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MODERN APPROACHES TO BUS PROTECTION AND BREAKER FAILURE RELAYING

by

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INTRODUCTION

Though bus faults and failed breakers are generally rare, they can be catastrophic, and therefore demand a high degree of reliable and secure protection. Basic concepts still apply in protective relaying for station buses and breakers, but are utilized with modern approaches to give more flexible, reliable and secure service. And, often-times, using a well-proven concept with new technologies in protective relays gives the best results.

This paper will look at the basic concepts of protection of station bus and breaker arrangements, and examine various protection schemes—discussing existing relay concepts and introducing some modern approaches of providing bus and breaker failure protection.

BUS PROTECTION CONCEPTS

Bus Configurations

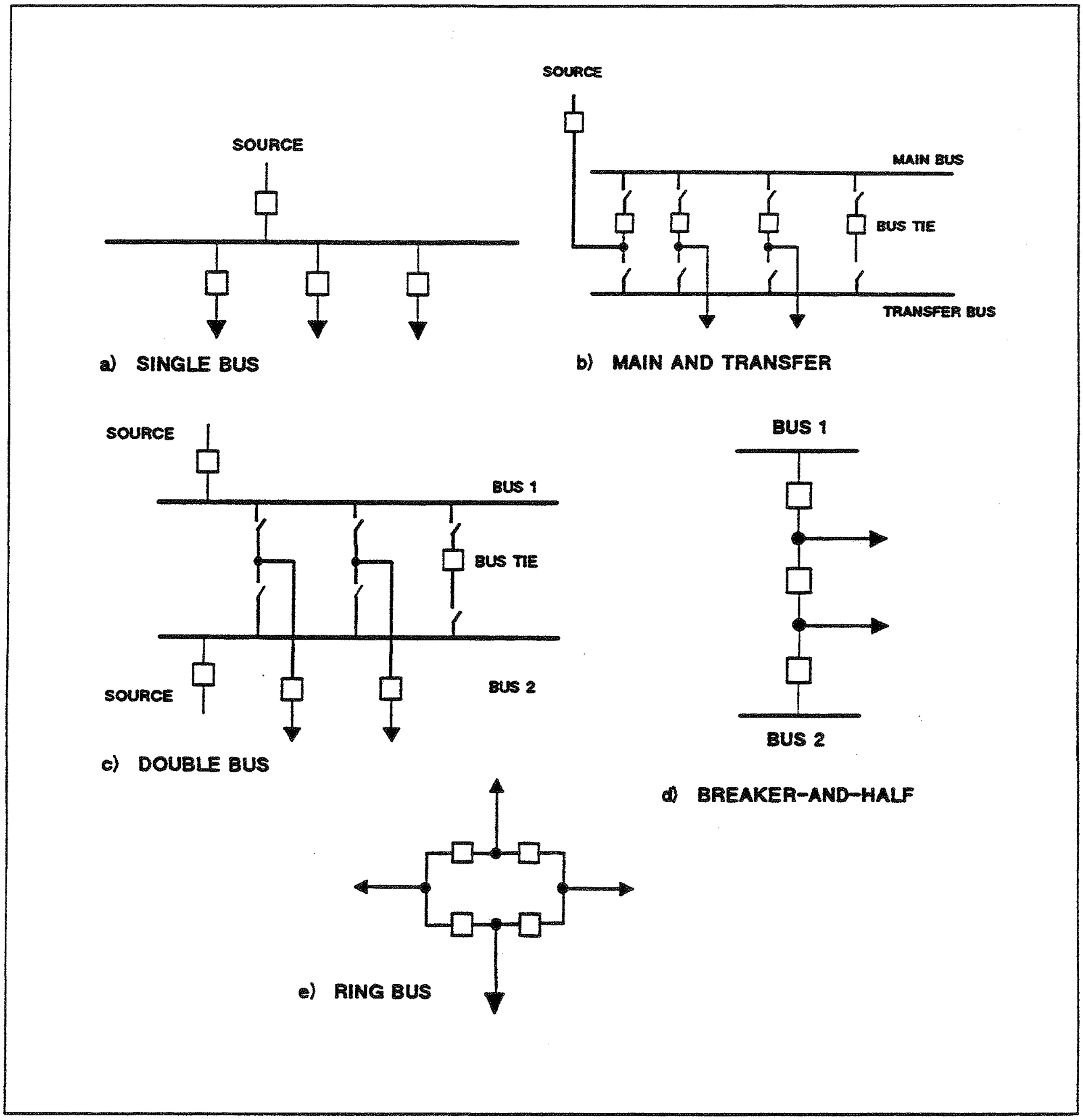
There are several common bus arrangements in use today. The type of configuration can be dependent on the number of circuits connected to the bus, ties between buses, location of circuit breakers, and the economic and flexibility requirements of the power system.

