Overcurrent Protection Theory

An Online Continuing Education Course for Engineers

Course Number: E-4053

Credit: 4 Hours / 4 PDH / 4 CPD

Overcurrent Protection Theory

Velimir Lackovic, Electrical Engineer

OVERCURRENT PROTECTION THEORY

Relay protection against high current was the earliest relay protection mechanism to develop. From this basic method, the graded overcurrent relay protection system, a discriminative short circuit protection, has been formulated. This should not be confused with 'overload' relay protection, which typically utilizes relays that function in a time related in some degree to the thermal capacity of the equipment to be protected. On the contrary, overcurrent relay protection is completely directed to the clearance of short circuits, even though with the settings typically assumed some measure of overload relay protection may be obtained.

CO-ORDINATION TECHNIQUE

Precise overcurrent relay usage asks for the knowledge of the short circuit current that can flow in each section of the power network. Since large-scale measurements and tests are typically unfeasible, system calculations have to be used. The information needed for a relay protection setting analysis is:

- Single-line diagram of the electrical power system, presenting the type and rating of the relay protection elements and their related current transformers
- Impedances in ohms, per cent or per unit, of all power transformers, rotating machine and transmission lines
- Maximum and minimum figures of short circuit currents that are anticipated to go through each protection element
- Maximum load current through protection elements
- Starting current requirements of electrical motors and the starting and locked rotor/stalling times of induction motors
- Transformer inrush, thermal withstand and damage curves
- Decrement curves presenting the decay rate of the short circuit current supplied by the generators
- Performance curves of the current transformers

The protection relay adjustments are first calculated to provide the shortest tripping times at maximum fault currents and then verified to understand if tripping will also be acceptable at the minimum short circuit current anticipated. It is typically suggested to print the curves of protection relays and other protection elements, such as fuses, that are to trip in series, on a common graph and scale. It is typically more convenient to utilize a scale referring to the current anticipated at the lowest voltage base, or to utilize the dominant voltage base. The options are a mutual MVA base or a different current scale for each system voltage. The fundamental rules for proper protection relay co-ordination can typically be presented as follows:

- Whenever feasible, utilize protection relays with the same tripping characteristic in series with each other
- Ensure that the protection relay farthest from the source has current settings same to or less than the protection relays behind it, that is, that the primary current needed to trip the protection relay in front is always same to or less than the primary current needed to trip the protection relay behind it.

RULES OF TIME/CURRENT GRADING

Among the different feasible methods utilized to accomplish precise protection relay co-ordination are those utilizing either time or overcurrent, or a mix of both. The common objective of all three methodologies is to provide precise discrimination. That is to say, each one has to isolate only the faulty part of the electrical power system network, leaving the rest of the power system untouched.

RELAY PROTECTION DISCRIMINATION BY TIME

In this system, an adequate time setting is provided to each of the protection relays controlling the power circuit breakers in an electrical power system to make sure that the circuit breaker nearest to the fault location opens first. A fundamental radial distribution electrical system is presented in Figure 1, to demonstrate the operational logic.

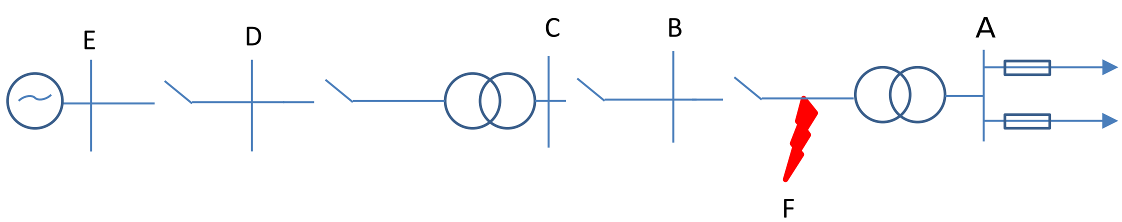


Figure 1. Radial electrical system with time discrimination

Overcurrent relay protection is given at B, C, D and E, that is, at the infeed position of each part of the electrical power system. Each relay protection device comprises a definite-time delay overcurrent protection relay in which the trip of the current sensitive element starts the time delay device. Given the setting of the current device is below the short circuit current value, this device plays no role in the accomplishment of discrimination. For this reason, the protection relay is sometimes known as an ‘independent definite-time delay protection relay’, since its tripping time is for practical uses independent of the overcurrent level.

