Shortcuts to

Selecting and Coordinating Electrical Trip Devices

By **R. L. SMITH, JR.,** Application Engineer, Industrial Power Systems, General Electric Co., Schenectady, NY

"THE FAULT WAS SO SEVERE that the plant service entrance breaker tripped." This statement is often made to describe the severity of an electrical fault. Tripping of the plant main breaker is not necessarily a measure of fault severity; it is, quite often, an indication that there is a lack of coordination or selectivity in the trip settings of electrical protective devices.

A typical example of improper coordination is the case of a small plant in the south which experienced a fault on a large low voltage feeder a few years ago. The only protective device which opened was the service entrance breaker, Fig. 1.

This short circuit was of a limited nature, and not a "bolted 3-phase fault." Short circuit current was estimated to be about 10,000 amps at 480 v. Subsequent examination of the settings on protective devices revealed the following operating times:

Low voltage feeder breaker . . . . . . 13 to 50 seconds
Transformer main secondary breaker . . . . 24 to 170 seconds
Plant service entrance breaker and relay . . . . 0.93 seconds

A bolted 3-phase fault of about 60,000 amps would have caused all three breakers to trip instantaneously.

Coordination, selectivity and backup. The example described illustrates a lack of coordination or selectivity between overcurrent protective devices in a typical power system. The words "coordination" and "selectivity" are, in a sense, complementary terms, and are used to describe the relative speeds at which two protective devices open when subjected to the same short circuit or ground fault.

By industry standard definition, a protective device is said to be *selective with* another, downstream, protective device if opening of the upstream device is intentionally delayed to permit the downstream device to operate first when they both "see" the same fault. Although not an industry definition, it is common practice for relay engineers to speak in terms of the downstream device *coordinating with* the upstream device. With such an arrangement, the selective device is sometimes called "backup" for the device set to operate first. It may also be the only protection (primary protection) for the circuit elements between the two devices. These relationships are shown in Fig. 2.

Protection and selectivity. Protection and selectivity are often contradictory goals. Fast removal of a faulty portion of a power system can cause nuisance tripping on short circuits in an adjacent portion of the system. Slowing a protective device to achieve selectivity with another protective device in an adjacent portion of a power system can result in more damage to the elements of the system for which the slower device is the only protection. Compromising of protection to limit the extent of a power outage must be balanced against the economics of possible increase in equipment damage and the increased potential safety hazard.

Protective device settings must be determined. Most protective devices received by the user are preset at an arbitrary point. Usually, low voltage power circuit breakers are shipped with the long-time delay preset at 100 percent and the instantaneous trip element preset at *maximum*. Time overcurrent relays frequently are received by the user with the time overcurrent tap preset at an arbitrary value such as 5 amps.

The time dial is preset either at "0" or "1" and blocked. The instantaneous element is preset at the *minimum*. Most molded case circuit breaker instantaneous elements are preset at *maximum*. Considering the settings of devices as received, it is apparent that neither the desired sensitivity nor selectivity can be achieved without onsite determination and readjustment.

Integrating with the power system. Often a load center or unit substation is planned and ordered prior to completion of the entire power system design. Sometimes primary system data are not available until after the load center is ordered; it is then difficult to accommodate any changes. General suggestions given here are applicable to both magnetic and static low voltage trip devices and protective relays.

The suggestions involve selection of ratings and settings for both primary and secondary trip devices, plus some general guides to feeder trip device size selection. Adherence to these recommendations will increase the probability that a given substation will integrate properly with the rest of the power system, and that any future, possibly more refined, coordination studies will present no unusual problems.

Primary system protective devices. Primary distribution system phase overcurrent relays protecting load centers or feeders to load centers usually are specified with tap ranges to allow pickup settings from 2½ to 6 times full load transformer current. These are the limits recognized by the National Electrical Code for liquid-filled transformers. Although a pickup point of six times full load current is permitted for protection of transformers with main secondary breakers, lower settings are often used to protect the primary feeder cable.