The basic single bus, shown in Figure 1a, is the most simple and reliable arrangement. It is fed by a single source and contains one breaker per circuit. Differential protection can be used, with one zone including all lines to the bus. Bus faults require opening of all breakers.

Variations of the single bus provide more flexible operation. Single buses can be interconnected by a bus tie arrangement, or can be used in a main and transfer bus scheme (Figure 1b). These allow some continuity of service for bus faults. Protection is accomplished by differential relays.

The double bus arrangement is shown in Figure 1c. Each circuit contains one breaker and can be connected to either bus. Switching between buses must be done in a sequence to ensure continuity of service and to prevent open-circuiting the ct secondaries. Two zones of differential protection are required, and a bus fault results in tripping of all circuits to that bus.

A similar double bus arrangement exists with a breaker in each line. A bus fault, in this case, would trip the breakers on the local end, and would still allow service to the circuits from the remote bus.



a) SINGLE BUS

b) MAIN AND TRANSFER

c) DOUBLE BUS

d) BREAKER-AND-HALF

e) RING BUS

Figure 1: Bus Arrangements.

The breaker-and-a-half (Figure 1d) is a two-bus scheme. Each bus supplies one line through a single breaker and a "shared" breaker. As with the double bus arrangement, two protection zones are required.

The ring bus (Figure 1e) is a combination line-bus scheme. Each line shares a bus and breaker with the adjacent line, which shares a bus/breaker with the next line, and so on. A fault on the "shared" bus requires tripping of the adjacent breaker.

Application Considerations

Several factors should be considered when applying protective relays to a particular bus arrangement. Both security and dependability are of equal importance. One contributing factor is ct performance—saturated cts on external faults, leakage impedance, knee point voltage and impedance burden. Depending on the relaying used, wiring arrangements and lead resistance should be considered. For a combination of bus and transformer protection, the relay must restrain on transformer magnetizing inrush. Other points to consider in application of the protective relay: number and arrangement of circuits, minimum fault current, ct ratios, ct mismatch.

Bus protection can be accomplished using differential relays such as medium or high impedance, variable percentage and linear coupler methods. The relays must be sensitive to light internal faults, yet restrain from operating on severe external faults with saturated current transformers.

Where simple bus arrangements exist and ct performance is good, an overcurrent differential scheme can be used for protection (Figure 2). Minimum internal fault current and maximum load current must be taken into account to accommodate using a time-overcurrent relay. Also, sensitivity and speed are sacrificed.

Another type of protection makes use of a linear coupler as shown in Figure 3. A linear coupler is an air-core reactor capable of accurately transforming current, usually producing 5 volts secondary for 1000 amps of primary current. They are not affected by saturation as with conventional iron-core cts. However the linear coupler scheme is limited in application. It is a more expensive device and would be dedicated to the linear coupler bus relay only.

Using conventional cts, where more sensitivity is required than with an overcurrent relay scheme, the multi-restraint differential

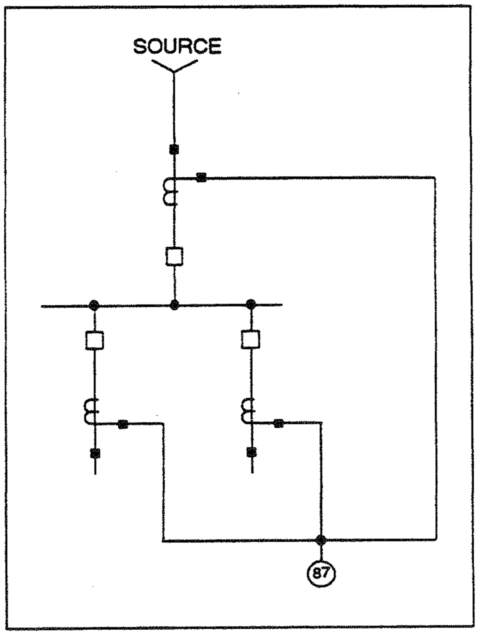


Figure 2: Time Overcurrent Differential.