It is the time delay device, hence, which gives the means of discrimination. The protection relay at location B is set at the shortest possible time delay to permit the fuse to operate for a fault at location A on the secondary side of the power transformer. After the time delay has completed, the protection relay output contact closes to operate the power circuit breaker. The protection relay at location C has a time delay setting equal to t_1 seconds, and likewise for the protection relays at locations D and E. If a short circuit happens at location F, the protection relay at location B will trip in t seconds and the later tripping of the power circuit breaker at location B will clear the short circuit before the protection relays at locations C, D and E have time to trip. The time interval t_1 between each protection relay time setting must be sufficiently long to make sure that the upstream protection relays do not trip before the power circuit breaker at the short circuit location has operated and cleared the short circuit.

The main drawback of this discrimination procedure is that the longest short circuit clearance time happens for short circuits in the section nearest to the power source, where the short circuit level (MVA) is the greatest.

RELAY PROTECTION DISCRIMINATION BY CURRENT

Relay protection discrimination by current is based on the fact that the short circuit current changes with the location of the fault because of the difference in impedance figures between the source and the short circuit. Therefore, usually, the protection relays controlling the different power circuit breakers are programmed to trip at appropriately tapered values of current such that only the protection relay closest to the fault operates its breaker. Figure 2 presents the method. For a fault at location F_1, the electrical system fault current is expressed as:

$$I = \frac{6350}{Z_s + Z_{L1}} A$$

where:

Z_S - source impedance = $\frac{11^2}{250} = 0.485\ \Omega$

Z_{L1} = cable impedance between C and B = 0.24 Ω

Therefore $I = \frac{6350}{0.725} = 8800\ A$

Therefore, a protection relay controlling the power circuit breaker at location C and programmed to trip at a short circuit current of 8800A would in theory save the whole of the underground cable section between locations C and B. Nevertheless, there are two critical practical points that impact this co-ordination procedure:

It is not efficient to differentiate between a fault at location F_1 and a fault at location F_2, since the separation between these locations may be only a few metres, corresponding to a variation in short circuit current of roughly 0.1% in practice, there would be variations in the source short circuit level, usually from 250MVA to 130MVA. At this lower short circuit level the short circuit current would not surpass 6800A, even for an underground cable short circuit near to location C. A protection relay set at 8800A would not save any part of the underground cable section concerned.

Relay protection discrimination by current is hence not a practical suggestion for correct grading between the power circuit breakers at locations C and B. Nevertheless, the issue changes appreciably when there is major impedance between the two circuit breakers concerned. Regard the grading needed between the power circuit breakers at locations C and A in Figure 2. Presuming a short circuit at location F_4, the short-circuit current is presented as:

$$I = \frac{6350}{Z_s + Z_{L1} + Z_{L2} + Z_r}$$

Where

Z_S – source impedance $= \frac{11^2}{250} = 0.485\ \Omega$

Z_{L1} – cable impedance between locations C and B =0.24 Ω

Z_{L2} – cable impedance between location B and 4 MVA transformer =0.04 Ω

Z_r – transformer impedance $=0.07\left(\frac{11^2}{4}\right) = 2.12\ \Omega$

Therefore, $\mathrm{I} = \frac{6350}{2.885} = 2200\ \mathrm{A}$

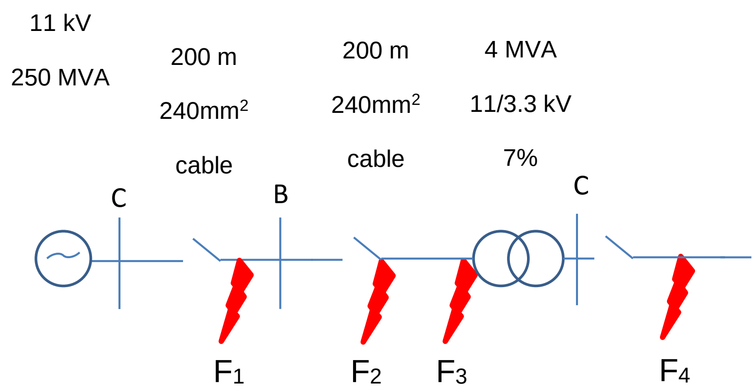


Figure 2. Radial electrical system with current discrimination

Due to this, a protection relay controlling the power circuit breaker at location B and programmed to trip at a current of 2200A plus a safety margin would not trip for a short circuit at F_4 and would therefore discriminate with the protection relay at location A. Presuming a safety margin of 20% to allow for protection relay errors and a further 10% for changes in the system impedance quantities, it is fair to select a protection relay setting of 1.3 x 2200A, that is, 2860A, for the protection relay at location B. Now, analysing a short circuit at location F_3, at the end of the 11kV underground cable supplying the 4MVA transformer, the short-circuit current is presented as:

$$I = \frac{6350}{Z_s + Z_{L1} + Z_{L2}}$$

This, presuming a 250 MVA source short circuit current level:

$$I = \frac{6350}{0.485 + 0.24 + 0.04} = 8300\ A$$

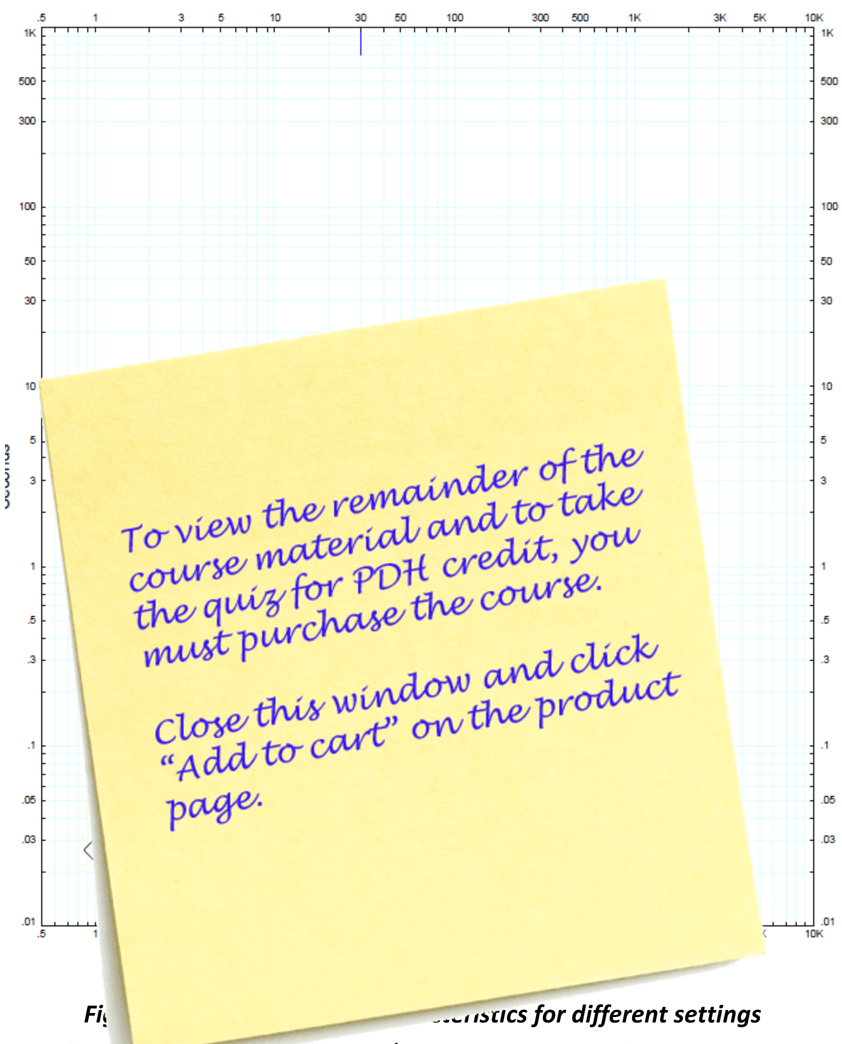
Instead, presuming a source short circuit current level of 130 MVA:

$$I = \frac{6350}{0.93 + 0.214 + 0.04} = 5250\ A$$

For either value of source level, the protection relay at location B would precisely function for short circuits anywhere on the 11kV underground cable supplying the transformer.

RELAY POTECTION DISCRIMINATION BY BOTH TIME AND CURRENT

Each of the two presented methodologies so far has a fundamental drawback. In the case of discrimination only by time, the drawback is due to the fact that the more serious short circuits are cleared in the longest tripping time. On the other side, discrimination by current can be used only where there is considerable impedance between the two considered power circuit breakers. It is due to the limitations introduced by the independent usage of either time or current co-ordination that the inverse time overcurrent protection relay characteristic has developed. With this characteristic, the tripping time is reciprocally proportional to the short circuit current level and the real characteristic is a function of both 'time' and 'current' settings. Figure 3 presents the characteristics of two protection relays given different current/time adjustments. For a great change in short circuit current between the two feeder ends, quicker tripping times can be accomplished by the protection relays closest to the source, where the short circuit level is the greatest. The drawbacks of grading by time or current alone are resolved.



Fi… …cteristics for different settings

Relay A: Current setting=1… A; TMS=0.1; Relay B: Current setting=300 A; TMS=0.2