Low time dial settings and relatively high instan-

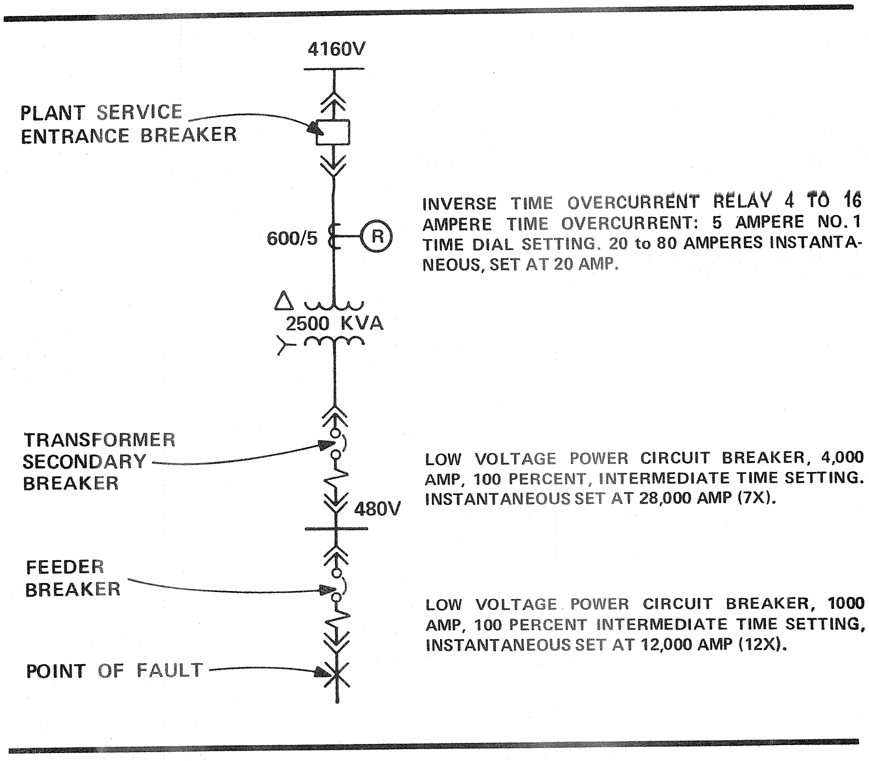
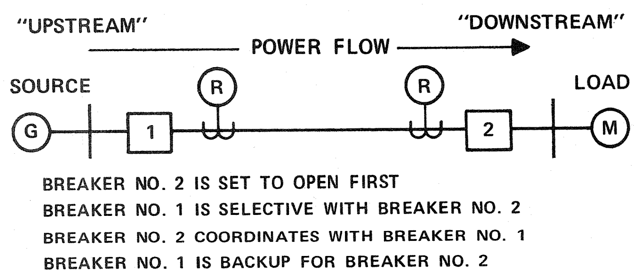


Fig. 1. One-line diagram of power system discussed in example. Lack of coordination caused service entrance breaker to trip on relatively light fault current of about 10,000 amps. A fault current of 60,000 amps would cause all three breakers in this system to open.

Fig. 2. Graphical description of expressions in common use to describe coordination (or lack of coordination). With proper coordination, only the first breaker upstream of the fault trips, preserving service to the rest of the system.



taneous trip element settings on the transformer primary provide fast operation for overload conditions and avoid instantaneous tripping for faults on the secondary. Primary fuses, if used, are usually rated from about 1½ to 2½ times full load transformer current. If a setting of 6 times transformer full load current is used, the primary cable may not be protected for overload by the primary relays.

However, if the sum of all the main secondary breaker settings allows a current in the primary cable within its rating, the primary relaying can be set to trip above the overload rating and below the short circuit heating limit of the cable. A low time dial setting and reasonably high instantaneous element setting usually affords adequate short circuit protection for primary cable.