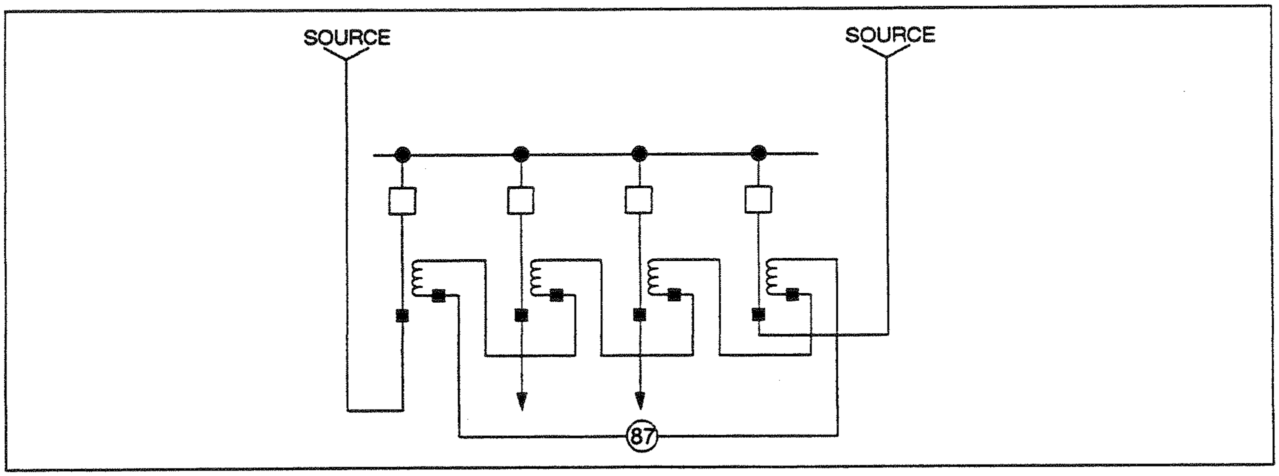


Figure 3: Linear Coupler Differential

relay can be used. An example of a six circuit bus is shown in Figure 4. A restraint circuit is connected to each line of the bus, so there is no response to external faults, even with saturated cts. This relay has a variable percentage characteristic which is more sensitive in detecting light internal faults and has less sensitivity at high external fault currents. This type of relay is more compatible with ct mismatch and errors due to non-linear ct characteristics.

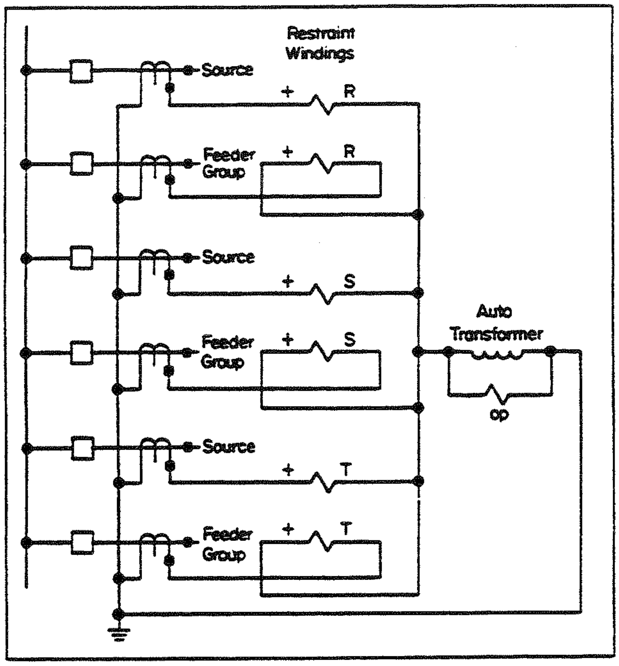


Figure 4: Multi-Restraint Differential

Other types of variable percentage multi-restraint relays are in use which include a 2nd harmonic restraint circuit. They are intended to be used when a transformer is included in the differential bus scheme.

A more common scheme used with conventional cts uses high impedance differential relays (Figure 5). These are high speed, high sensitivity relays. For an internal fault, the feeder cts appear as high magnetizing impedances. The relay impedance is also high. These provide a high burden to the source ct, producing a high voltage to operate the relay. For load or light external

