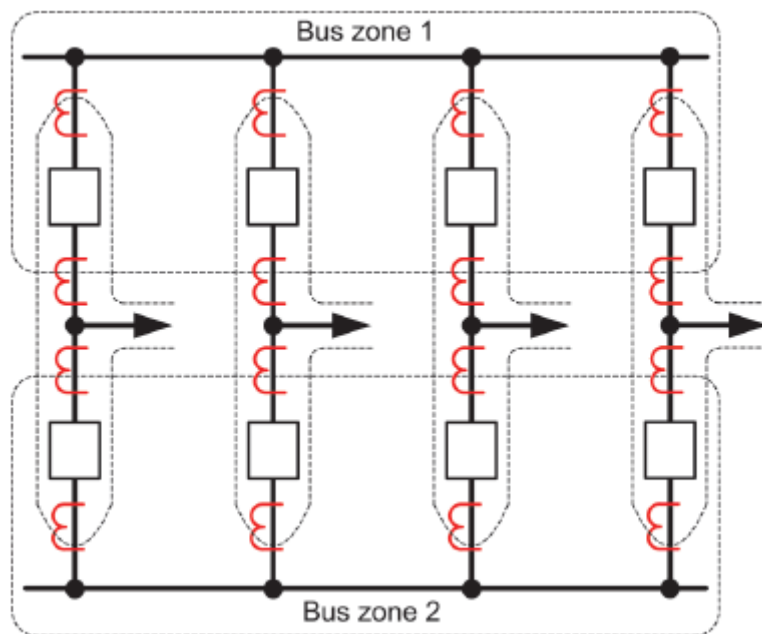


Figure 6—Double-bus double-breaker configuration

In this configuration, a failure or maintenance of one bus section does not interrupt service to any of the network elements; a problem [with](#) or maintenance of a breaker does not require taking the connected network element out of service.

From the point of view of protection of the network elements, two sets of CTs are connected to the protection scheme in order to bound a zone of protection (CT summation or dual-CT-input relays), and two breakers are tripped to isolate a fault on the network element. The increased number of breakers elevates the probability of a BF situation.

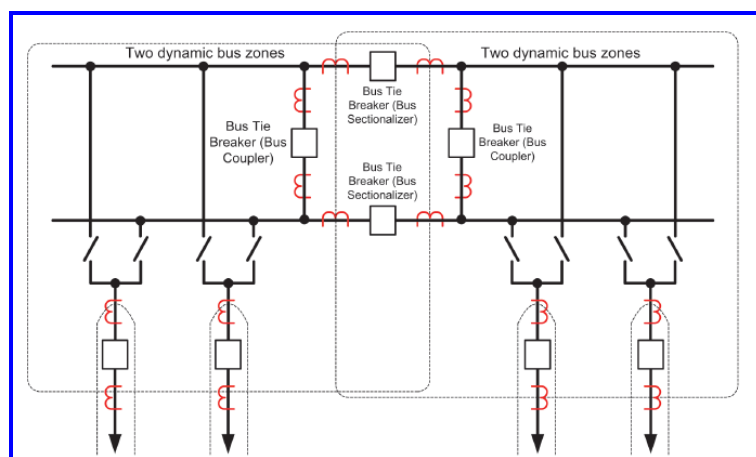
Upon a BF condition for tripping a network element fault, the entire [adjacent](#) bus section is cleared. This, however, does not interrupt service to any other of the network elements.

Bus protection is simple for this bus configuration. Two independent bus zones are used to cover the two bus sections. Upon a bus trip and BF condition, the other breaker in the diameter is tripped. In this way the healthy bus section always remains in service.

4.5 Double-bus single-breaker

This configuration delivers a good compromise between reliability and flexibility on ~~the one hand~~, and the footprint requirements and [economic](#) ~~economical~~ factors on the other. This is at the expense of more complicated bus protection schemes.

[As presented in](#) ~~In reference to~~ Figure 7, each network element is connected via a single-breaker (hence the designation *single-breaker*), but can be routed to either of the two bus sections via a disconnect switch. A bus tie breaker is often used in this configuration to connect the two buses.