The 1971 edition of the *National Electrical Code* requires that the maximum rating or setting of the primary overcurrent protective device for a dry type transformer be no more than 250 percent of rated full load current for a transformer equipped with a main secondary breaker that is rated or set at no more than 125 percent of transformer full load rating. Other rules applying to installations where no main breaker is present are set forth in Article 450-3 of the Code.

Main secondary circuit breakers. The continuous current rating of the main secondary circuit breaker trip device is usually 1¼ to 1½ times transformer full load current. This breaker should be equipped with long-time and short-time delay trip elements.

A long-time delay device is usually set at 100 percent of the trip coil rating, and it must not be set any higher than 250 percent of full load rating for liquid-filled transformers. This is the upper limit permitted by Code.

Adherence to these recommendations will help assure an adequately coordinated load center unit substation design:

- Equip main secondary circuit breakers with long-time delay trip elements set at 125 per cent of transformer full load current and short-time delay trip elements set at 2 times trip device rating.
- Equip feeder circuit breakers rated no larger than 1/3 of transformer full load current with long-time delay and instantaneous elements. Set the instantaneous elements at 6 times the trip device rating.
- Equip feeder circuit breakers rated at more than 1/3 transformer full load current with long-time, short-time, and instantaneous elements. Set the short-time elements at 2 times the trip device rating. Set the instantaneous element at 6 times the trip device rating.
- Set primary relay pickup no lower than 2½ times transformer full load current and no higher than 6 times. Set the instantaneous element no lower than 20 times transformer full load current rating.
- Check the degree of protection afforded the primary cable by primary relaying. Overload protection may be obtained by lower settings on transformer secondary breakers, while relying on primary relaying for short circuit protection only.
- After finished design of the complete power system, perform a final, formal coordination study to verify selection of ratings and settings for protective devices.

Fig. 3. Trip characteristic curves are plotted for 1000 kva substation (where low voltage circuit breakers are equipped with magnetic overcurrent trips). Value of device ratings and settings were determined empirically from table in this article; trip characteristic curve plot verifies validity of criteria in table.

