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Foreword

(This Foreword is not a part of ANSI/IEEE C37.97-1979, Guide for Protective Relay Applications to Power System Buses.)

This publication was prepared by the Transformer and Bus Protection Subcommittee of the IEEE Power System Relaying Committee. The Subcommittee expresses its gratitude to past and present members, members of the Power System Relaying Committee, Liaison Committees and Groups who have contributed their time and knowledge in preparing this guide.

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IEEE Guide for Protective Relay Applications to Power System Buses

1. Introduction

1.1 Purpose and Scope

This guide has been prepared to assist the reader in the effective application of relays for protection of power system electrical buses. The bus protection described refers only to protection at the bus location, independent of equipment at remote locations. Common bus arrangements and some special arrangements used in the United States are covered. Not all bus protection systems or all possible bus arrangements are included.

1.2 Factors Which Determine the Need and Type of Bus Protection

A bus is a critical element of a power system, as it is the point of convergence of many circuits — transmission, generation, or loads. The effect of a single bus fault is equivalent to many simultaneous faults and usually, due to the concentration of supply circuits, involves high current magnitudes. High-speed bus protection is often provided to limit the damaging effects on equipment or system stability or to maintain service to as much load as possible. Without bus protection, the remote terminals of lines connected to a faulted bus must be tripped. This will result in the loss of load tapped to these lines. Inadequate bus protection can result in catastrophic failures and present serious personnel hazards.

Factors such as bus configuration, relay input sources, operating time, sensitivity, and existing facilities are important in selecting the type of bus protection system. Existing stations may not have the required relay input sources for bus protection. Technical and economic considerations determine whether additional facilities are to be installed. If a common scheme cannot be used, consideration may be given to special bus protection methods.

1.3 Basic Principles of Bus Protection Operation

Several methods of bus protection are available. Probably the most sensitive method employs the differential principle, in which the phasor summation of all the measured current entering and leaving the bus must be zero unless there is a fault within the protected zone. For a fault not in the protected zone the instantaneous direction of at least one current is opposite to the others.

Other bus protection schemes such as partial differential, directional comparison, and the fault-bus methods use either or both the magnitude and direction of fault current and are described in Section 3.

2. Relay Input Sources

(Current Transformers and Linear Couplers)

2.1 General Background

Historically, the major problem in a bus protection system has been unequal core saturation of the current transformers (ct) used in the system. This unequal core saturation is due to the possible large variation of current magnitude and residual flux in the individual current transformer used in the system. The basic requirement is that the total scheme will provide the degree of selectivity necessary to restrain from operating on the most severe external fault and yet have the required sensitivity to operate on the minimum expected internal fault. In an existing installation, this usually requires selecting a scheme compatible with the existing current transformer, unless it is feasible to change or add current transformers. In a new installation, relay input sources can usually be selected which are compatible with the preferred scheme.

2.2 Types of Current Transformers

2.2.1 *Bushing Current Transformers*

The bushing current transformer is the most widely used for relaying because the installed cost is less than for other types of current transformers. It is generally applicable in most bus protective systems. It consists of a tapped secondary winding on an annular magnetic core and is referred to as a multiratio bushing current transformer. The core encircles a high-voltage insulating bushing used on circuit breakers, power transformers, generators, and switchgear, through which a power conductor passes to form the primary turn.

The secondary turns of a bushing current transformer should be distributed to minimize leakage reactance. Physically, this is accomplished by distributing each section of the tapped secondary winding completely around the circumference of the core [31].[1]

2.2.2 *Window-Type Current Transformers*

The window-type current transformer, which is used at medium and lower voltages, has a magnetic core with a center opening through which a power conductor passes to form the primary turn. The secondary is wound on the core, and in some styles the entire assembly is encased in molded insulating material. The core may be annular in shape with a uniformly distributed secondary winding, similar to a bushing current transformer, or rectangular in shape with the secondary winding either distributed or wound on only two legs.

2.2.3 *Wound-Type Current Transformers*

A wound-type current transformer has a primary winding of one or more turns and a secondary winding on a common core, similar to a power transformer.

2.2.4 *Auxiliary Current Transformers*

Auxiliary current transformers are sometimes used in the secondary circuit of other types of current transformers to change either or both the ratio and phase angle of the secondary current. The auxiliary current transformers should be selected to make sure theft characteristics do not adversely affect the performance of the selected bus protection scheme.

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[1] Numbers in brackets correspond to those of the Bibliography, Section 6. of this guide.

2.2.5 *Linear Couplers (Air Core Mutual Reactors)*

A linear coupler consists of a toroidal secondary winding on a nonmagnetic annular core. Like the bushing current transformer, it is designed to be mounted on equipment bushings with the power conductor forming a single primary turn. The absence of iron in the core eliminates core saturation problems. A linear relationship exists between primary current and secondary voltage.

2.3 Current Transformer Characteristics

Since a current transformer has a magnetic core, it may not have a linear operating characteristic over the desired operating range of primary current. This results in a variation of ratio and possible variation of phase angle between primary and secondary currents for different values of primary current. This phenomenon is called saturation. In addition to magnitude of ac current, factors that affect this saturation are the following.

2.3.1 *DC Transient Current*

The transient dc component of short circuit current is a major cause of current-transformer saturation and consequent misoperation of some bus differential systems [1], [2], [3]. The maximum flux density in the current transformer core, attributable to the dc component of fault current, varies with the time current of the dc transient [4]. Hence, the L/R ratio of the system impedance which determines the fault current should strongly influence the type of bus protective relaying which is selected. Typically the dc time constants for the different circuit elements can vary from 0.01 s for lines to 0.3 s or more for generating plants. The nearer a bus location is to a strong source of generation, the greater the L/R ratio and resulting dc component of fault current.