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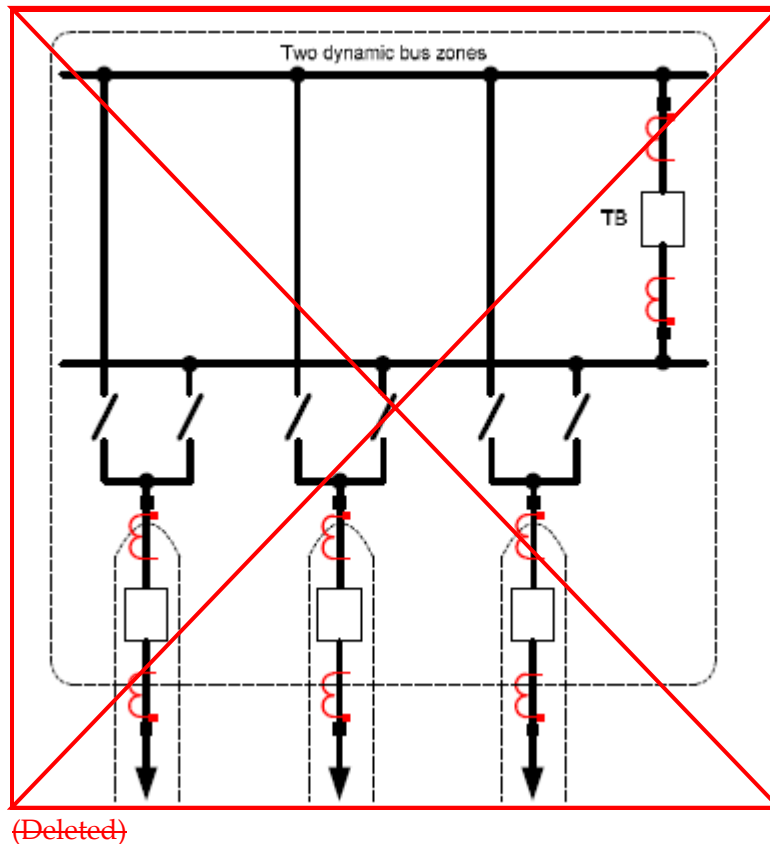


Figure 7—Double-bus single-breaker configuration

At any given time, each network element is connected to one bus section only, except during transfers between the buses. The [bus coupler tie-breaker](#) is used to equalize potentials between the two buses, before transferring a given network element from one bus section to the other.

From the point of view of protection of network elements, this configuration calls for a straightforward single-breaker application, as in the case of a single bus.

For maximum selectivity, bus protection is deployed with two zones of protection for each of the bus sections. However, the zone boundaries change, depending on which network element is connected to which bus section. For this application, the bus protection scheme dynamically assigns currents to its measurement zones and dynamically selects breakers to be tripped. This capacity is referred to as *dynamic bus replica* and is described in 8.98.

When transferring a network element between bus sections, the two sections are briefly connected ~~together~~ via both disconnect switches without the possibility of being able to measure the individual current flows toward either of the sections. This upsets the current balance for the two bus zones and requires ~~a~~ special treatment, as described later in 8.9 8.

The BF application is more complicated, too. When a given breaker fails, the BF trip signal is dynamically routed to those breakers that are connected to the same bus section at that time.

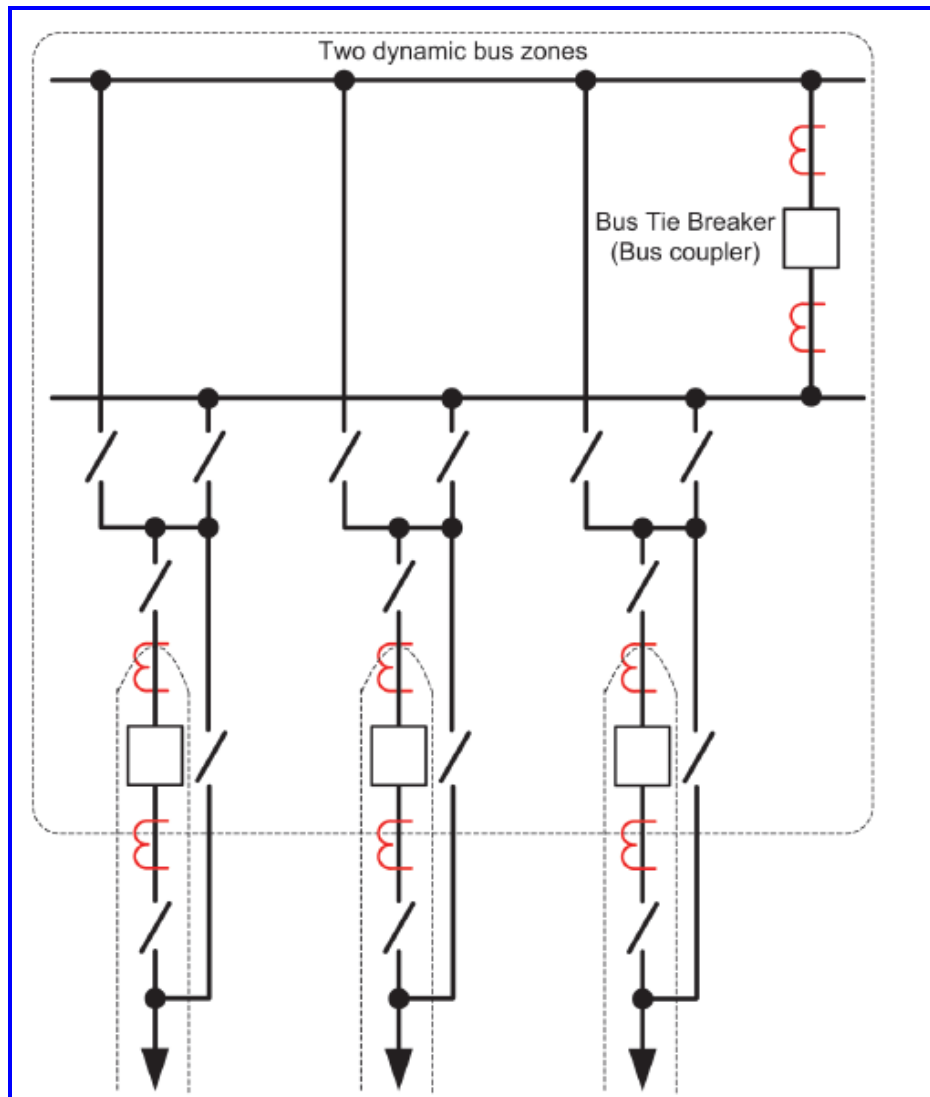
Even though the network elements connected to the same bus section as the failed breaker are cleared following the BF condition, they can be quickly and automatically restored to the other bus or the same bus after isolating the failed breaker.