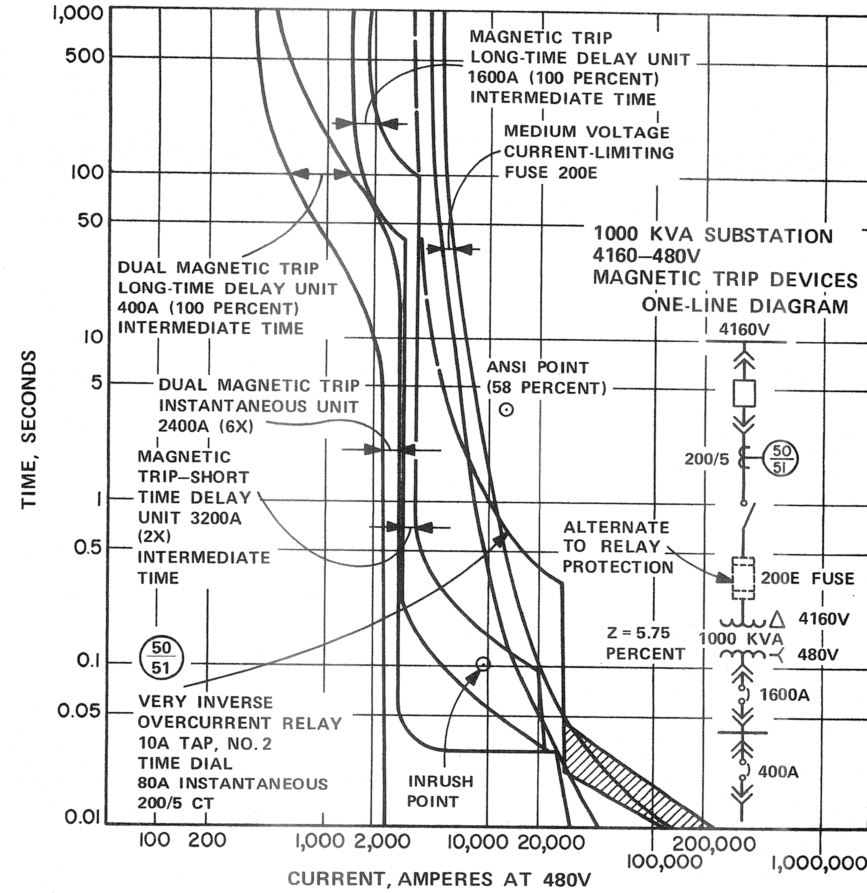
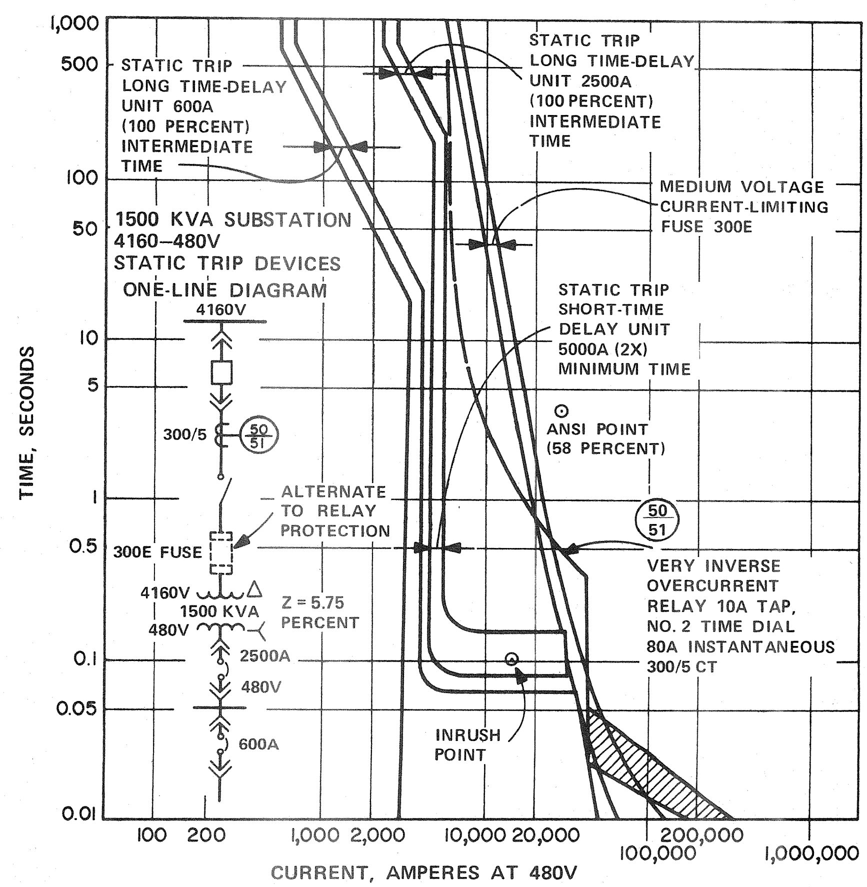


Fig. 4. Trip characteristic curves are plotted for 1500 kva substation (where low voltage breakers are equipped with static trip devices). Coordination criterion had been determined from table; results are verified by these curves.