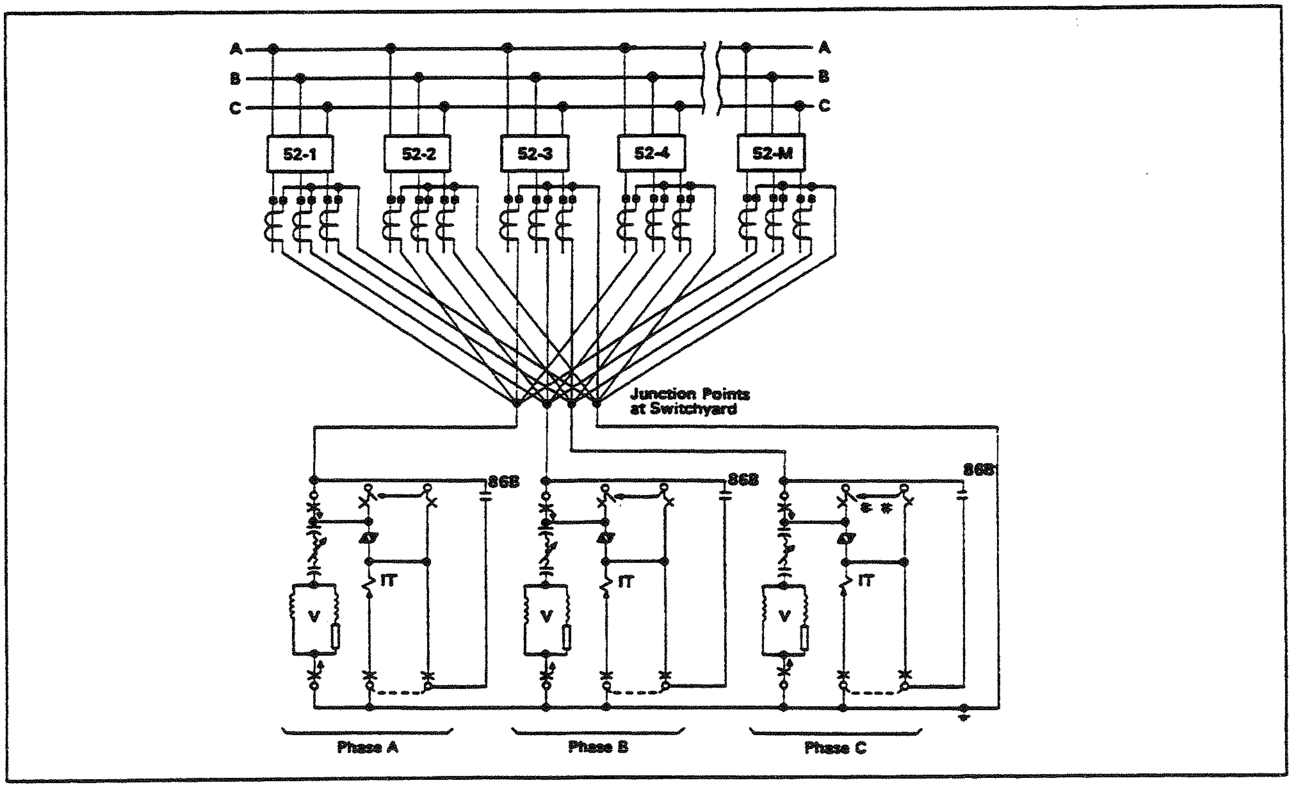


Figure 5: High Impedance Differential

faults, the differential voltage at the relay is approximately zero, preventing operation. For severe external faults when the faulted circuit ct saturates, currents are forced though the source and faulted circuit cts. A voltage is produced, however, it is less than the relay setting, preventing operation. Wiring is generally easier and less costly with these relays in that all leads from the cts are brought together to a junction point in the switchyard. Only one lead per phase is then wired back to the relay.

BREAKER FAILURE RELAYING

The subject of backup and breaker failure protection and all its application considerations and schemes can be discussed extensively, and is beyond the scope of this paper. However, some basic protection principles and existing relays will be discussed, as well as new technologies applied to breaker failure relay design.

Traditional Breaker Failure Scheme

The traditional breaker failure scheme is shown in Figure 6. At the occurrence of an internal fault the fault detector overcurrent unit (50) operates and the breaker failure (62X,62Y) is initiated. Both of these conditions are satisfied, the BF timer is started, and after a set time delay, the BF relay operates. The setting of the timer is critical for this arrangement. The normal clearing time of the fault is the operate time of the protective relay plus the breaker interrupting time. The BF timer must be set longer than the normal clearing time, including the overcurrent fault detector (50) reset time, plus a safety margin. Factors to consider in allowing a safe margin are breaker interrupting times, magnitude of fault currents, BF initiate (62X,62Y) times, and accuracy of the BF timer and the fault detector (50).

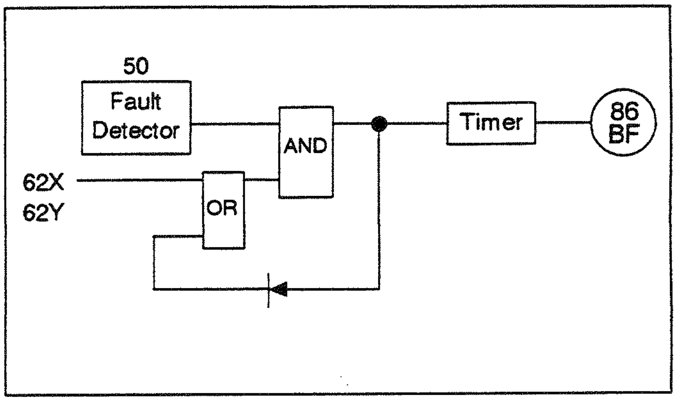


Figure 6: Traditional Breaker Failure Scheme.