As an alternative to dynamically assigning currents, two independent bus zones can be manually set up based on a set plan of service of the network elements, using, for instance, test switches. This simplifies the bus protection but decreases the flexibility of operation.

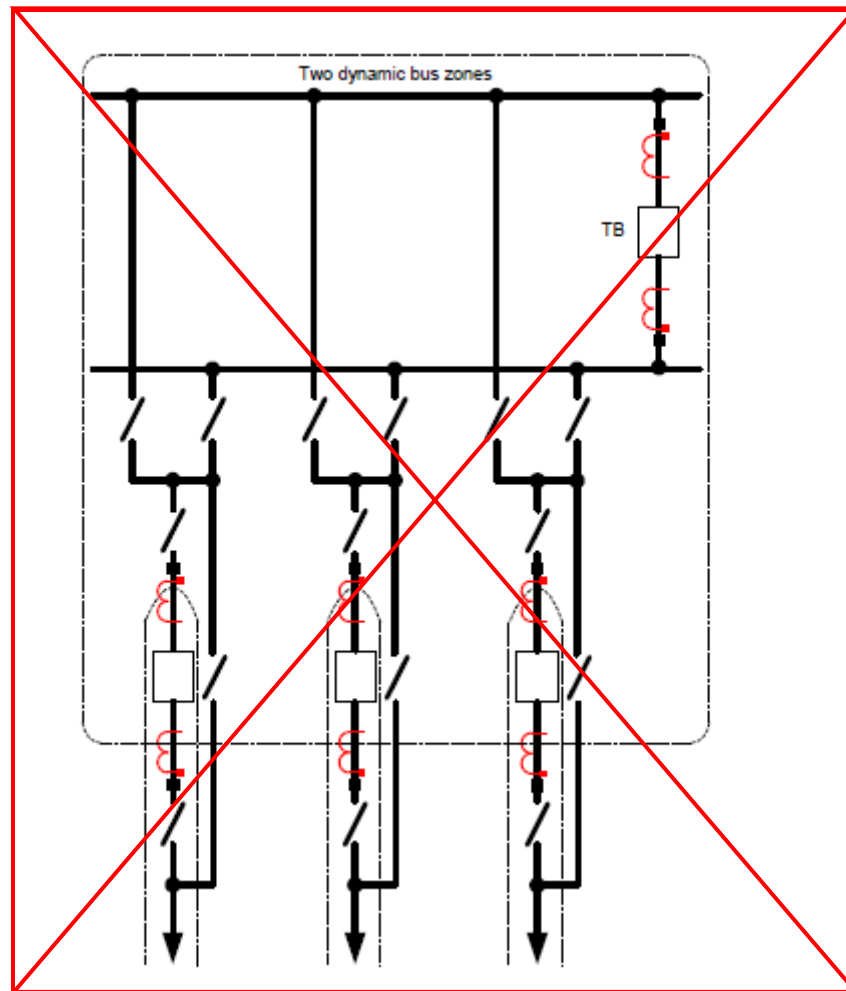
The double-bus single-breaker configuration is often further expanded toward a transfer bus capability. ~~In order~~ To use one of the buses as a transfer bus and the bus coupler ~~tie breaker~~ as a substituting breaker, bypass switches are added to the network element breakers as shown in Figure 8. During breaker maintenance, all network elements would be switched to one bus with a final configuration as presented in Figure 9 and described as follows:

- The connected ~~To maintain a given breaker, all~~ network elements are routed to ~~one bus, the network element of the said breaker is routed to~~ the other bus, ~~the~~
- The bypass switch is closed, ~~and the~~
- The maintained breaker is isolated via its disconnect switches, ~~disconnects while the~~
- The bus tie breaker is closed, substituting for ~~and used to substitute~~ the maintained ~~said~~ breaker ~~(Figure 9).~~

Refer to 8.15 14 for more information on protection during breaker substitution.