2.3.2 *Impedance of Secondary Current Transformer Leads and Associated Relays, Meters, and Auxiliary Current Transformers*

Lead resistance [4], as well as current transformer winding resistance, contributes to core saturation. Therefore, length of secondary lead runs should be held to a minimum. However, location of a breaker and its associated current transformer is determined by physical requirements. Hence, the planning stage must ensure that the type and rating of current transformer and its location with respect to the protected bus are comparable with the proposed bus protection scheme. Where lead runs are excessive, an increase in wire size or use of parallel conductors are means to reduce lead resistance. Location of the differential relay junction points in the breaker yard rather than at the relay location is also practiced. The preferred practice is to use current transformers dedicated to bus differential protection only. If possible, connection of meters, auxiliary current transformers, and other relays in differential type bus schemes should be avoided since these devices introduce additional burden into the current transformer circuit.

2.3.3 *Current Transformer Accuracy Classification for Relaying*

ANSI/IEEE C57.13-1978, Requirements for Instrument Transformers, establishes relaying accuracy classifications for relaying current transformers. Because relaying current transformers must operate at high overcurrent levels, ANSI classifications define minimum steady-state performance at those levels. Performance is described by an identification system which consists of a letter and a number selected from the following: (C, T) (10, 20, 50, 100, 200, 400, 800).

The first term describes performance in terms relative to construction. The C classification covers bushing current transformers with uniformly distributed windings and any other current transformer in which leakage flux has negligible effect on ratio error. Ratio correction at any current can be adequately calculated by knowing the burden and the excitation characteristic. The T classification covers most wound-type current transformers and any other current transformer in which leakage flux has an appreciable effect on ratio. Ratio correction must, therefore, be determined by test. The C and T classification is applicable to all tap sections of a current transformer winding.

The second term of the classification is the secondary terminal voltage rating. It specifies the secondary voltage that can be delivered by the full winding at 20 times rated secondary current without exceeding 10% ratio correction.

Furthermore, ratio correction is limited to 10% at any current from 10 to 20 times rated current at any lesser burden. The ANSI secondary voltage rating applies only to the full winding. If other than the full winding is used, the voltage rating is reduced in approximate proportion to turns used.

As an example, relay accuracy Class C100 means that ratio correction can be calculated and that it will not exceed 10% at any current from I to 20 times rated secondary current if the burden does not exceed 1.0 Ω. (1.0 Ω times 5 A times 20 times rated current equals 100 V).

3. Bus Protection Systems

3.1 Differential Protection

Differential relaying is the preferred protection system for new installations when all factors for providing bus protection can be planned and the appropriate relay input sources can be provided. Unless otherwise stated, differential protection will detect both phase and ground faults. The type of differential relaying to be applied would depend upon which factors described in 1.2 are the most important.

There are many variations of differential relays. Each has its own characteristics which are too numerous and detailed to be discussed in this guide. Information concerning these characteristics should be carefully examined before applying these relays.

3.1.1 *Differential Relaying with Overcurrent Relays*

Differential relaying with overcurrent relays requires connecting current transformers in each phase of each circuit in parallel with an overcurrent relay for that phase. (See Fig 1, illustrating the connections for 1 phase of a 3-phase system.) While it is permissible to utilize auxiliary current transformers to match ratios, it is most desirable for all current transformers to have the same ratio on the tap used so that auxiliary current transformers are not required.

Ground differential relaying, with an overcurrent relay for bus ground faults only, has been applied where current transformers are not available to dedicate to bus protection and where the bus construction minimizes the possibility of phase faults. In this case only the current transformer residual current circuits are connected, as shown in Fig 1. The usual precautions concerning burden, etc, apply. Where bus selection flexibility is provided, the system can be switched. Switching of residual current is less hazardous than switching phase currents.

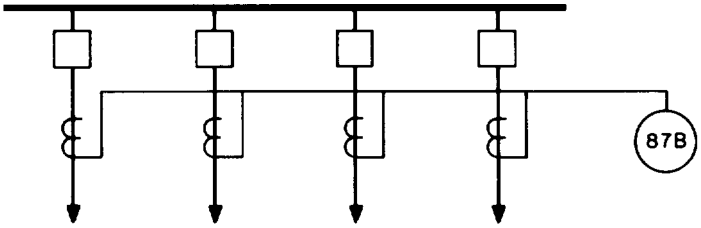

Figure 1— Differential Relaying with Overcurrent Relays

When applying overcurrent relays in differential schemes, special consideration should be given to the current transformer saturation problem. Based on an assumed value of residual flux, calculations can be made to estimate the extent of the error due to dc saturation of the current transformer core [1].

In general, this type of protection should be limited to locations that are electrically remote from generating stations which can produce large dc offset fault currents with long time constants.

To minimize possible incorrect operations, the relay may be set less sensitive, time delay may be increased, and inverse time induction-type overcurrent relays with short time characteristics may be used. The induction principle and design makes these relays less sensitive to the dc and harmonic components of the differential current. Depending upon the application, delaying relay operation allows the transient differential current to subside before the relay operates.

3.1.2 *Differential Relaying with High-Impedance Voltage Differential Relays*

A differential relaying scheme for bus protection using a commonly referred to high-impedance voltage-actuated relay [20], [32], designed for this application with the conventional differential connections of Fig 1, circumvents the effects of current transformer saturation during external faults. This system discriminates between external and internal faults by the relative magnitudes of voltage that appear across the differential junction points during these faults. All the current transformers should have the same ratio on the tap used, and low effective secondary leakage impedance as, for example, obtained with completely distributed windings on toroidal cores. This negligible secondary leakage impedance also applies to auxiliary current transformers if they are used to match ratios.

