19.3 Design of Feeders for Industrial Power Systems

Most feeders are comprised of cables enclosed in *raceways*. Raceways are defined as enclosed channels designed expressly for holding wires, cables, or busbars. The most common type of raceway is the *conduit*, which is a pipe that can be either rigid or flexible, and can be made from conducting or non-conducting material.

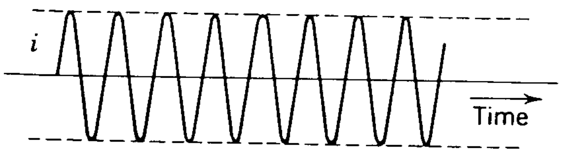
The size of feeder conductor is selected on the basis of three criteria:

- Continuous current rating of the load.
- Short-circuit current rating of the highest fault.
- Voltage regulation.

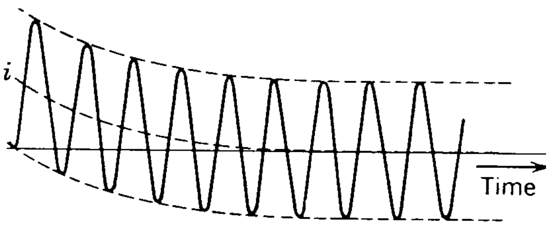
The conductor size selected is the smallest that will satisfy all three criteria.

19.3.2 Short-circuit Current Rating

Evaluation of the magnitude of fault currents will be dealt with later in the course; but for now we will note that when fault currents flow they will result in a *transient* that will cause one phase to have virtually no off-set and one phase to have virtually maximum off-set, as shown below.



No Transient



Maximum Transient

The rms equivalent of the asymmetrical current (I_{ASY} shown on the right) can be expressed in terms of the symmetrical rms current (I_{SYM} shown on the left) as:

$I_{ASY} = K_0 \times I_{SYM}$, where the value of K_0 depends on the type of protection used and is presented in table 19.5.

Faults can produce very high currents, hopefully for short durations because the protection devices (fuses, circuit breakers) interrupt the faulted circuit promptly. Even though the fault durations are short, the magnitude of the fault current can cause a significant rise in cable temperature and will result in damage to the insulation if the conductor is not sized large enough to dissipate the resulting heat.

The calculation to determine the short-circuit current rating of a cable is fairly complicated, but reduces to the form:

$$\frac{I_{ASY}}{A} = \frac{K}{\sqrt{t}} \qquad \textbf{(19.1)}$$

Where: I_{ASY} = Magnitude of Fault Current (kA), A = Conductor Area in MCM,
K = Constant of Proportionality, and t = Duration of Short-circuit (sec)

The constant of proportionality depends on the conductor material (copper or aluminum) and the type of insulation used. For example, copper conductors with type THW insulation (75^0 C maximum steady-state temperature and 150^0 C maximum transient temperature) will have $K = 52.94 \times 10^{-3}$, and leads to the set of graphs shown in figure 19.5, in which short-circuit current is plotted against conductor size for different fault clearing times.

Different cable types will produce different graphs and some additional K values are: copper conductors with type XHHW insulation $K = 71.95 \times 10^{-3}$, while for aluminum conductors with type XHHW insulation $K = 47.04 \times 10^{-3}$.