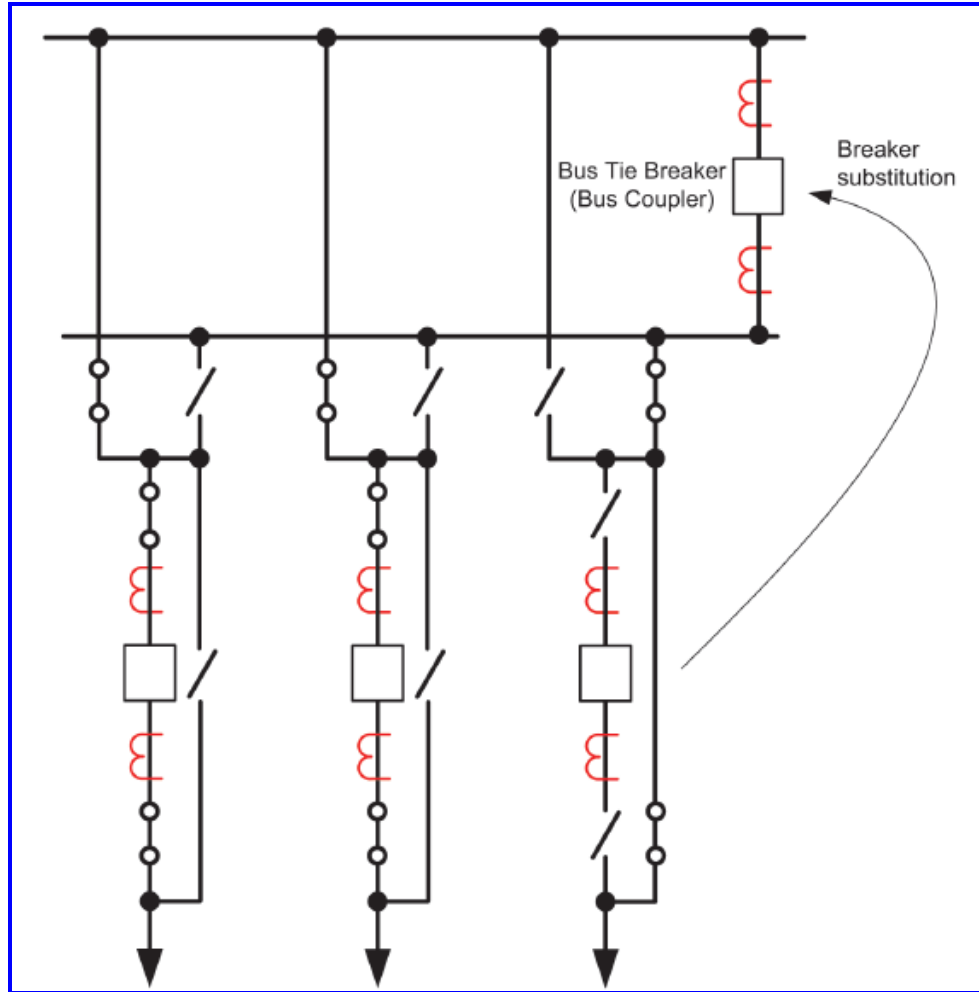


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Figure 8—Double-bus single-breaker configuration with bypass switches



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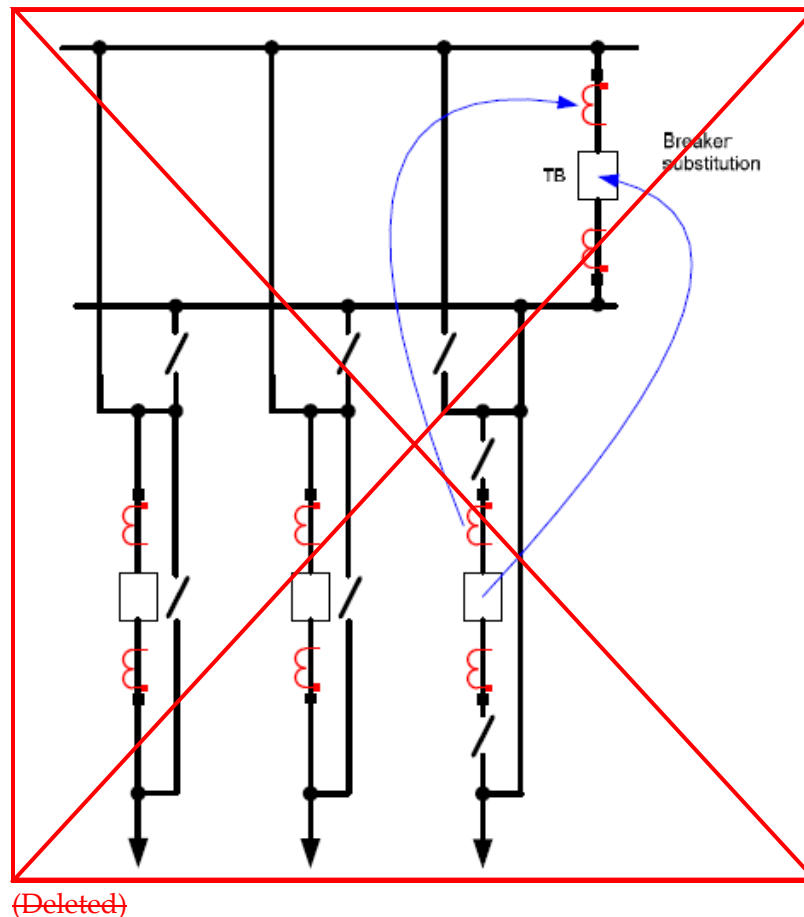