3.1.3 *Differential Relaying with “Linear Couplers” and Voltage Relays* [18]

This system uses linear couplers (air core mutual reactors) of the same general size and configuration as, and in place of, conventional iron core bushing-type current transformers. As the name implies, these couplers have linear characteristics. They produce a secondary voltage that is proportional to the time derivative of the primary current. The secondaries of all the linear couplers on the protected bus are connected in series with a low-energy instantaneous overvoltage relay. (See Fig 2.)

3.1.4 *Differential Relaying with Percentage Differential Relays*

Percentage differential relays have restraint and operating circuits [32], as shown functionally in Fig 3. While only one operating circuit per phase is required, one restraint circuit for each phase of each circuit or combination of circuits connected to the bus is necessary. The required current to operate the relay is dependent upon the restraint currents. Maximum security to external faults is obtained when all current transformers have the same ratio but satisfactory operation can be expected using high-quality auxiliary current transformers as required.

3.1.5 *Differential Relaying with Moderately High-Impedance-Type Percentage Differential Relay*

The percentage restraint characteristic of this type of relay makes the relay application independent of the maximum external fault condition [28], [29]. The commonly referred to moderately high-impedance differential circuit together with the restraint action makes the relay insensitive to the effects of current transformer saturation on external faults. The relay responds to internal faults regardless of any possible current transformer saturation.

The relay generally connects into the system, as shown in Fig 3, with a special auxiliary current transformer required for each restraint circuit when 5A rated current transformers are used. One restraint circuit is required for each phase of each circuit or combination of circuits connected to the bus. The auxiliary current transformers permit the use of unmatched current transformer ratios to bring the overall ratios into agreement and permit the possible use of other burdens in the current transformer circuits.

3.2 Partial Differential Protection

This type of bus protection is also referred to as “bus overload” or “selective backup” protection. It is a variation of the differential principle in which currents in one or more of the circuits are not included in the phasor summation of the currents to the relay. (See Fig 4.) This method may be used as a backup to a complete differential protection scheme, as primary protection for a station with loads protected by fuses or to provide local breaker failure protection for load breakers, or both.

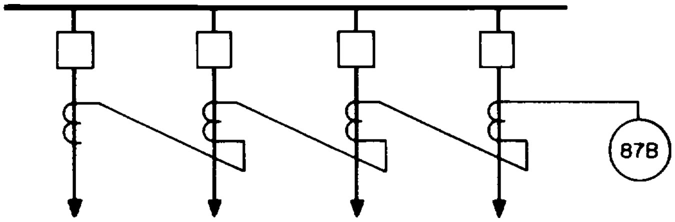

Figure 2— Differential Relaying with Linear Couplers

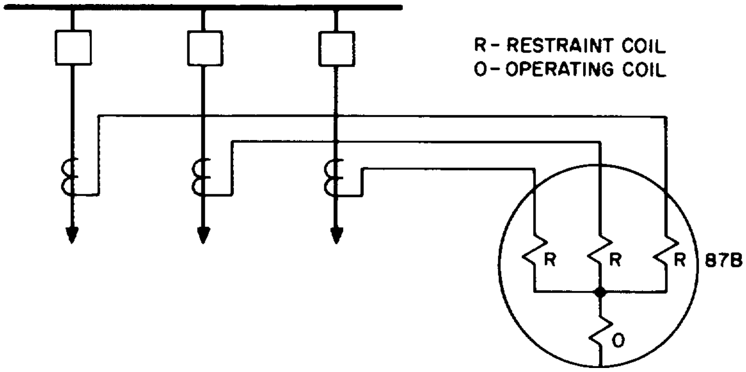

Figure 3— Differential Relaying with Percentage Restraint Relays

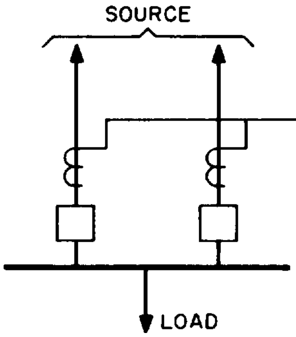

Figure 4— Partial Differential Protection

Either overcurrent or distance-type relays can be used for partial differential protection. Since these relays must be selective with the relays on the load circuits, pickup setting will be high, and time delay rather long. Consequently, the sensitivity and speed of partial differential protection is not as good as with complete differential protection.

3.3 Combined Differential Zones

Differential protection of power system buses can be extended to include apparatus not normally considered part of the bus. This equipment may be power transformers, combination of power transformers and the low-voltage bus, a tie line to another station, capacitor banks, reactors, or regulators. A typical example is a substation where two transmission lines supply a step-down transformer, as shown in Fig 11. A separate restraint winding in the differential relay is connected to each circuit which can be a source of fault current. If the transmission lines only provide supply to this substation, a combined differential arrangement can protect both the bus at which the lines terminate and the transformer. This arrangement accommodates omission of the high side transformer breaker.

Disadvantages of combined differential zone are: (1) an outage to all equipment in the protective zone occurs for any fault within the zone, (2) determination of fault location may be more difficult, and (3) sensitivity is usually not as good as that of a separate differential relaying system for each zone. The latter is evident when a bus zone is combined with a transformer zone. Here, the sensitivity of the combined zone is about equivalent to that of a transformer differential relaying system. When a bus zone is extended to include a short tie line, sensitivity is usually not a problem. A possible problem is excessive current transformer burden due to long current transformer secondary connections. Where this length is reasonable, the burden can be reduced by using larger conductors for current transformer secondary leads.

3.4 Directional Comparison Bus Relaying

Occasionally, it is desirable to add bus protection to an older substation where additional current transformers and control cable are too costly to install. In this instance, the existing current transformer circuits used for line relaying can also be used to provide protection for bus faults.