New and existing relays have been using a scheme which is an improvement over the traditional arrangement. This scheme is shown in Figure 7. The BF timer is started by the BF initiate (62X,62Y) only. After it has timed out, the fault detector circuit is enabled. If current above a set magnitude is present, the BF relay trips. The advantage of this scheme over the traditional is that the total breaker failure clearing time is shorter, since the time is not affected by reset of the fault detector (50).

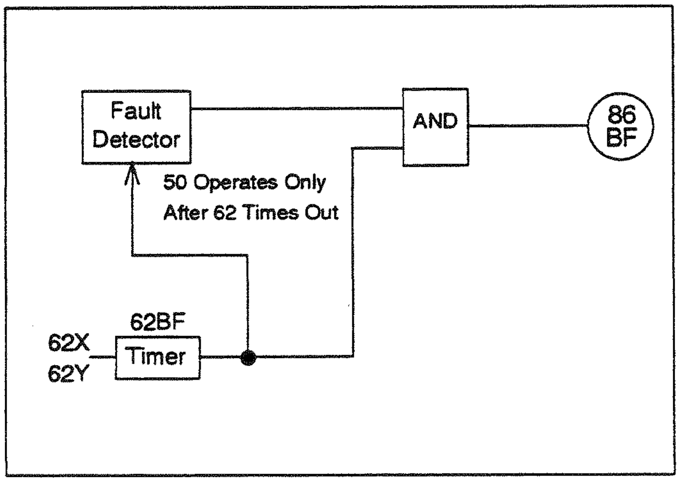


Figure 7: Improved Breaker Failure Scheme.

MODERN TECHNOLOGIES APPLIED TO STATION PROTECTION

Basic principles of bus protection, relay schemes, bus arrangements and breaker failure schemes have been fairly standard and unchanged in recent years. However, with the advancement in technologies, use of microprocessor relays can be applied which encompass a higher degree of dependability, flexibility, reliability in self-supervision, more bus/breaker circuits, and additional features previously not available with the traditional bus and breaker failure relays.

Differential Relay Bus Protection

One type of relay used is a medium impedance, percentage restrained differential relay for phase and ground fault protection of buses. It is a high speed relay, with fault detection in 1-3 ms, which provides reliable operation for internal faults and secure restraint on external faults. It can accommodate a large range of line ct ratios, other relays may be included with the same ct circuit, and station arrangements can be easily changed or added without concern for mixed ct ratios. This relay takes advantage of a well-proven design and the features of using a microprocessor. A simplified schematic and single bus connection are shown in Figure 8.

