21.4 Grounding Systems and Electrical Safety

Grounding is a very important aspect of electrical safety. When correctly applied, grounding virtually eliminates both shock hazards and fire hazards. It is essential that all engineers understand why grounds are placed on electrical equipment and systems.

Satisfactory grounding is usually obtained by driving a *ground rod* (a copper-clad steel spike, usually about ten feet long) into the ground as near to the service entrance as possible. The earth's mass provides a zero volt reference point.

The ground rod is then connected to the neutral of the incoming three-phase supply. Under these conditions, the neutral is referred to as the *grounded wire* since it normally carries current and is also connected to ground. This connection is often referred to as the *system ground* to distinguish it from *equipment grounds*, which refer to conductors that do not carry current under normal conditions but bond the frames and enclosures of equipment to ground. Figure 21.1 shows how system grounding and equipment grounding are related. It is important to note that a single ground rod be used; otherwise *ground loops* i.e. multiple paths for current to flow through ground will exist and these will cause problems with the protection system.

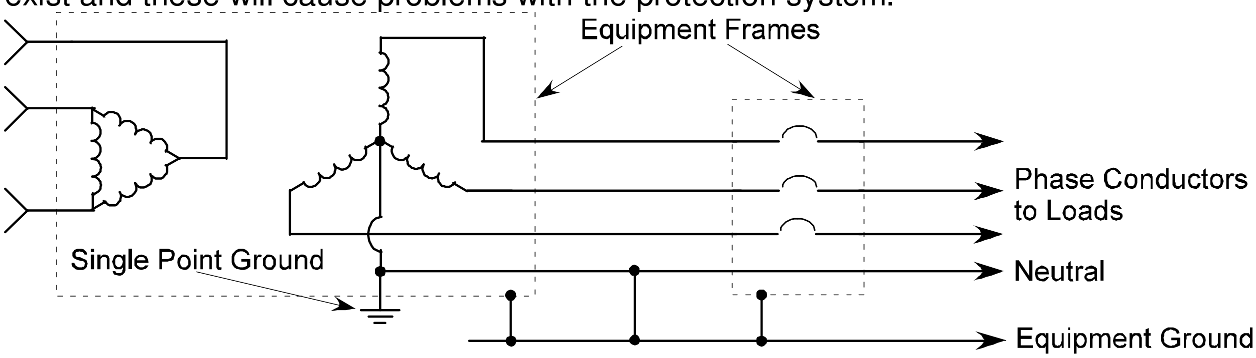

Figure 21.1

The phase wires must not be white or green; they are usually black or black and red. The neutral must be white, while the equipment grounds are usually green or green with yellow stripes, or bare wire can also be used. Individual wires are not always required for equipment grounding as this function will be adequately performed by any raceway (conduit) that is constructed from electrically conducting material.

21.4.1 Sizing of Grounding Equipment

The gauge of the conductor connecting the system neutral to the single point ground is determined by the total area of the service entrance conductors, the requirements laid out by the NEC are summarized in table 21.2.

Table 250-94.
Grounding Electrode Conductor for AC Systems

Size of Largest Service-Entrance Conductor or Equivalent Area for Parallel Conductors		Size of Grounding Electrode Conductor	
Copper	Aluminum or Copper-Clad Aluminum	Copper	*Aluminum or Copper-Clad Aluminum
2 or smaller	1/0 or smaller	8	6
1 or 1/0	2/0 or 3/0	6	4
2/0 or 3/0	4/0 or 250 kcmil	4	2
Over 3/0 thru 350 kcmil	Over 250 kcmil thru 500 kcmil	2	1/0
Over 350 kcmil thru 600 kcmil	Over 500 kcmil thru 900 kcmil	1/0	3/0
Over 600 kcmil thru 1100 kcmil	Over 900 kcmil thru 1750 kcmil	2/0	4/0
Over 1100 kcmil	Over 1750 kcmil	3/0	250 kcmil

Where multiple sets of service-entrance conductors are used as permitted in Section 230-40, Exception No. 2, the equivalent size of the largest service-entrance conductor shall be determined by the largest sum of the areas of the corresponding conductors of each set.

Where there are no service-entrance conductors, the grounding electrode conductor size shall be determined by the equivalent size of the largest service-entrance conductor required for the load to be served.

* See installation restrictions in Section 250-92(a).

(FPN): See Section 250-23(b).

Table 21.2

EXAMPLE 21.1

a) The service entrance feeder conductors for a system are three parallel runs of 300 MCM copper. Determine the minimum size of the common copper grounding electrode conductor.

b) Repeat part (a) if the service entrance feeder conductors are three parallel runs of 400 MCM aluminum and the common grounding electrode conductor is copper-clad aluminum.

Solution

a) The total area of the parallel conductors is 3 x 300 = 900 MCM
From table 21.2, column 3, the grounding electrode size has to be at least:
2/0 copper.

b) The total area of the parallel conductors is 3 x 400 = 1200 MCM
From table 21.2, column 4, the grounding electrode size has to be at least:
4/0 copper-clad aluminum.

The gauge of individual equipment ground wires that have to be run inside non-conducting conduit are determined by the rating of the overcurrent device (fuse or breaker) that is protecting the circuit, the requirements laid out by the NEC are summarized in table 21.3

Table 250-95. Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size	
	Copper Wire No.	Aluminum or Copper-Clad Aluminum Wire No.*
15	14	12
20	12	10
30	10	8
40	10	8
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0
800	1/0	3/0
1000	2/0	4/0
1200	3/0	250 kcmil
1600	4/0	350 "
2000	250 kcmil	400 "
2500	350 "	600 "
3000	400 "	600 "
4000	500 "	800 "
5000	700 "	1200 "
6000	800 "	1200 "

* See installation restrictions in Section 250-92(a).

