ZERO-SEQUENCE OVERCURRENT RELAY SCHEME

The zero-sequence overcurrent relay scheme employs a bushing current transformer with the power leads passing thru the opening as shown in Figure 1. An overcurrent relay is connected to the secondary winding. During balanced load conditions and during fault conditions that do not involve ground (such as line-line or 3 phase short-circuits), the sum of the phase currents is zero. The magnetic flux in the core of the current transformer is the sum of the fluxes set up by each phase current passing thru the opening. Since the sum of the currents is zero, the net flux in the current transformer is also zero; thus, under these conditions, there is no secondary current in the relay.

For line-to-ground fault conditions or unbalanced line-to-neutral load current, the sum of phase currents is not zero but instead equals 3 times the zero sequence current. The secondary current (neglecting exciting current) is given by the formula,

$$\text{secondary current} = \frac{3I_o}{\text{CT ratio}}$$

where Io is the zero-sequence current flowing in the power leads that pass thru the current transformer. For the case of a single line-to-ground fault, 3Io equals the ground fault current. For example, for a single line-to-ground fault of 100 amperes on phase A (see Figure 1a), the secondary current would be equal to 100 divided by the CT ratio; that is, 100 ÷ (100/5) or 5 amperes.

The conventional neutral overcurrent relay scheme is occasionally subject to improper operation due to false transient neutral current and this imposes limitations on the sensitivity and speed of the scheme. Since the zero-sequence scheme responds only to the flow of zero-sequence current in the power leads, it is not subject to false operation due to current transformer saturation during sudden balanced overcurrents such as motor starting current. Thus, the zero-sequence scheme can generally be made more sensitive and faster than the neutral overcurrent relay scheme. However, since the power leads must pass thru the opening in the current transformer, the zero-sequence scheme is applicable only to cable circuits.

CO-ORDINATION OF CURRENT TRANSFORMER & RELAY CHARACTERISTICS

In the example in Figure 1a, the exciting current of the transformer was neglected. In actual applications, the exciting current plays an important part in the overall performance of the scheme, especially in the ability of the scheme to detect low ground fault currents. The characteristics of the current transformer and the burden of the relay are the principal factors that determine the overall performance of the scheme.

The type BYZ, 100/5 ratio zero-sequence current transformer has been designed for the zero-sequence overcurrent scheme. It is a single ratio bushing current transformer with a mounting frame designed for mounting in metalclad switchgear. Its characteristics have been co-ordinated with the various standard overcurrent relays to give sensitive ground fault detection. To simplify the application of the zero-sequence scheme, the following table has been prepared to indicate the minimum ground fault current for which the relays shown will operate with the type BYZ, 100/5 ratio zero-sequence current transformer.

APPLICATION	TYPE RELAY & CURRENT RANGE	SETTING	APPROXIMATE MIN. GROUND FAULT CURRENT FOR WHICH THE RELAY WILL OPERATE AT THE SETTING SHOWN.
Instantaneous	ITH (.25-.5)*	.25	8 amperes
	SC (.5-2.0)	.5	17
Time Delay	CO-8 CO-9 (.5-2.5)	.5	15
	CO-11 (.5-2.5)	.5	12

*range can be extended to .25-1.0 by adjustment of relay.

The relays that are more commonly used are shown in the above table, however, other relays may be used for special applications. Although the above relays operate on relatively low ground fault current, they are protected from excessive secondary current during the flow of high ground fault current in the primary by saturation of the BYZ current transformer.

SELECTION OF OVERCURRENT RELAY

The preceding table shows that either instantaneous or time delay relays may be used in the zero-sequence scheme. For individual motor circuits or transformer circuits, instantaneous tripping is generally desirable; hence, the type ITH relay is recommended for these applications. An important exception to this recommendation occurs where the motor or transformer is equipped with lightning arresters for surge protection. The reason for this is that the power-follow current flowing thru the arrester before the arrester "seals-off" is equivalent to a momentary ground fault with fault resistance. The power-follow current may have a duration up to 1/2 cycle (based on the frequency of the power system) and is capable of causing the improper operation of instantaneous type relays. Hence, for motor circuits having arresters for surge protection, instantaneous type relays should not be used, and instead, a type CO-11 relay is recommended. The short time delay provided by the CO-11 relay will override the power-follow current of the arrester.