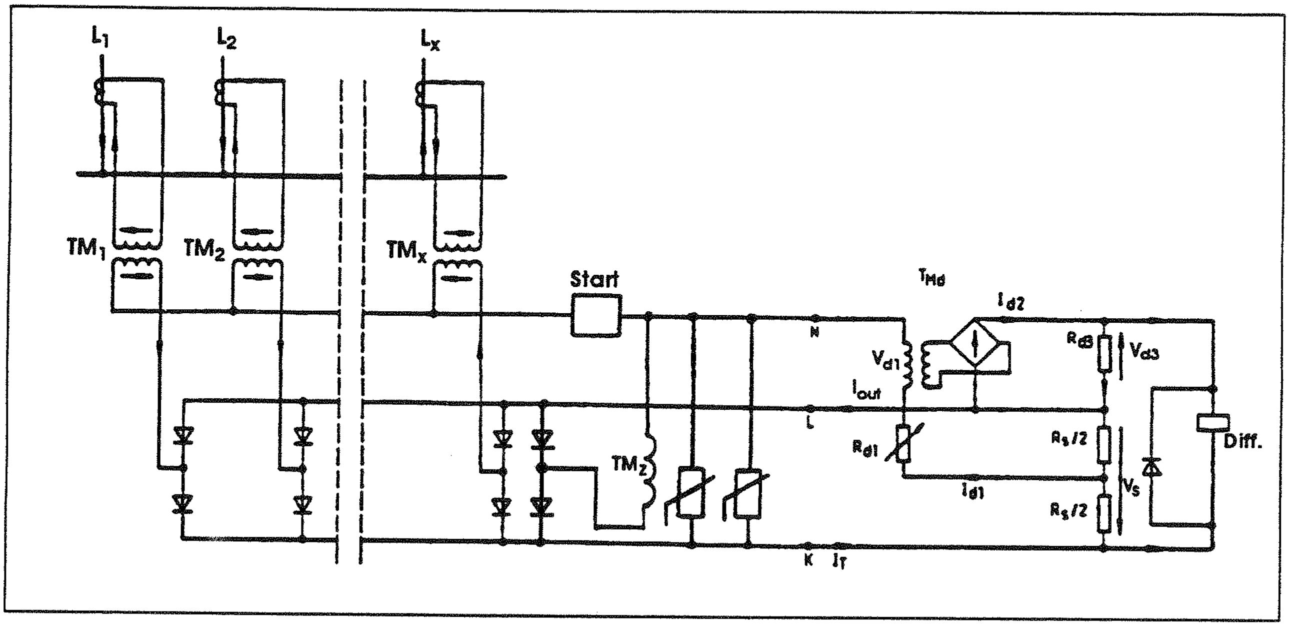


Figure 8: Medium Impedance Differential Relay

The relay operates on the principle of a differential comparison between all incoming and outgoing lines to the bus. Circuits L_1, L_2, ...L_x are connected to auxiliary transformers TM_1, TM_2, TM_x, respectively, which balance the main ct ratios. Current fed into the relay becomes I_{L1}, I_{L2}, I_{Lx}, combining for a total input of I_T at terminal K.

The comparator circuit is made up of resistors R_S, R_{d3}, R_{d1}, and transformer T_{MD}. Resistor R_S, across which is developed the restraint voltage V_S, is made up of two equal resistors. Operate voltage V_{d3} is developed across resistor R_{d3}. The differential resistor R_{d1} is a series connection of resistors which are connected depending on the characteristics of the cts and the required total circuit resistance.

The T_{MD} is a toroidal core transformer. The voltage developed across the primary V_{d1} is proportional to the differential current I_{d1}. This produces the transformed secondary voltage V_{d2}. Secondary current I_{d2} flows to develop operate voltage V_{d3}. However, the relay will not operate until V_{d2} is greater than the restraint voltage V_S.

Transformer T_{MZ} and the associated diodes are varistors make up the voltage limiting circuit.

For normal load flow, total outgoing current at terminal L (I_{out}) equals input I_T, and no differential current is present at terminal N. The relay will restrain.

During an external fault, the amount of differential current required to produce operation of the relay determines the stability, or restraint characteristic of the relay, slope S (Figure 9a). This indicates that the operate and restraint voltages will be equal when the differential current is a fixed percentage (50%)of the total incoming current I_T. As the ct saturates during an external fault, total loop resistance external to the relay is becoming more resistive. The amount of differential current that can flow is then dependent on the ratio of the total differential resistance of the relay (R_{TMD} + R_{d1}) to the total loop resistance. The relay will continue to restrain for differential currents up to the percentage slope value, with the total loop resistance within the allowable limits.

During an internal fault, the magnetizing impedance of the unloaded line cts appears as an inductive load to the relay. As differential current begins to flow, the restraint voltage developed across R_S is now partly reactive and lags the operate voltage V_{d3}. Differential current through the resistive circuit of the relay with almost a zero time constant produces an instantaneous operate voltage, compared to the rate-of-rise of the restraint voltage due to

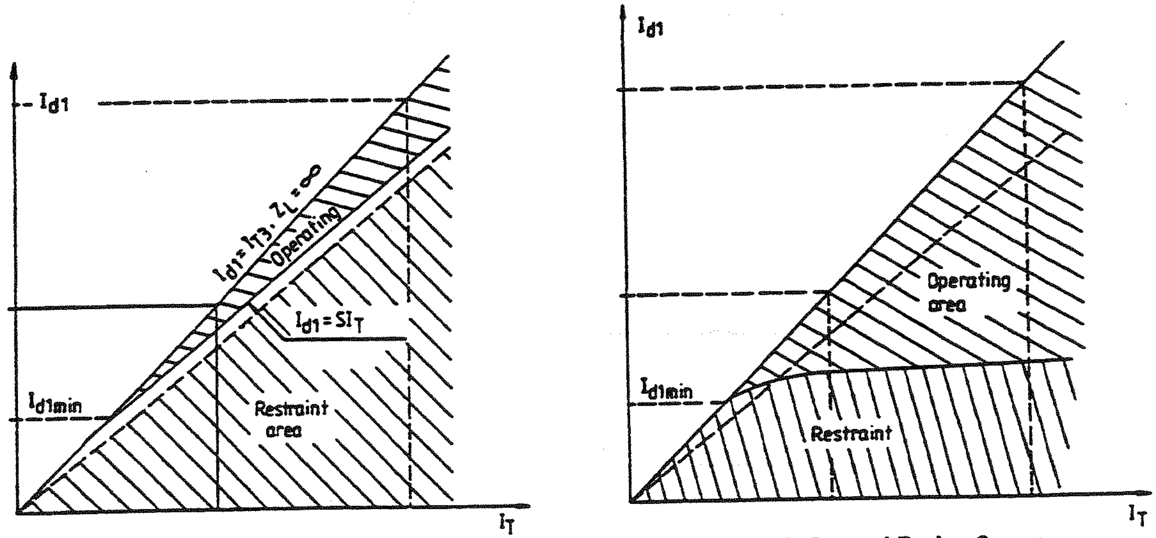


Figure 9a: External Fault—Restraint

Figure 9b: Internal Fault—Operate

Figure 9: Characteristics of Medium Impedance Relay

the magnetizing current of the cts, with a longer time constant. This causes the operate voltage to exceed the restraint voltage and ensures dependable operation of the relay for internal faults (Figure 9b).