LOAD CENTER PROTECTION COORDINATED SYSTEM
4,160V DELTA – 480V WYE①

Substation Size, kva	500	750	1000	1500	2000
Substation Impedance, Percent Z	4.5	5.75	5.75	5.75	5.75
Primary Voltage	4160	4160	4160	4160	4160
Secondary Voltage	480	480	480	480	480
Primary Maximum Rated Load Current, Amperes	69.3	104	139	208	278
Secondary Maximum Rated Load Current, Amperes	601	902	1203	1804	2406
ANSI Point (in 480V amps) $= 0.58 \times \frac{1}{\text{impedance}}$ x FL for 3.7 Secs (5.75 Percent Z) or 2.5 Secs (4.5 Percent Z)	6062	9098	12,138	18,184	24,269
Inrush Point 8 x FL for 0.1 Sec (in 480V amps)	4808	7216	9624	14,432	19,248
Primary CT	100/5	150/5	200/5	300/5	400/5
Primary Relay②	IAC53	IAC53	IAC53	IAC53	IAC53
Primary Relay Pickup Amps (about 3 x FL)③	200	300	400	600	800
Primary Relay Tap (Amp)	10	10	10	10	10
Primary Relay Time Dial (No. 2–No. 5)	No. 2	No. 2	No. 2	No. 2	No. 2
Primary Relay Instantaneous (20 x FL Amp)	80	80	80	80	80
Primary Fuse	150E	200E	200E	300	375
Main Secondary LT Setting (125 Percent Max. Rated Current)	800	1200	1600	2500	3000
Main Secondary ST Setting (2 x Trip Device Rating)	1600	2400	3200	5000	6000
Largest Feeder LT Setting (1/3 Transf. FL)	200	300	400	600	800
Largest Feeder Inst. Setting (6x)	1200	1800	2400	3600	4800
Illustrative Curve			Fig 3	Fig 4	
Type of Trip Devices Shown			Magnetic	Static	

①For phase protection. Other considerations apply to ground fault protection schemes.
②IAC53 is General Electric relay type designation. ③Use 2½x for dry type transformers.

Ratings and trip device settings can be determined empirically from this table, minimizing trial and error plotting to determine device settings. Results should, however, be verified by trip characteristic plots after power system design has been completed. Note that similar tables can be developed for different primary and secondary voltages by adhering to this format and the principles outlined in this article.

The short-time delay element should be set at 2 to 3 times the trip device continuous rating in order to coordinate with primary phase overcurrent relay pickups. If an instantaneous element is used in addition to a short-time delay element, it should generally be set no higher than 10 times the continuous current rating of the breaker.

Feeder circuit breakers. To permit coordination with transformer main secondary breakers, feeder breakers rated ⅓ of transformer full load current or less should have instantaneous element settings no greater than 6 times the circuit breaker trip element rating. Feeder breakers rated at more than ⅓ of transformer rating should be equipped with long-time delay, short-time delay, and instantaneous trip elements. Short-time delay trip elements should be set at 2 to 3 times the trip device continuous current rating. Setting of the instantaneous trip element should be lower than 10 times the continuous rating of the trip device.

If an instantaneous trip element setting of more than 6 times is required on smaller feeder breakers, the incorporation of short-time delay elements in the trip device may be necessary to achieve coordination. To avoid specifying different types of trip devices on the same transaction, some engineers will specify long-time, short-time, and instantaneous trip elements for all sizes of feeder breakers.

Setting up the system. Empirical solutions can be applied to protective device settings, greatly simplifying coordination studies. The table gives ratings and settings for protective devices for several sizes of substations. The degree of coordination that can be achieved by applying data in this table will probably meet most of the coordination requirements for typical power systems.

Some feeders may be equipped with current transformers of different ratios than those shown, requiring that appropriate adjustments be made in trip device settings to achieve desired results. Tables for different primary and secondary voltages can easily be developed by utilizing the format and principles set forth in this article and the table. Note that pickups as high as 6 times rated full load current may still protect an individual transformer as well as, or better than, individual fuse protection.

Figures 3 and 4 provide graphical proof of the viability of this table. If criteria outlined in the table are adhered to, plotting of trip curves for a more refined coordination study can be an interesting, pleasant exercise instead of a frustrating chore.

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