*A steel tube liner is used in the opening of the current transformer to protect the secondary winding from high voltage and from primary faults. The opening sizes given are the inner diameters of the steel tube liner.

For circuits requiring time delay for coordination with other ground relays such as on group feeder circuits, the types CO-8 and 9 relays are recommended.

SELECTION OF CURRENT TRANSFORMERS

Three type BYZ current transformers are available with different size openings to accommodate the full range of cable sizes. The standard inside diameters are 2-3/4, 4 and 7 inches.* The 2-3/4 and 4 inch openings will accommodate the great majority of cables circuits. The current transformer core has been designed to compensate for the various opening sizes so that the sensitivity of the scheme is independent of the size opening. Thus the application table in the preceding section applies to all BYZ, 100/5 ratio zero-sequence current transformers and the only factor that needs be considered in the selection of the current transformer is the size opening to accommodate the cable.

LEAKAGE FLUX EFFECTS

On Page 1, the theory of the zero-sequence current transformer was presented; that is, the magnetic flux in the core is the sum of the fluxes set up by each phase current passing thru the opening. Since the sum of the currents is zero under normal conditions, the net flux in the core is also zero and there is no secondary current. The theory is valid for a "perfect" toroidal current transformer; that is, a current transformer that has no leakage flux.* The practical design of zero-sequence current transformer has a small amount of leakage flux.

The presence of leakage flux means that the net flux in the core may not be zero even though the primary currents are balanced, hence inducing a small secondary voltage. Leakage flux effects in the type BYZ current transformer has been investigated by high current tests with the following results:

(a) Symmetrical spacing of the primary conductors in the center of the opening tends to minimize the induced secondary voltage due to leakage flux.

(b) The steel tube liner in the BYZ design appreciably reduces the leakage flux effects as compared to the same design without the tube liner.

(c) The relays as listed on Page 2 will not operate due to leakage flux during the flow of balanced short-circuit currents as high as 44,000 amperes even for unsymmetrical spacing of the conductors in the opening of the BYZ current transformer. Thus, symmetrical spacing of the conductors in the opening, although helpful, is not necessary as far as the relay performance is concerned.

*A theoretically "perfect toroid" is one having an infinite number of turns so that the secondary appears as a solid sheath around the core.

CURRENT TRANSFORMER INSTALLATION & CABLE CONNECTIONS

The BYZ current transformer may be mounted at the top or bottom of the rear compartment in standard metalclad switchgear to accommodate cables that enter from either the top or the bottom of the switchgear. In either case, the cable should enter the current transformer at the H1 terminal marking; that is, the cable should enter the steel mounting plate, pass thru the steel tube liner and then "fan-out" to the bus or phase current transformers or pothead. The following paragraphs list some additional factors that should be considered when using the zero-sequence overcurrent relay scheme.

1. **Potheads:** When using the zero-sequence scheme, the pothead mounting should be insulated from the switchgear structure. The frame of the pothead should be grounded by means of a separate ground lead (4/0 or larger) connected to the pothead frame and passing thru the opening of the BYZ current transformer and then connected to the ground bus in the switchgear. By this means, a failure of insulation in the pothead results in the flow of ground fault current thru the BYZ current transformer and thus such faults can be detected by the zero-sequence scheme. See Figure 2.

2. **Armored Cable:** Generally, it is recommended that the armor be terminated before the cable enters the BYZ current transformer.

3. **Lead Covered Cable:** Lead covered cable including the lead sheath should pass thru the BYZ current transformer and terminate at the pothead. As mentioned in Paragraph (1) the pothead should be insulated from the switchgear structure, and a separate ground lead, connected to the pothead frame, should pass thru the BYZ opening to the switchgear ground bus.