Figure 9— An example of a network element transferred to ~~the~~ bus
coupler tie-breaker

4.6 Breaker-and-a-half

The breaker-and-a-half configuration is built on two bus sections connected via diameters of three breakers. Two network elements are tapped from each diameter as shown in Figure 10. In this way, three breakers are required to connect two network elements, hence the designation *breaker-and-a-half*.

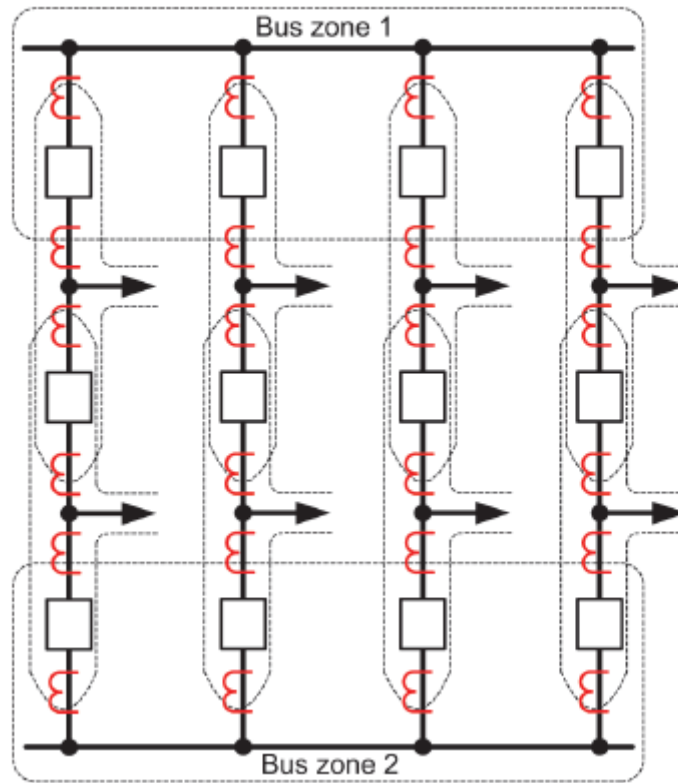


Figure 10—Breaker-and-a-half configuration

This configuration provides for very good flexibility and reliability, while allowing simple protection for both network elements and the bus sections. It is relatively economical, calling for 1.5 breakers per each network element.

Each breaker or bus section can be taken out of service for maintenance without interruption of service to any network elements. Breaker failure of any of the bus breakers calls for tripping the entire bus section, but no service is interrupted as each circuit is permanently supplied from both bus sections.

From the point of view of bus protection, protecting the breaker-and-a-half configuration is simple and equivalent to protecting two single bus sections.

From the viewpoint of the network element protection, dual-breaker relay application is required as explained ~~in 4.5-earlier~~ in conjunction with the double-bus double-breaker configuration.

In addition, the two breakers normally connecting a network element can be closed while the said network element is out of service or energized but isolated from the local ~~substation bus~~ via ~~its the~~ disconnect switch. This is to keep the diameter intact and supply the other network element on the diameter from both the bus sections. Such temporary configuration requires a special treatment known as *stub bus* protection, as described ~~later~~ in 8. ~~17~~ 16.

4.7 Ring bus

In the ring bus configuration, ~~several—a number of~~ breakers—typically ~~three~~ 4 to ~~six~~ 6—are connected in a closed loop, hence the *ring bus* designation. Network elements are tapped between breakers as shown in Figure 11. In this way, each network element is supplied via two breakers, allowing maintenance of one of them without service interruption to any of the network elements. However, with a breaker out of service, the ring is broken and the benefit of reliability of supply is temporarily limited or lost. A danger of splitting an open ring bus into two sections upon a fault on any of the connected network elements arises and needs to be factored into the system planning and operation.