All signals from the comparator circuit, settings, and external signals are input to a measuring unit which controls all the logic operations, timing, controlling and output functions, as shown in Figure 10. In addition to the differential function, the Start function operates when differential current through the Start transformer is above

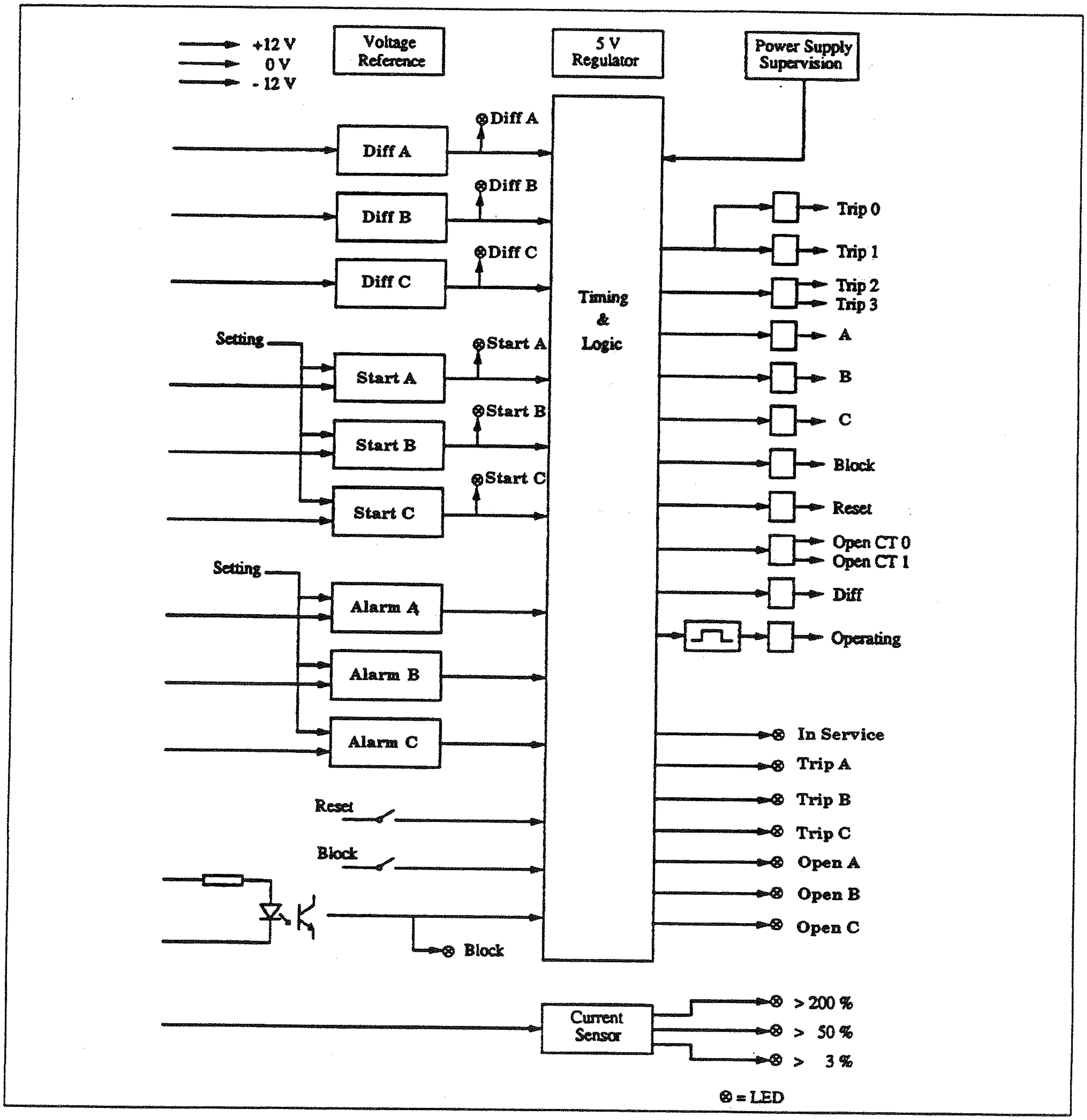


Figure 10: Measuring Unit—Medium Impedance Differential Relay.

the setting. The Start signal AND the differential signal is required for trip. When enabled, the Start function is then used to supervise trip. The Alarm function operates for an open-ct condition and will block trip.