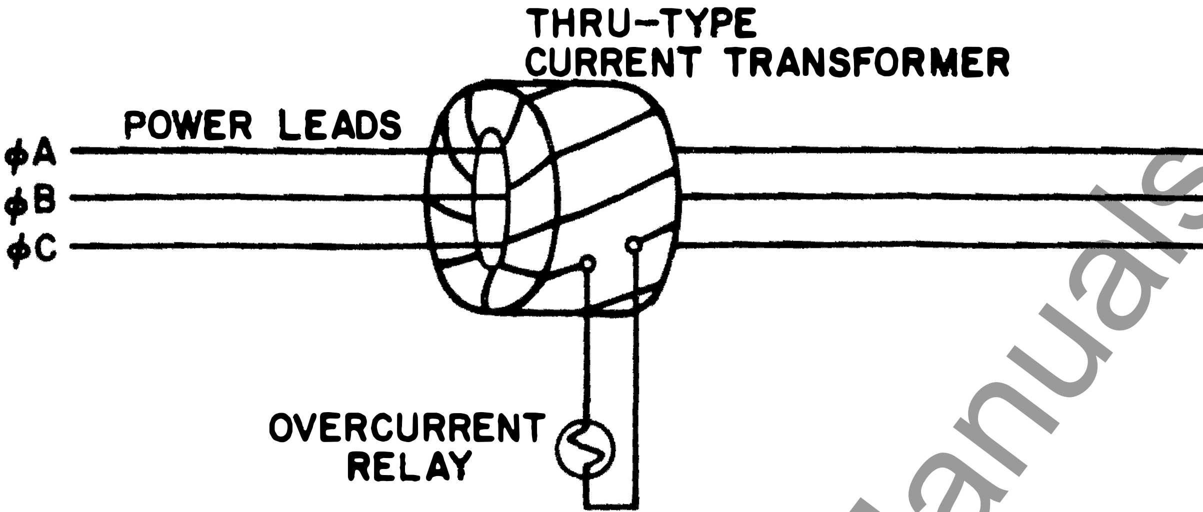

FIGURE 1 ZERO-SEQUENCE OVERCURRENT RELAY SCHEME

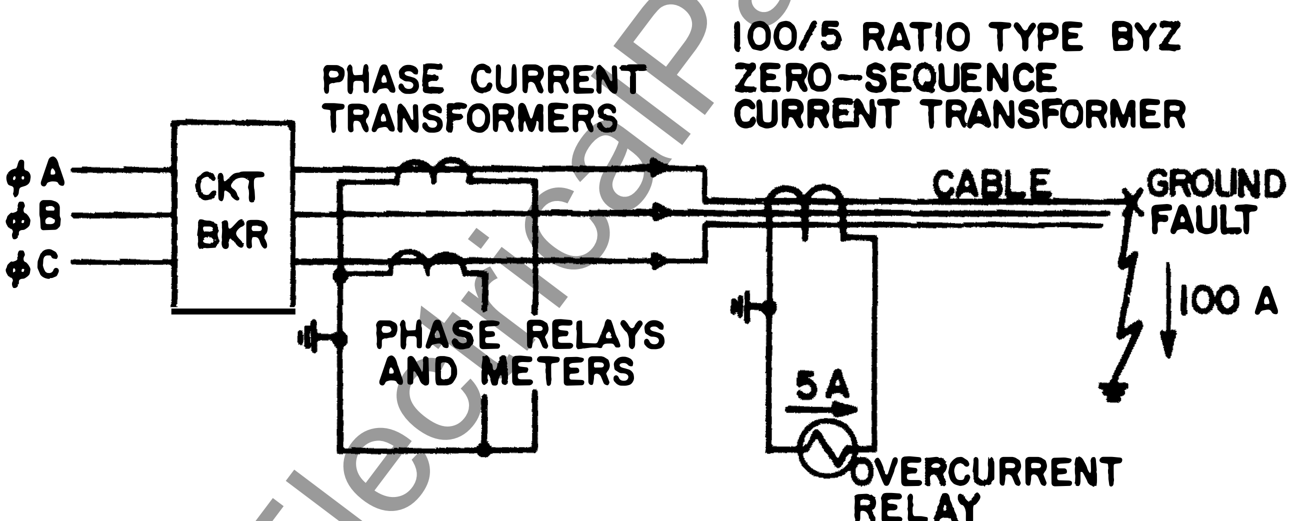

FIGURE 1A EXAMPLE OF ZERO-SEQUENCE OVERCURRENT RELAY