A directional comparison bus protection system compares the direction of current flow in each circuit connected to the bus [9]. If the currents in all the circuits flow into the bus, a bus fault exists. If the current in one or more circuits is flowing away from the bus, an external fault exists. Fault detectors are used to initiate the system. This system can be used for either or both phase and ground bus fault protection.

The basic system requires directional relays, fault detectors, and a timer. Directional relays are used on each circuit connected to the bus. Fault detectors are used to indicate a fault within the vicinity of the bus. Phase fault detectors are instantaneous overcurrent relays connected to a bus tie breaker or to one or more of the circuit connections. Ground fault detectors are instantaneous overcurrent relays connected in power transformer neutrals or to one or more of the circuit connections. A timer is required to permit contact coordination of the directional relays. The contacts of the directional relays are connected in series with the timer contact to initiate a trip signal.

Current transformer saturation is usually not a problem when comparing direction of current rather than comparing magnitudes of current as is done in conventional bus relaying systems. The current transformers in each circuit do not require the same ratio and can be used for other forms of relaying and metering. In some cases, the directional elements of relays used for normal circuit connection relaying can also be used for this bus protection system.

The system is rather complex and requires rigorous maintenance due to the number of relay contacts. The timer must be set for at least four cycles to assure contact coordination. Contact bounce must be avoided in the directional relays and in the overcurrent fault detector relays. Contact bounce should be checked when high-magnitude fault currents are likely.

The relays and relay settings must be reviewed when system changes are made near the protected bus to make certain that selectivity between initiating and blocking relays exists.

There is presently available [27] a directional comparison system based on directional comparison of the current in all circuits connected to the bus in relation to the sum of all the currents. This system employs solid-state relays. Intermediate current transformers are used, and main current transformer ratios and characteristics need not be the same on all circuits.

3.5 Fault Bus Protection

The fault bus system for the detection of ground faults requires isolating the bus support structure from ground and grounding this structure at one point through a current transformer. An overcurrent relay connected to this fault bus current transformer controls a multicontact auxiliary relay that initiates the trip circuits to all the breakers connected to the bus. The maximum effectiveness is obtained by this method when the switchgear is of the isolated phase construction, in which case the faults will always involve ground.

Since fault currents do not flow in this fault bus current transformer except for bus faults, the system can be made very sensitive. The trip circuit may be supervised by a relay in the neutral of the station ground relay current polarizing circuit to prevent false tripping from the accidental grounding of power tools, etc. Where unsupervised or where there is an overlap in the protected zone, a time delay is recommended.

The fault bus system is applicable to new installations where provision can be made for effective isolation from ground and where adequate treatment can be given to safety. Certain existing installations may not be adaptable due to alternate paths for ground fault current in concrete reinforcing rods or structural steel. It is necessary to insulate cable sheaths from the switchgear enclosure. An external flashover on an entrance bushing may cause improper operation unless the bushing support is insulated from the structure and independently grounded.

The integrity of the fault bus insulation is preferably tested by isolating the bus structure from ground. To permit testing of this insulation, a disconnect in the ground connection with a shunting safety gap can be provided. The system can also be tested by connecting a current source to the switchgear, accurately measuring the current and comparing it to the current in the fault bus relay. The trip circuit must be opened while this test is performed.

4. Common Bus Arrangements with Relay Input Sources

4.1 General

The application of bus protection to basic bus and circuit breaker configurations is discussed in this section and illustrated by single line diagrams. Relay input sources, such as current transformers or linear couplers, are shown in their normal locations for a typical bus protection scheme. Relay input sources are preferably located on the line side of each breaker to include the breaker within the protected zone. A faulted breaker may not be isolated by the successful operation of the bus protection system when a power source exists on the line side of a faulted breaker. The fault is still energized from this source and other relay systems must also operate to isolate the fault. See 5.9 on bus backup protection.

4.2 Bus Configurations

4.2.1 *Single Bus (Fig 1)*

This arrangement consists of a single main bus, with a relay input source for each connected line, generator, or transformer. This basic bus arrangement is a simple and economical design with a minimum of equipment. Similarly, the bus differential system can be simple and economical.

4.2.2 *Multiple Bus Sections with Bus Ties (Fig 5)*

This arrangement consists of single buses connected by means of bus tie breakers. Differential relay zones can be established with each overlapping the bus tie breakers. Only the faulted bus section is removed for a bus fault.

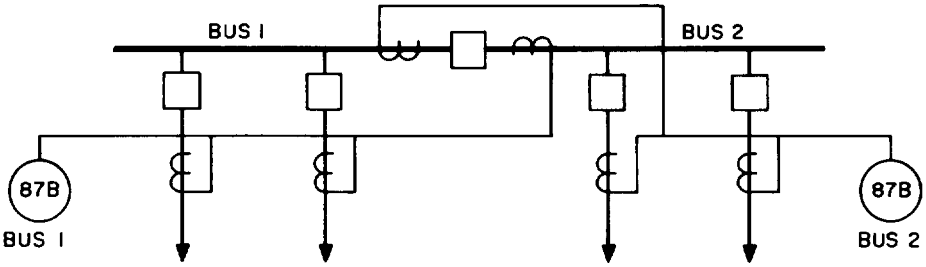

Figure 5— Multiple Bus Sections with Bus Ties

4.2.3 *Double Bus—Double Breaker (Fig 6)*

The double bus—double breaker configuration is shown in Fig 6. Each bus and its breakers are protected by a separate differential relay system. A fault on either bus clears that bus only; the other bus and all circuits remain in service.

4.2.4 *Main and Transfer Bus (Fig 7)*

The main and transfer bus is a modification of the single bus scheme, with the addition of a transfer breaker, transfer bus, and disconnects. The transfer bus may be rated less than the main bus. The purpose of the transfer system is to provide a means for bypassing a breaker during maintenance without circuit interruption.