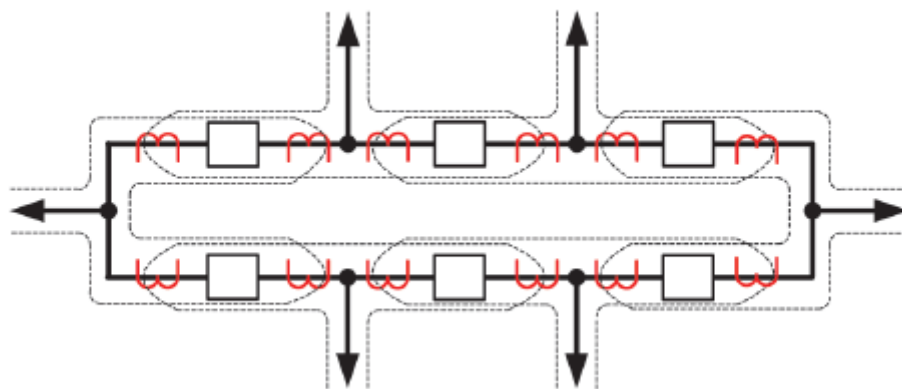


Figure 11—A six-breaker ring bus configuration

The configuration is economical, requiring ~~basically~~ one breaker per each circuit connected, but is limited in terms of the number of network elements that can be connected together and has a limited switching flexibility. Basically, a ring bus is a connection point between ~~several~~ ~~a number of~~ lines and transformers in a power system arrangement that requires these elements to be connected together under normal conditions.

The ring bus arrangement does not normally require bus protection. Overlapping zones of network element relays protect connections of breakers and disconnect switches.

In some cases, however, a dedicated bus zone may be needed to maintain sensitivity of protection for a connected network element in cases when the said network element does not feed much fault current, and the load transfer through the bus is high. For example, if one of the network elements is a transformer with only load or weak source connected, it is beneficial to apply the transformer zone from the bushings of the transformer. This gives better sensitivity by not restraining the transformer relay from the large load current flowing through the two breakers. A dedicated bus protection zone is consequently needed between the two breakers and the transformer bushings to cover the transformer connections.

From the point of view of network element protection, the dual-breaker application is required as explained ~~in 4.4 earlier~~ with respect to the double-bus double-breaker configuration.

~~Similar~~ ~~Similarly~~ to the breaker-and-a-half arrangement, the two breakers ~~normally connecting a~~ ~~of~~ ~~an out-of-service~~ network element ~~can be~~ ~~are typically~~ closed ~~while the said network element is out of service or energized but isolated via its disconnect switch~~ ~~in order to keep the ring intact~~. This calls for stub bus considerations as explained in 8.17 ~~16~~.

4.8 Other bus arrangements

Practical bus configurations often exhibit irregularities due to expansions and modifications over the lifetime of a substation. For example, a diameter in a breaker-and-a-half configuration can be initially built to connect just one network element in a single-breaker arrangement to one of the buses, or, in a dual-breaker connection, to both ~~the~~ buses. Only when the second network element is added, the said diameter may be fully expanded to contain all three breakers and form the regular breaker-and-a-half pattern.

Sometimes, a station may be physically laid out as breaker-and-a-half but operated as a ring bus until additional network elements are added.

In other cases, bus configurations are continuations or re-combinations of the classical arrangements. Examples include triple or quadruple buses, double-bus single-breaker with a transfer bus, and so on.

Also, more structured and fully symmetrical bus configurations have been proposed, but not commonly used. These include breaker-and-a-third, crossed ring, ring tripod, ring bridge, 4 ~~x~~ 6 configuration, and others (see Anderson [B2 B4]).

During the bus protection scheme engineering phase, it is typically sufficient to recognize the dominating characteristics of a given bus configuration, categorize it to one of the classical arrangements previously presented, and deal with exceptions using the general rules of bus protection.

5. Introduction to bus protection

5.1 General

A bus may be a critical element of a power system as it may be the point of convergence of many circuits (i.e., transmission, generation, or load). Usually, due to the concentration of short-circuit sources, bus faults are of high current magnitudes. High-speed bus protection is often provided to limit the damaging effect on equipment or system stability or to maintain service to as much load as possible.

Inadequate bus protection can result in widespread system disturbances and equipment failures. Fast clearing of bus faults is also desirable to reduce arc flash incident energy such that maximum incident energy levels are below the levels requiring special personal protective equipment or fences within the substation.

These factors call ~~All this calls~~ for dependability and availability of bus protection. On the other hand, unnecessary operation of bus protection interrupts multiple network elements, potentially causing system-wide problems or disrupting power ~~supply to a large amount number of load loads.~~ Therefore, the security of bus protection is typically considered paramount.

The major types of bus protection systems are as follows:

- a) Differential
- b) Blocking zone-interlocked schemes
- c) Time-coordinated relays that overlap the bus zone
- d) Fault bus
- e) Specialized sensors built into gas-insulated switchgear (not covered in this guide)
- f) Arc flash protection utilizing light-sensing relays for metal-clad switchgear (not covered in this guide, see IEEE Power and Energy Society [B22])

The major factors that influence the selection and design of the bus protection system are [detailed in 5.4](#), as follows:

- 1) ~~Bus arrangement and operational flexibility~~
 - ~~Fixed bus arrangements~~
 - ~~Switchable (reconfigurable) bus arrangements~~
- 2) ~~Availability and characteristics of CTs~~
- 3) ~~For reconfigurable buses, availability of auxiliary contacts of disconnect switches~~
- 4) ~~Performance requirements of the application~~
 - ~~Security~~
 - ~~Selectivity~~
 - ~~Speed~~
 - ~~Sensitivity~~
- 5) ~~Cost and complexity~~

[Clause 5](#) ~~This clause of the guide~~ briefly introduces principles of bus protection, introduces major types of bus protection schemes, and reviews factors influencing selection and design of bus protection schemes.

5.2 Zones of bus protection

In terms of its ability to detect bus faults, the bus protection zone is defined by [the](#) location of CTs surrounding the bus. In terms of its ability to clear the fault once detected, the bus protection zone is defined by [the](#) location of breakers surrounding the bus.

Ideally, bushing CTs are located on both sides of a breaker, and the breaker is overlapped by the bus and network element protective relaying zones as shown in Figure 12. As a result, no blind spots exist in the system, and the measuring boundary of the bus protection zone is slightly larger than the tripping boundary of the bus zone.

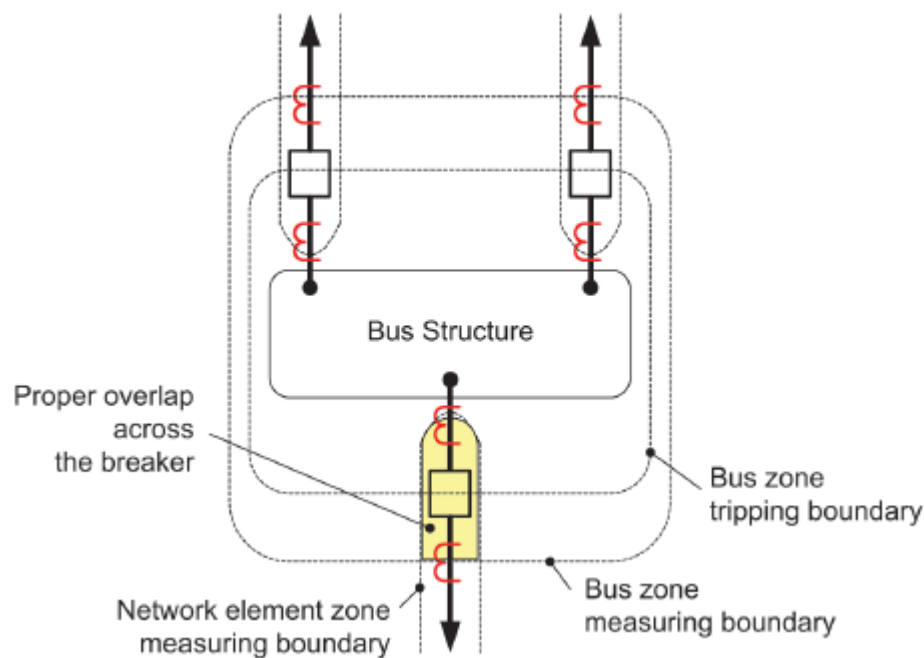


Figure 12— Proper measuring and tripping boundaries of bus and network element zones of protection

Bus protection schemes reviewed and categorized later in this clause perform a task of detecting an internal bus fault within the measuring boundary of the zone of protection, with the intent to issue a trip command to the breakers located on the tripping boundary of the zone.

For maximum selectivity, a dedicated zone of protection covers each bus section with its own measuring and tripping boundaries.

Several exceptions can be considered as a part of the basic principles of bus protection.

As a rule, live-tank breakers are accompanied with freestanding CTs. Each phase has a separate freestanding device containing multiple CT cores. To realize the economy of live-tank breakers, these CTs are typically located on one side of the breaker only. Hence, the breaker ~~is~~ ~~will be~~ within only one of the overlapping protection zones as shown in Figure 13 and Figure 14.

Figure 13 is the case of a network element ~~line~~-side CT where the freestanding CT is located between the breaker and the connected network element. ~~The term line refers here to any network element associated with the bus.~~ In this case, the section of the primary conductors, between the breaker and the CT, calls for ~~a~~ special treatment. This is a blind spot for the protection of the network element, and it is an over-tripping spot for the bus protection, should the breaker be opened.