Table 21.3

EXAMPLE 21.2

a) A feeder is protected by a 1200 A frame breaker with an 800 A trip unit. Determine the minimum size of the equipment grounding copper conductor.

b) Repeat part (a) if the grounding conductor is copper-clad aluminum.

Solution

a) Although the frame size is 1200 A, it is the trip rating that is important when sizing the ground wire. From table 21.3, column 2, the ground conductor has to be at least:

1/0 copper.

b) From table 21.3, column 3, the ground conductor has to be at least:

3/0 copper-clad aluminum.

21.4.2 Ground Fault Protection

The vast majority of faults involve one or more phase conductors coming into contact with ground. This can be caused by insulation failure or sometimes by a person inadvertently touching a live part of the equipment (something that ideally should never happen.) When this occurs a high current will flow through the point of insulation failure or through the body of the person. It is essential that such faults be cleared with no intentional delay i.e. instantaneous tripping as described in chapter 19. It is strongly recommended that the reader reviews section 19.4.2 before proceeding.

However, because ground faults typically involve an arc being drawn between the faulted phase and ground and since arcs drop typically ~100V (50 V to 150 V range) the magnitude of the resulting current is lower than for non-ground faults and often will not initiate instantaneous tripping. Therefore a special *ground fault* detection unit is applied to initiate instantaneous tripping whenever a fault involving ground is detected. The principle of most units is very simple and involves summing all currents flowing in the phase conductors and the neutral conductor; if the result is not zero then current must be flowing to ground and tripping is initiated. The system shown in figure 21.1 has been expanded to show the placement of the ground fault detection unit and is presented in figure 21.2.

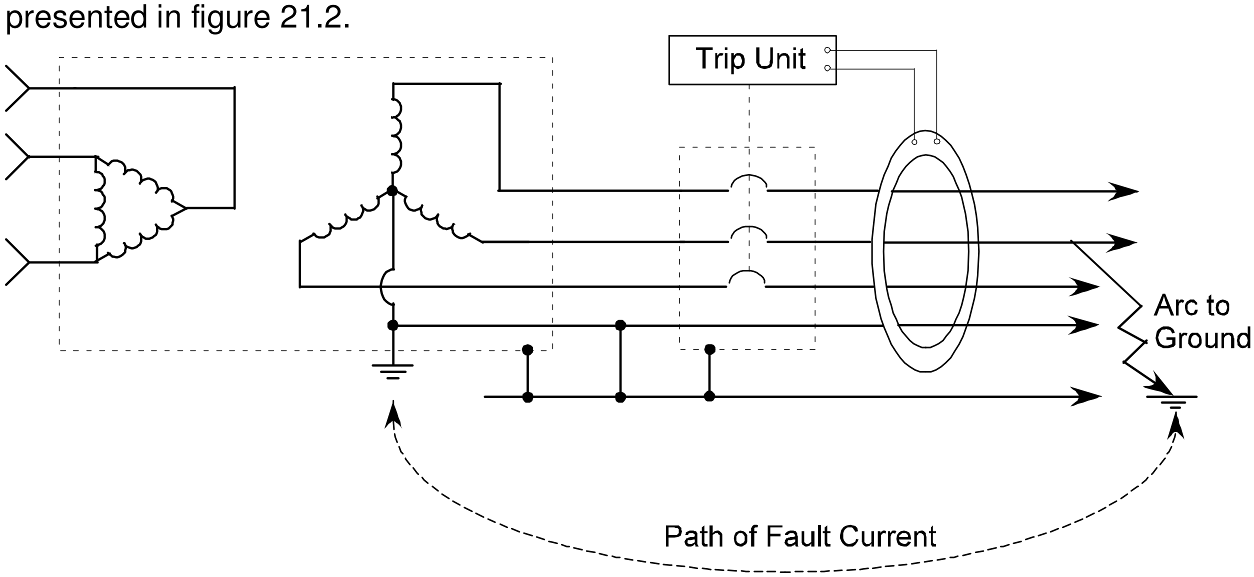

Figure 21.2

The oval unit in figure 21.2 represents the secondary of a current transformer whose primary is the three phase currents plus the neutral current, the primary can be thought of as a single turn coil. The secondary current is the sum of these four currents divided by the number of turns in the secondary, and has to be zero if there is no current flowing to ground. The trip unit senses when this current is not zero and opens the breaker with no intentional delay.

Arcs are a major hazard to both personnel and equipment. On systems at 60 V and below, a significant fraction of the voltage is dropped on the arc itself and since the arc is mainly resistive, the fault energy is the fault duration times the fault current times the arc voltage, which is generally assumed to be constant at 100 V. Since this fault energy is usually confined in a small volume it can be extremely damaging. Table 21.4 presents a highly judgmental assessment of likely damage sustained from an arcing ground fault.

Fault Energy (kW-cycles)	Probable Damage
Below 100	Smoke marks – easily cleaned
100 – 1000	Slight damage to equipment – repair of damaged insulation - unlikely that major replacement of equipment will be required
1000 – 10000	Significant damage to equipment – likely that replacement will be required – unlikely that arc will burn through normal enclosure
Above 10000	Considerable damage to equipment and surrounding area – arc will likely burn through a normal enclosure

Table 21.4

EXAMPLE 21.3

a) Determine the fault energy and hence state the estimated level of damage if a 500 A arcing ground fault occurs on a feeder protected by a 400 A frame molded-case circuit breaker with a 125 A trip unit (figure 20.10). Assume maximum time delay.

b) Repeat part (a) if the ground fault relay initiates the instantaneous trip.

Solution