The transfer breaker is included in the main bus differential scheme. The transfer bus becomes a part of the incoming line with the bypassed breaker and is not included in the bus differential zone.

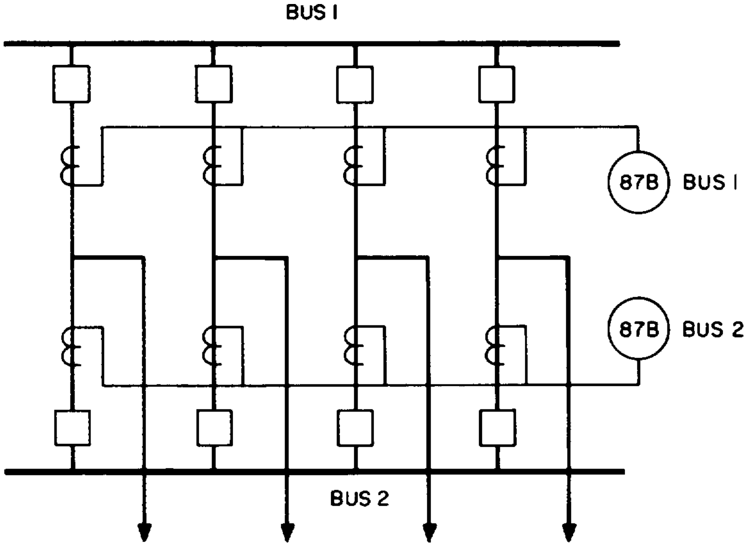

Figure 6— Double Bus — Double Breaker Arrangement

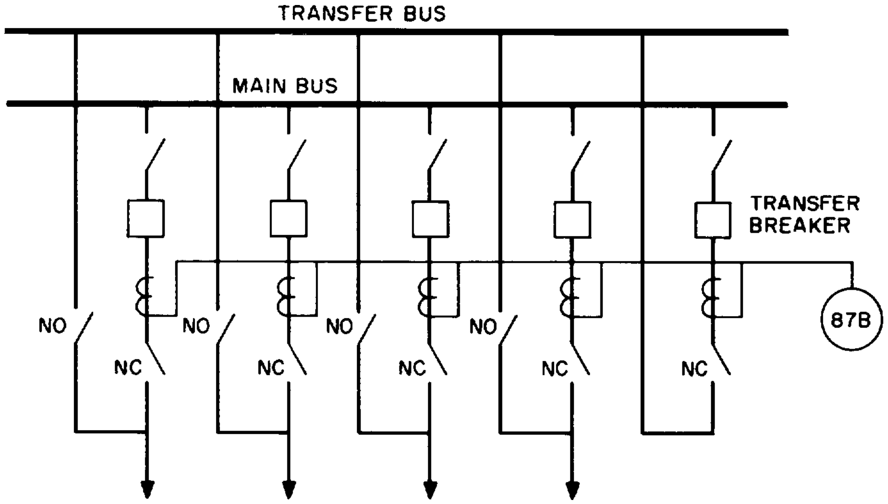

Figure 7— Main and Transfer Bus Arrangement

4.2.5 *Double Bus—Single Breaker with Bus Tie (Fig 8)*

The double bus—single breaker with bus tie provides operating flexibility comparable to that of the double bus—double breaker scheme of Fig 6. However, the use of only one circuit breaker per circuit results in increased differential relaying problems. Both buses are main operating buses and either or both may be energized at any given time. When both are energized, they may or may not be electrically connected. Furthermore, each circuit can be switched to either of the two buses.

Two bus differential zones can be provided, one for each bus with each zone overlapping the bus tie breaker. Because each primary circuit can be switched to either bus, each relay input circuit and breaker trip circuit must be capable of being switched to the proper relay zone. With this arrangement, special precautions are required to prevent incorrect differential relay operations. For example, when a circuit is transferred without interruption, the buses are tied through its two sets of bus switches prior to opening the bus switches to the initial bus. With both of these switches closed, unmeasured current may flow through this connection between buses resulting in an incorrect summation of currents in each differential relay circuit. If this incorrect current is of sufficient magnitude, incorrect operation of both bus differential relaying systems will occur.

One method of preventing this incorrect operation is to deactivate both relay trip circuits before switching. This requires that operating personnel know how to deactivate the relays and remember to reactivate them immediately following the switching procedure. A disadvantage is that no primary bus protection is provided for either bus during the switching. This is one of the periods when the probability of bus faults is high, and when it is desirable that bus protection be in service.

Another method is to reconnect the relay input circuits to convert temporarily to a single bus differential zone configuration. This eliminates the ability of the differential relays to discriminate between buses, but does retain primary bus protection during switching.

In another version of this bus arrangement bypass switches are installed on the line breakers. During breaker maintenance, one of the buses serves as the main bus while the other is used as a transfer bus supplied by the bus tie breaker. The bypassed breaker line is directly connected to the transfer bus without a breaker. All other lines are connected to the main bus through breakers. Since the relay input devices on the bypassed breaker are also bypassed, the differential scheme on the transfer bus now measures line current and may trip. Hence, this bus section's differential relays must be removed from service prior to bypassing the breaker. (For further discussion on problems associated with switching and bypassing, see 5.5.)