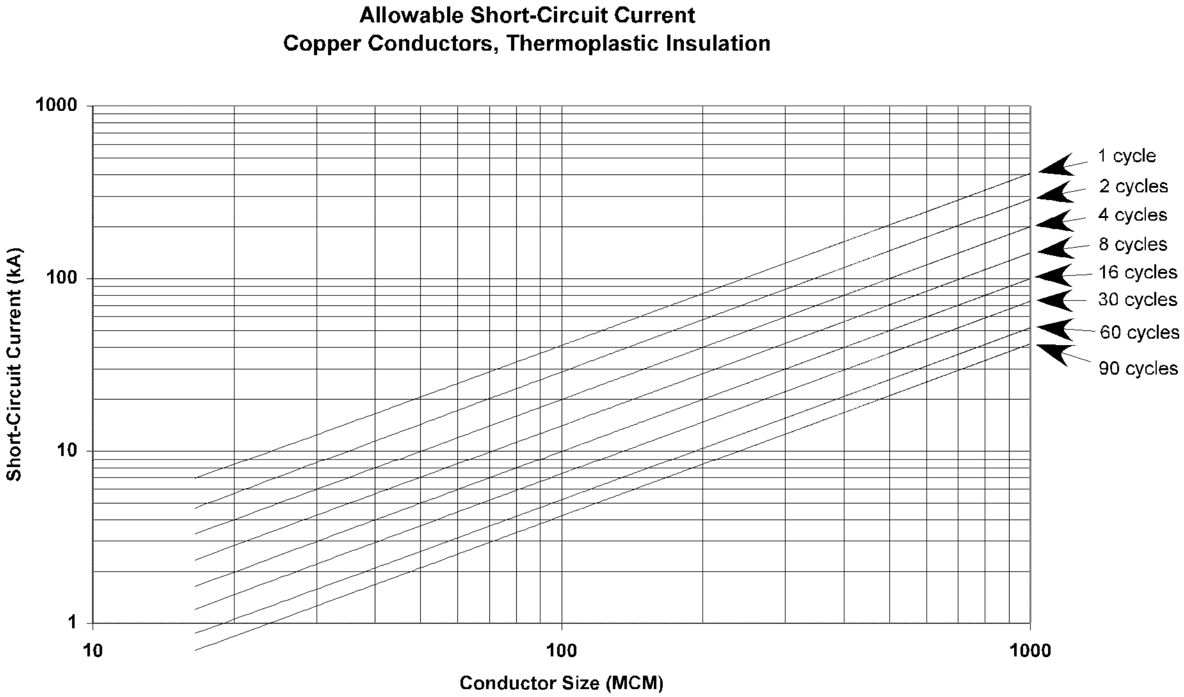


Figure 19.5 Short Circuit Current vs. Conductor Size

Re-arranging equation 19.1 gives equation 19.2, which forms the basis for Figure 19.5.

$$I_{ASY} = \frac{52.94 \times 10^{-3} \times A}{\sqrt{t}} \quad \text{kA} \tag{19.2}$$

Protection schemes are designed to remove faults without any intentional delay; this is referred to as *instantaneous tripping*, but since nothing happens instantaneously some unintentional delay occurs and fault clearing times depend on the type of protection used. Some typical fault clearing times are shown in table 19.5.

System Voltage	Protection Device	Clearing Time (cycles)	K_0
Under 1 kV	Low-Voltage Circuit Breaker	2	1.3
Under 1 kV	Current-limiting fuse	0.5	1.4
Above 1 kV	Air Circuit Breaker	5	1.15
Above 1 kV	Oil Circuit Breaker	8	1.1
Above 1 kV	Power Fuse	1	1.6
Above 1 kV	Current Limiting Fuse	0.5	1.6

Table 19.5 Typical Fault Clearing Times

The different types of protection devices are discussed in more detail in section 19.4. Note that the times given in table 19.5 are typical instantaneous tripping times that are associated with faults, while overloads (non-fault conditions) are tripped with intentional delays and so will take longer to clear.

EXAMPLE 19.3

Determine the asymmetrical and symmetrical short-circuit current ratings of the following copper conductor, THW cables with the stated protection devices:

a) 480 V, 250 MCM, protected by a low-voltage circuit breaker.
b) 480 V, 250 MCM, protected by a current-limiting fuse.
c) 4.16 kV, 1/0, protected by an oil circuit breaker.

Solution

Strategy: Equation 19.2 gives current in terms of conductor size in MCM and the clearing time of the protection device. Since the insulation specified is THW and the conductor is copper, the constant of proportionality will be 52.94×10^{-3}.

Assumptions: Fault clearing times in Table 19.5 apply.

Analysis:

Using the equation: $I_{ASY} = \dfrac{52.94 \times 10^{-3} \times A}{\sqrt{t}}$ kA , we get:

EXAMPLE 19.4

Determine the minimum gauge of copper conductor for the following applications. All conductors are THW cables with the stated protection devices:

a) 480 V, 62 kA asymmetrical short-circuit level, protected by a low-voltage circuit breaker.

b) 13.8 kV, 12 kA symmetrical short-circuit level, protected by an oil circuit breaker.

Solution

Strategy: This is the converse of example 19.3. Equation 19.2 can be re-arranged to give conductor size in MCM in terms of current and the clearing time of the protection device. Once again, the insulation specified is THW and the conductor is copper, so the constant of proportionality stays at 52.94 x 10^{-3}.

Assumptions: Fault clearing times in Table 19.5 apply.

Analysis:

Re-arranging equation 19.2 to give: $A = \dfrac{I_{ASY} \text{ x } \sqrt{t}}{52.94 \text{ x } 10^{-3}}$ MCM, we get: