Chapter 12 - Protection

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12.1 Introduction

Power protection consists of three fundamentals – ground, over-voltage, and overcurrent protection. The basis is an adequate ground system to provide a path for unbalance currents or location for a system reference. Over-voltage protection takes the form of arrestors or surge suppressors. Over-current protection is divided into overload and short circuit.

12.2 Grounding - NEC 250 and NESC

Grounding is provided as a safety precaution. Nevertheless, it is not a guarantee that no electrical shock will occur. Sensation of electrical shock may occur with as little as 1 to 3 ma. Women and children are sensitive to values as low as three-fourths that amount.

12.2.1 Grounded - Neutral

A current carrying conductor for alternating current systems is grounded under the noted conditions. The conductor is identified by white insulation.

1. Ground the neutral conductor to assure the maximum voltage on the ungrounded conductors does not exceed 150 volts.
2. Ground the neutral if the system is nominally rated 277 / 480Y, 3 phase, 4-wire.
3. Ground the mid-point of one phase used as a circuit conductor for a 120 / 240 volt, 3-phase, 4-wire system.

12.2.2 Grounded - Locations

The current carrying conductor is grounded at the point of origin.

1. Separately derived systems (transformers, generators, converters) must be grounded at the origin.
2. A single source supplying multiple systems must be grounded at the supply side of the disconnects.
3. Do not bond the neutral of a second breaker box or panel. Ground loops would result.

12.2.3 Grounding - Safety

The grounding system does not carry current under normal operating conditions. It is a low impedance path for the flow of current to earth under extraordinary conditions. Non-current carrying metal parts must be bonded to ground if

1. Within 8’ vertically or 5’ horizontally of ground or grounded metal objects subject to contact.
2. Located in damp or wet locations and not isolated.
3. In electrical contact with metal.
4. Located in hazardous (classified) locations.
5. Operated with any line over 150 volts to ground.
6. Constructed with metal frames.
7. Connected by cord and plug.
8. Uses metal raceways and enclosures.

12.2.4 Equipment Grounding Conductor

An equipment grounding conductor provides the bond between the metal and the ground. It may be one of these

1. Metal conduit, raceway, or enclosure.
2. Bare or insulated (green) wire contained in same raceway. Conduit enclosing a grounding conductor must be bonded.
3. The neutral when 2 hot lines are used in 3-wire non-metallic sheathed (NM) cable supplying appliances (ranges and dryers).
4. Liquid-tight flex in sizes of 1 1/4” or smaller, if less than 6 feet total length and if the circuit is protected for 20 amps or less.
5. Type MC metal clad cable.
6. Note: Structural steel is not permitted for use as an equipment grounding conductor.

12.2.5 Grounding Electrode Conductor

The conductor bonds the service equipment enclosure, the system grounded circuit conductor (neutral), and the equipment grounding conductors (safety) to all the grounding electrodes.

12.2.6 Grounding Electrode - Acceptable

A grounding electrode is the electrical point of contact with earth. Acceptable electrodes have a priority of selection.

1. Bond to a metal cold water pipe in direct contact with the earth for at least 10 feet. If available, this must be used. Additional electrodes may be required.
2. Bond to the nearest available grounded structural steel imbedded in earth or in buried concrete.
3. Construct concrete encased electrode(s) consisting of at least 20' of 1/2" steel rebar or #4 AWG copper or larger.
4. Construct a ground ring at least 2-1/2 feet down using at least 20 feet of #2 AWG copper.

12.2.7 Grounding Electrode - Made

Made electrodes are constructed for electrical contact with the earth.

1. Use underground bare metal gas pipe, tanks, and casings.
2. Use non-corrosive rod (5/8"+) and pipe (3/4"+) electrodes at least 8' long. Drive the electrode. If rock is encountered at less than 4 feet, bury the rod below permanent moisture level.
3. Plate electrodes must have at least two square feet of exposed surface.

12.2.8 Resistance - NEC

Made electrodes for power circuits must have a resistance to ground of less than 25 ohms. Use additional electrodes to reduce the resistance. Separate the electrodes by at least 6 feet. The desired distance is 2.2 times the length of the electrode. A triad arrangement is one of the preferred configurations.

Lightning rod grounds are not used in lieu of other made electrodes.

12.2.9 Resistance - Lower Concerns

A 25 ohm ground circuit is *inadequate* for most personnel and electronic protection systems. As an example, assume a 120 volt circuit comes in contact with a ground path of 25 ohms. The current flow will be $I = 120\ V / 25\ ohm = 4.8$ amp. This will not trip a 20 Amp circuit breaker. So the line and the ground will be continuously energized.

Many personnel safety guidelines suggest a resistance of less than 5 Ohms. Lower than 2 Ohms is preferred.