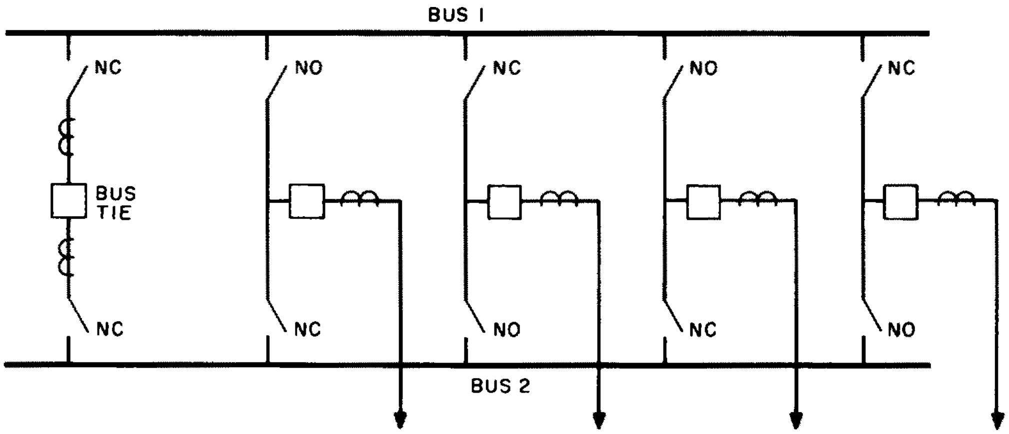

Figure 8— Double Bus — Single Breaker with Bus Tie Arrangement

4.2.6 *Breaker and One-Half Bus (Fig 9)*

The breaker and one-half bus is similar in operating advantages and bus relaying to the double bus—double breaker arrangement. Its advantage is economic, in that three breakers instead of four are required for each two circuits. Bus relaying is required for each main bus section only.

Directional-type bus protection systems are not recommended for use on the breaker and one-half bus arrangement since the direction of flow of fault current in component parts of the extremely low impedance bus network may not be predictable during bus faults.

4.2.7 *Ring Bus (Fig 10)*

The ring bus does not require bus differential protection. The bus section between each pair of circuit breakers is relayed as a part of the connected circuit.

4.2.8 *Single Bus with Connected Load (Partial Differential Protection) (Fig 4)*

The single bus with a transformer connected load may be protected by instantaneous relays or units of overcurrent relays which are set above low-side fault magnitude to provide proper coordination. The time overcurrent elements are set to sense low-side faults, to provide transformer protection, and to provide backup protection for low-side faults. If the primary of the transformer is fused, instantaneous protection cannot be coordinated.

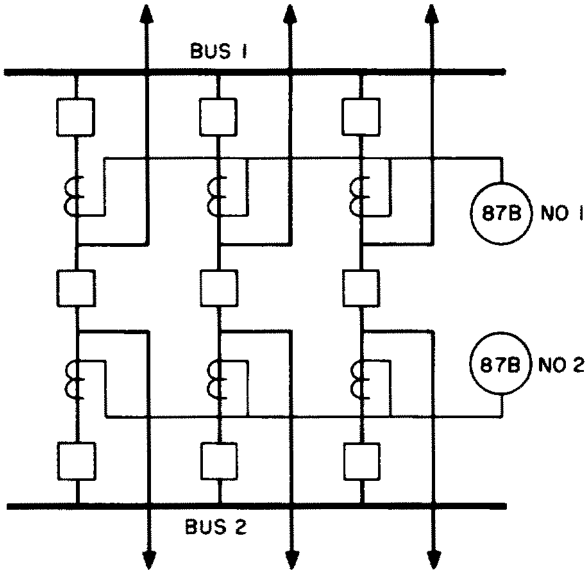

Figure 9— Breaker and One-Half Arrangement

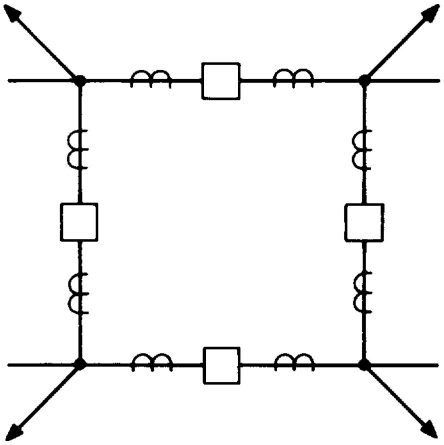

Figure 10— Ring Bus Arrangement

4.2.9 *Single Bus with Connected Load (Combined Differential Zones) (Fig 11)*

The bus arrangement with connected load illustrates the application of the combined differential zones discussed in 3.3.

The differential zone extends from the current transformer on the bus breaker(s) to the current transformer on the other side of the transformer. Both the bus and transformer are included in the differential zone.

Generally, transformer differential relays, rather than bus differential relays, are used in this application to accommodate transformation ratio and other problems associated with transformer differential protection. Hence, the bus is included in the transformer zone.

5. Other Considerations Associated with Bus Protection

5.1 Current Transformer Location

Bushing current transformers are not used in some extra high-voltage breakers. Each phase has a separate device containing a multicore multiratio current transformer. These current transformers are located on one side of the breaker.

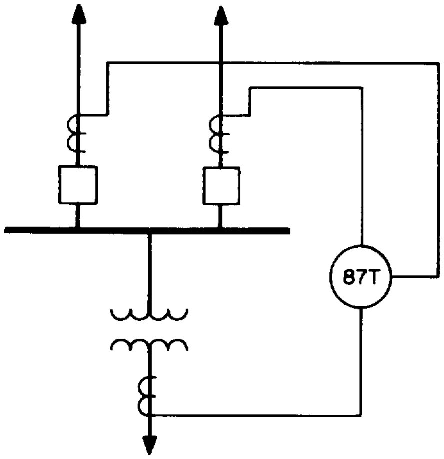

Figure 11— Combined Differential Zones

Hence, the breaker may not be within the bus protection zone. Additional relaying is usually provided in this case for breaker failure and current transformer failure.