APPLICATION OF A CABLE CIRCUIT WITH A 100A GROUND FAULT ON ¢ A

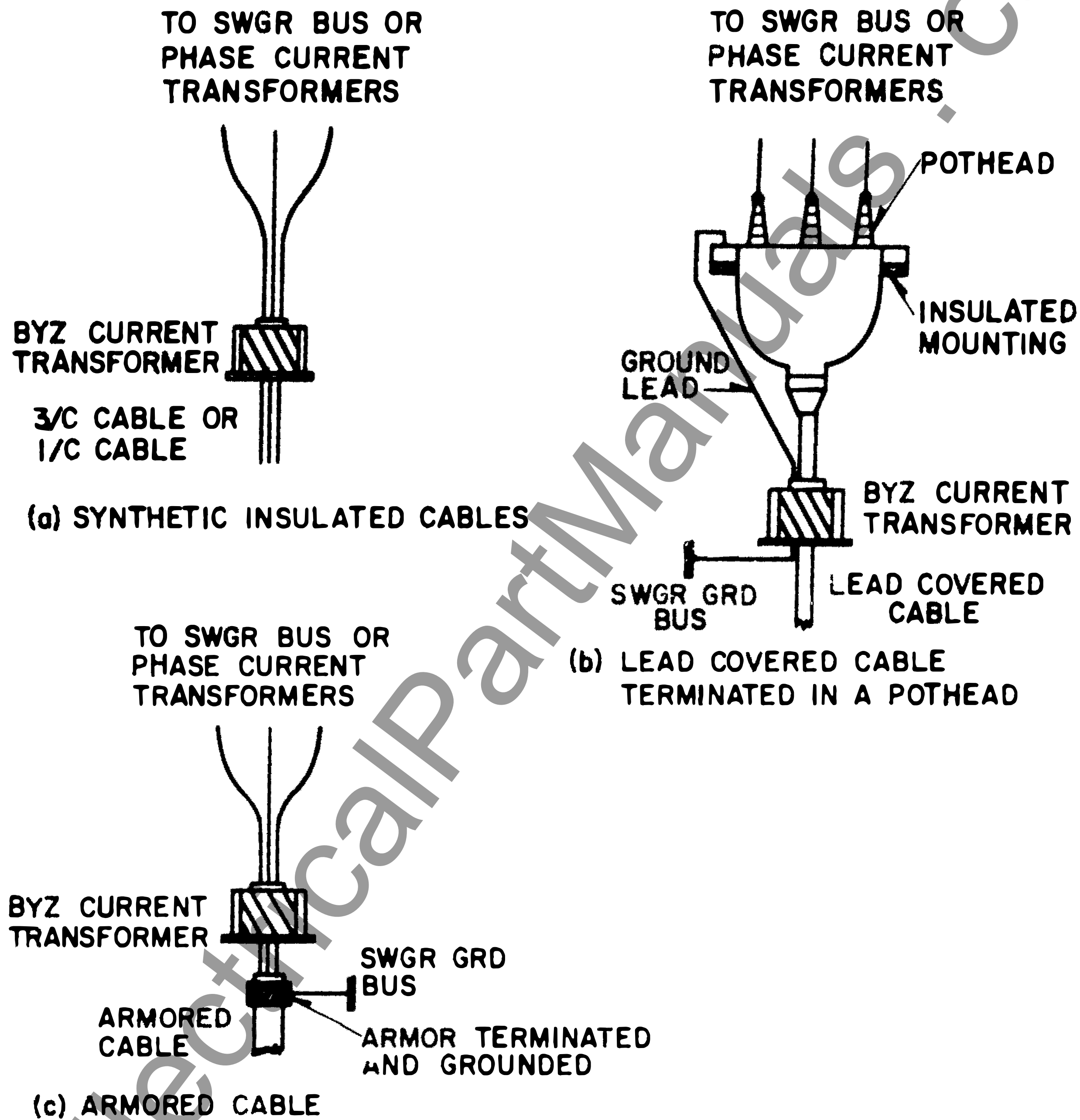

FIGURE 2 RECOMMENDED CABLE CONNECTIONS WHEN USING THE ZERO-SEQUENCE OVERCURRENT RELAY SCHEME