Breaker Failure Protection Relay

In one type of breaker failure relay used, the scheme described earlier is integrated with microprocessor timing and control to provide accurate and dependable breaker failure operation.

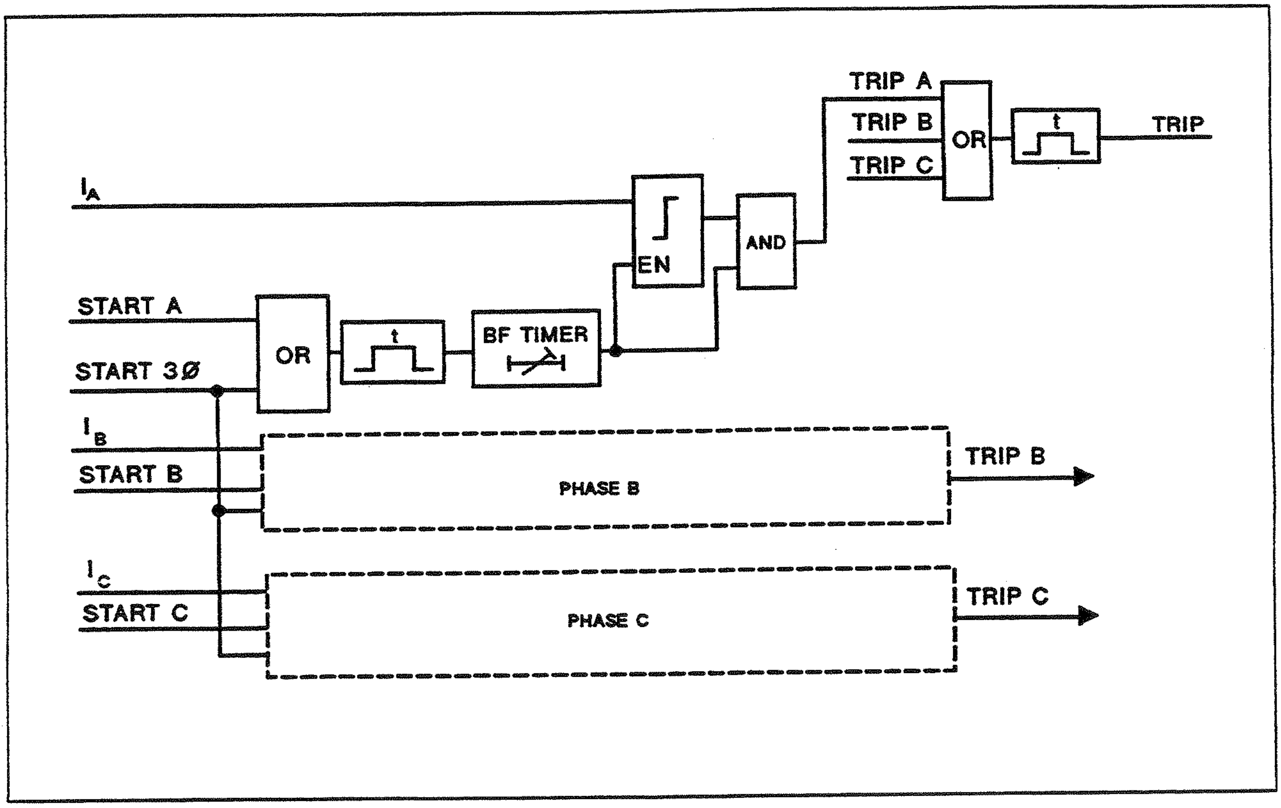


Figure 11: Breaker Failure Relay.

A simplified block diagram for one breaker is shown in Figure 11. Each breaker failure function, per line, is a self-contained modular unit. This is a 3-phase unit, with a Start input (BF initiate) for each separate phase or one 3-phase start. The Start signal starts the BF timer. After it has timed out, the timer signal enables the current comparator. Any one phase or a 3-phase initiate can be used as Start. One BF timer setting is used for all three phases. The timer signal and the current input, if present, are are fed to an AND function. If both conditions are satisfied, a trip signal is output. Provisions are made to seal in the Start signal for a fixed time delay. Provisions are made to seal in the Start signal for a fixed time delay, and also a function to retrip after a set time delay.

CONCLUSIONS

Many bus/breaker configurations are in use today. It is important to realize that though rare, bus faults and breaker failures can have a severe impact on equipment damage, safety, cost and system stability. Therefore, the protection used must be of equal importance.

Hopefully, by discussing several types of configurations and application considerations, and various relay schemes available, this paper has given insight into bus/breaker protection requirements and available solutions.

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