5.2 Wiring and Grounding

The coupling of extraneous currents or voltages into bus differential circuits should be adequately considered. The principles of single point grounding of each metallically connected part of the current transformer system is particularly important in minimizing these effects [33].

5.3 Location of Bus on the System

The location of the bus on the system has a bearing on the selection of the type of bus protection scheme. Where system stability is a consideration, as at most generating station buses and bulk power substations, high-speed bus protective schemes must be used. At other locations, high-speed schemes minimize fault damage and duration of outage to loads tapped to the connecting lines, but slower speed schemes may be tolerable.

5.4 Bus Construction

Buses are built using several types of construction, such as strain bus, rigid bus, isolated or segregated phase bus, or are a part of metal-clad switchgear. A bus may be located indoor or outdoors or partially in both. Enclosed buses may be gas insulated.

Factors related to bus construction, such as electrical clearances and insulation levels, shielding against lightning, environmental conditions, etc, are of concern because of their effect on system reliability and the protection required.

However, few aspects of bus construction bear directly on the type of bus protection applied. An exception is the fault-bus scheme.

5.5 Problems Associated with Switching and Bypassing

Most special application problems involved in bus protective relaying are the result of the adaptability of the bus design to the required line switching and bypass procedures for the breakers connected to the bus. Usually, these problems occur at older stations that have been enlarged or at new stations based on lower cost design. These schemes may introduce limitations and undesirable features.

As an example, Fig 12 shows an arrangement where a transfer breaker can be used for either breaker bypassing or transformer protection. The transfer breaker normally protects the power transformer. When a line breaker is bypassed for maintenance, the power transformer is switched to the main bus without a breaker. The transfer breaker now protects the line whose breaker is bypassed. With the transformer connected directly to the main bus, it is necessary to trip the main bus for transformer faults. The trip and current circuits must be manually switched to protect the configuration during and after switching. Although manual control transfer switches are often necessary, it is wise to minimize their use. There is a hazard of switching them improperly. Reliability is decreased by extra contacts in the current and control circuit wiring. An indicating light is recommended for the abnormal position of the control transfer switch. It may be more desirable to switch control and current circuits automatically with auxiliary relays operated from bypass and other switches where practical. Although this will not improve the relay system reliability, it minimizes improper switching and failure to switch the proper circuits. A make-before-break switch or relay must be used for current transformer secondary switching. It is desirable to maintain bus protection while bus switching operations are performed. A switching operation introduces the possibility of a flashover or a switching error causing a bus fault. A transfer switch with an intermediate position or automatic transfer can keep differential relay protection in service during primary switching. Such provision does increase control circuit complexity and the hazard of improper control circuit switching. However, this may still be preferable to the removal of protection at a time when it may be needed the most.

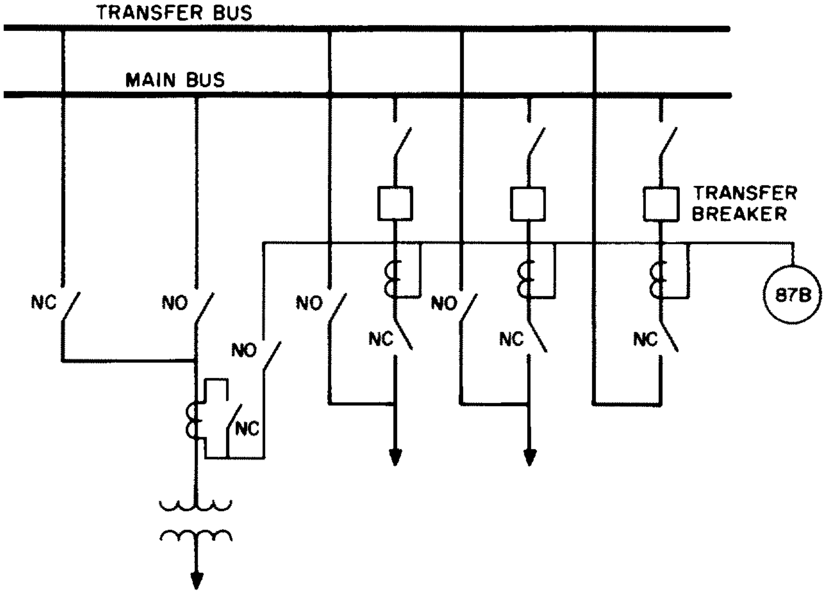

Figure 12— Special Main and Transfer Bus Arrangement

5.6 Auxiliary Tripping Relays

Bus protection relays usually energize a multicontact auxiliary relay which has individual tripping contacts for each breaker connected to the bus.

5.6.1 *Lockout Relays*

A common practice is to use a lockout type tripping relay to prevent reenergizing the bus until an inspection is made. It may also be desirable to interrupt the breaker closing circuits by separate lockout relay contacts connected in the closing circuit of each breaker to prevent breaker closing, even though the breaker would be immediately tripped by the unreset lockout relay tripping contacts.

One type of lockout tripping relay is spring actuated, with a latch released by a tripping solenoid. In one version of this relay a manually operated handle is used to reset the relay. In another version, a motor performs this reset function so that the relay can be reset remotely.

A second type of lockout relay uses an electrical seal-in coil to lock itself in the operated position. The seal-in coil is energized by one of the tripping contacts on the relay. A reset pushbutton momentarily opens the energized seal-in coil to reset the relay. A third type of lockout relay has a mechanical latch that is reset electrically.

5.6.2 *Nonlockout Relays*

Nonlockout (self-reset) tripping relays are used in some installations to permit automatic reenergization of a bus. A self-reset relay automatically resets when its coil is deenergized (in the case of bus protection, this means when the fault is cleared). It is often used at unattended locations where there is open bus work, no supervisory or remote control facilities are provided, and operator travel time is long. Hence, automatic reenergization of a bus will reduce outage time if successful.