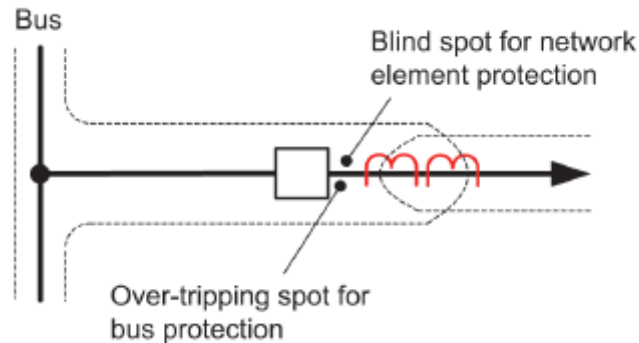


Figure 13—The case of network element ~~a line~~ - side current transformers ~~transformer~~

Figure 14 is the case of the bus-side CT where the freestanding CT is located between the breaker and the bus. In this situation, the primary conductors between the breaker and the CT are in the blind spot for the bus protection, and are an over-tripping spot for the network element protection should the breaker be opened.

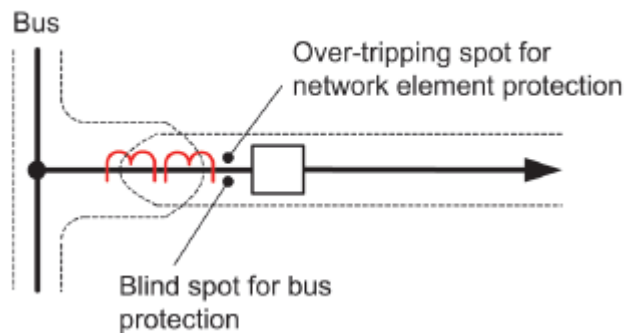


Figure 14—The case of a bus-side current transformers transformer

The preceding situation applies not only to live-tank breakers but may take place in other applications due to size or economical limitations preventing installation of CTs on both sides of a breaker.

In general, there is no perfect location of a single CT with respect to its breaker and the bus. The chosen location depends on the availability of means of solving the problem created by the lack of overlap of the two zones across the breaker. These solutions are discussed in detail in 8.13 12.

Stub bus protection is another consideration related to measuring and tripping boundaries of the protection zones. As shown in Figure 15, a dual-breaker connection to a network element can be kept closed for maintaining integrity of the bus (ring bus and breaker-and-a-half configurations) while the network element is disconnected from its breakers and CTs via a disconnect switch. Depending on the type of protection applied to the network element, this situation may cause security and/or dependability problems for the network element, and dependability problems for the area between the two closed breakers and the opened disconnect. Stub bus considerations are discussed in detail in 8.17 16.

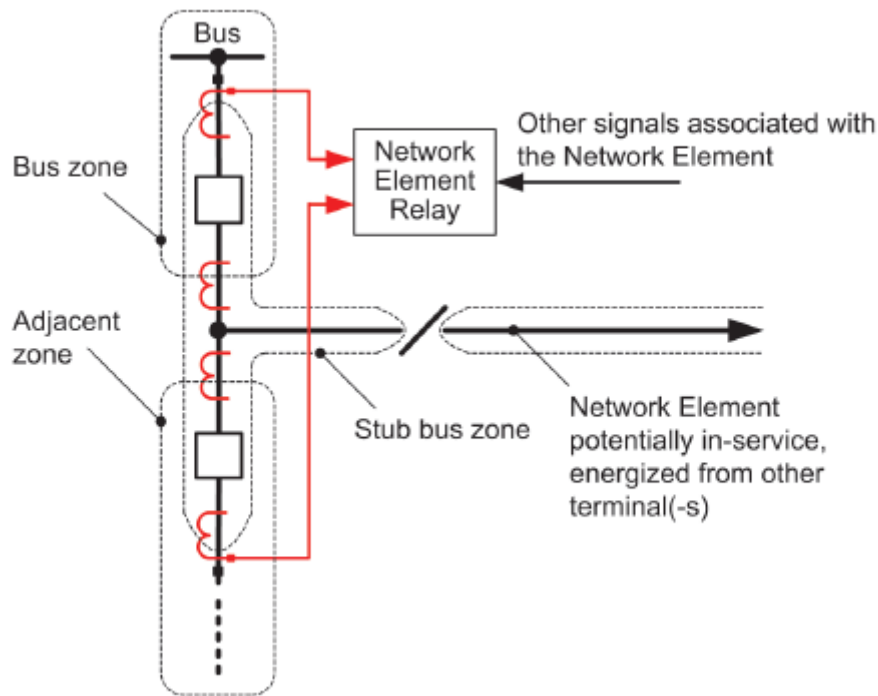


Figure 15—Stub bus configuration

Reconfigurable buses, such as double-bus single-breaker, require both the measuring and tripping boundaries of bus zones to adjust dynamically to follow the actual bus configuration. This is illustrated in Figure 16 where the shown breaker and CT can be connected to two or more buses via disconnect switches. This application calls for dynamic association of currents to the measuring zones, and breakers to the tripping zones. This and is known as *dynamic bus replica* (see 8.98). This application includes not only the detection and isolation of bus faults, but also tripping under [breaker failure BF](#) conditions. For this reason, in applications calling for the dynamic bus replica, the bus protection and BF protection functionalities are often integrated.