For protection of electronics and other sensitive devices, the goal for the ground systems is near 1 ohm or less.

12.3 Overvoltage Protection

Power systems are exposed to the elements, so they are prone to lightning and other transient disturbances. Two considerations are necessary for protection. First an excellent ground path must be provided. Next, over-voltage devices are used to shunt the extraneous current to the ground.

1. The most basic grounding system consists of a single rod in contact with the earth. For high resistivity soils, contact resistance may be improved by chemicals or concrete. To handle more current and lower the resistance, multiple ground rods are arranged in a symmetric pattern around the installation.

2. Larger areas should have a ground grid under the site. This consists of copper wire on a grid of approximately 50 feet. Then grid keeps all the equipment at the same potential relative to a natural electrical disturbances.

3. A cone of protection can be constructed above the site by using lightning rods. These must be above the structure. Use at least two down-comers from the network.

4. A tower can be used to create the cone of protection. The protected area is under an approximate 45^o triangle.

5. Power lines can be shielded by placing the neutral or ground above the phase conductors. The cost of construction is more. Safety concerns arise if the neutral breaks and touches the phase wires. Another safety concern is the lineman will encounter a phase conductor as the first line. This pattern is not as effective in reducing the electric and magnetic fields near the earth surface.

6. Some installations use a tower with various spikes and protrusions in an effort to dissipate the lightning energy. These are only as effective as the ground.

7. Lightning arresters are connected from the phase wire to the ground. Keep the ground wire as short as possible. Make all bends with a sweeping radius of at least 8 inches. Sharp bends increase the impedance and dilute the effectiveness of the ground path.

8. Build one pole past the last device. Place arresters on the last pole. This moves the traveling wave peak away from the devices. Place a ground wire on each pole.

9. The most basic arrester consists of a spark gap. This is simply an air space that will arc-over at an elevated voltage. Conventional arresters use a silicon carbide (SiC) varistor in series with air gaps. First the voltage arcs across the gaps. Then the varistors develop a lower resistance as the current increases.

10. Metal oxide varistors (MOV) are more responsive than SiC. However, they deteriorate with each surge handled.

12. Arresters may be station, intermediate, or distribution class. Station class provide the best protection and should be applied where greater protection is required. Distribution class are comparatively small, inexpensive, and provide less protection.

12.4 Overcurrent Coordination

The primary control components used for current protection are short-circuit and over-current devices. These are typically fuses and overload relays, respectively. The two type devices have different operating characteristics.

The short-circuit (fault) device is primarily for protection of the power line. A short-circuit will draw very large amounts of current in a very short time. Typically, current amounts greater than six (6) times full load current (FLC) are considered a short. Note this is also the motor starting current value. However, motor starting time is only for a few cycles (fraction of a second).

The over-current device is primarily to protect the operating equipment. An overload will draw slightly excess current for a sustained period of time. Overload values are typically considered less than 150% of the full load current.

Since both type devices are current sensitive, it is necessary to make them operate in the proper time sequence under various conditions. This is coordination.

In most cases the characteristics of the protective device are given by a curve. The heating energy (W) of the element due to the current is usually shown as an I^2t plot.

$$W = P * t = I^2 * R * t$$

If the resistance does not change appreciably as the current increases, then the heating energy change depends only on the current and time.

Two calculations or chart readings are necessary to determine the response time for each device. The time for the overload current is found. Then the time for the short-circuit current is determined.

The overload (heater-type) device is selected to be large enough for the overload current. Nevertheless, it must be small enough so its time to trip on overload is less than the short-circuit (fuse-type) device.

Similarly, the short-circuit (fuse-type) device is selected so that it can handle starting currents. Furthermore, it has a shorter time to clear than the overload when a fault appears.

FUSE / BREAKER SIZES: 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 1000, and higher values.

PROBLEM:	Select current protection for a 20 Hp, 27 amp motor.	
CALCULATE:	Overload = 27 * 1.5 = 40 amp	Fault = 27 * 6 = 162 amp
HEATER:	Westinghouse FH51, One size less than chart rating for service factor =1	
FUSE:	Min Fuse = 30 amp FRS	Max Fuse = 27 * 1.75 = 50 amp FRS
HEAT TIME:	Overload = 180 sec (1.5X)	Fault = 14 sec (6X)
FUSE TIME:	Overload = >600 sec (40 A)	Fault = 9 sec (162 A)

The overload will trip first on a sustained over-current, while the fuse will trip first on a fault current. This is proper coordination. Alternate types or sizes would have to be used, if the coordination time sequence were not in proper order.

If a 50 amp fuse were used, the overload time would be infinite while the time to clear a fault would be 60 seconds. Although this fuse is acceptable from a NEC perspective, it is unacceptable to coordinate for this application.