5.6.3 *Ratings and Connections*

Bus tripping auxiliary relays are usually selected with underrated trip coils to obtain fast and positive operation. With a 130 V dc tripping supply a 24 V rated coil is frequently used. With lockout type relays two b contacts of the relay are usually connected in series with the operating coil to interrupt the coil current after the relay operates. This sudden interruption of the coil current may produce a high transient voltage across the coil. Diodes are sometimes used to minimize the effect of this transient voltage not only on this coil, but also on other portions of the control circuitry or other solid state components [26].

As with any auxiliary tripping relay, it may be necessary to use resistors in parallel with the relay coil to be sure that the target coils of the bus protection relays receive sufficient current to operate. If these resistors are used, they may eliminate the need for diodes to limit the aforementioned transient voltages.

5.7 Reclosing of Breakers After a Bus Differential Operation

After a bus has been cleared by the operation of its protective relays, an attempt to reclose the breakers can be accomplished by one of the following three methods:

1) Manually reclose the breakers, after repairs to the bus are made, or an examination of the bus indicates no visible damage
2) Reclose the breakers by supervisory control, provided that no lockout of breaker close circuits exists, or the lockout relays can be remotely reset
3) Reclose the breakers by automatic reclosing relays, provided that no lockout of breaker close circuits exists

The choice of the reclosing method is dictated by a tradeoff between the effect of the duration of a bus outage versus the consequences of reclosing into a bus fault. Type of bus insulation, system factors, safety, and possible damage to system equipment, such as transformers and turbine generators, should be considered.

A bus may be insulated so as to provide physical protection to the bus from outside interference. Examples of this type of bus are insulated cable, isolated phase bus, buses in metal-clad switchgear, SF_6 bus, and so on. A fault on a bus with this type of insulation is usually not self-clearing. For this reason, remote supervisory controlled reclosing or automatic reclosing of breakers is not likely to be successful for this type of bus. In this case the preferred practice is to reclose manually the breakers after examination and repair of the bus. Use of a manually reset lockout relay for tripping can also be used to lock out the close circuits of the breakers. The lockout relay will remind the operator that the different relays have operated and that the bus should be visually examined.

A bus which primarily uses air as the insulation medium is subject to faults from foreign objects, lightning, small animals, flashover of dirty insulators, and so on. An example of this type of bus is an outdoor open rigid bus or open strain bus. If these types of faults are promptly cleared, there is good probability that reclosing without inspection will be successful. One of the breakers connected to the bus can be equipped with a single-short reclosing relay to reclose the breaker for a dead bus—hot line condition. However. the differential relay must be sensitive to the reduced fault level to permit tripping in case of a permanent fault. If reclosing of this breaker is successful, the remaining breakers on the bus can be reclosed with automatic reclosing relays programmed to close the breakers for a hot bus—hot line condition provided other system conditions permit.

System stability may be such that the system may be able to withstand the initial fault without exceeding its transient stability limit, but subjecting the system by high-speed reclosing to the fault again may exceed the system transient stability limit. In this case, delayed automatic reclosing or delayed supervisory controlled reclosing can be employed if sufficient time is allowed for system oscillations to decay.

5.8 Testing of Bus Differential Relaying

The testing of bus differential relays and associated systems requires special care and accuracy on the part of the tester. The consequences of an inadvertent trip, due to tester error or of a false trip due to incorrect or incomplete test practices, are usually severe in that numerous circuits can be effected. Practices have been developed which considerably ease the problems facing the relay tester and improve quality and thoroughness. Specific practices are as follows.

5.8.1 *Test Switches*

Many utilities provide a test switch in each output circuit and in the coil of the lockout relay or other auxiliary devices used to control multiple breakers. These test switches are used to ensure that no inadvertent trip occurs when removing the relay from service or returning it to service. Test switches are also of significant value when performing trip tests in that the breakers can be tripped and closed one at a time to verify the integrity of the relay output circuitry. Covers are usually provided which cannot be put in place until the test switches are returned to their normal position.

5.8.2 *Permanent Test Facilities*

Permanently installed test equipment has been designed to check some types of differential relay circuits while the power circuit is in operation. These facilities use indicating meters to monitor preselected points in the relay circuit by means of a test selector switch. These types of test systems are described in the manufacturers' literature.

5.8.3 *Verification of Relay Input Sources*

Many problems with bus differential relay systems can be attributed to improper connections of current transformers and associated circuitry. Consequently, it is important to verify the ratio and polarity of the current transformers and the connections to the relays. Procedures for performing the above tests are well known throughout the industry. However, if not properly performed, failure to trip or false trips will result.

5.9 Bus Backup Protection

Failure of protective system components can occur, and backup for such failures must be considered. When a circuit breaker(s) fails to operate to clear a bus fault, it is necessary to initiate tripping of another circuit breaker(s) that feeds the fault through the failed breaker.

Circuit breaker failure can be detected by providing each circuit breaker with a fault detector that, working with the bus relays, initiates a timer to trip another circuit breaker(s). This detection system can trip local breakers directly, or it can initiate remote tripping of lines by direct transfer trip, by stopping carrier or line blocking schemes or by sending a permissive signal where required.

To protect against relay system failure, a duplicate set of relays with separate input sources, battery, and trip circuits may be provided. These relays may initiate direct tripping of the bus breakers or operate through a timer and a breaker failure scheme to trip other breakers, or both.

The backup systems described are not necessarily applied to all station buses. Other protective relay systems on the power input sources, such as overcurrent relays or impedance relay tripping through timers, may be adequate for backup. Longer fault clearing times and less sensitivity can be expected.

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