Vol. XXXVIII No. 5 A CLB MEDIA PUBLICATION May 2002

ELECTRICAL BUSINESS

THE AUTHORITATIVE VOICE OF CANADA'S ELECTRICAL INDUSTRY

Grounding of industrial power systems

High-resistance grounding is by far the most effective method

By Andrew Cochran

The term "grounding" is commonly used in the electrical industry to mean both "equipment grounding" and "system grounding". The two types, illustrated in Figure 1, are defined as follows:

Equipment grounding: The connection of earth ground to non-current-carrying conductive materials (e.g., conduit, cable trays, junction boxes, enclosures and motor frames);

System grounding: The connection of earth ground to the neutral points of current-carrying conductors (e.g., the neutral point of a circuit, a transformer, rotating machinery or a system), either solidly or with a current limiting device.

Characteristics of ungrounded systems

An ungrounded system is one in which there is no intentional connection between the conductors and earth ground. However, as in any system, a capacitive coupling exists between the system conductors and the adjacent grounded surfaces. Consequently, the "ungrounded system" is, in reality, a "capacitively grounded system" by virtue of the distributed capacitance. See Figure 2.

Under normal operating conditions, this distributed capacitance causes no problems. In fact, it is beneficial because it establishes, in effect, a neutral point for the system, as shown in Figure 3a. As a result, the phase conductors are stressed at only line-to-neutral voltage above ground.

However, problems can arise under ground fault conditions. A ground fault on one line results in full line-to-line voltage appearing throughout the system. Thus, a voltage 1.73 times the normal voltage is present on all insulation in the system, as shown in Figure 3b. This situation can often cause failures in older motors and transformers, due to insulation breakdown.

The interaction between the faulted system and its distributed capacitance may cause transient over-voltages (several times normal) to appear from line to ground during normal switching of a circuit having a line-to-ground fault (short). These over-voltages may cause insulation failures at points other than the original fault. In addition, a second fault on another phase may occur before the first fault can be cleared. This can result in very high line-to-line fault currents, equipment damage and disruption of both circuits.

In addition to the cost of equipment damage, ungrounded systems complicate locating fault(s), involving a tedious process of trial and error: first isolating the correct feeder, then the branch, and finally, the equipment at fault. The result is unnecessarily lengthy and expensive down-time.

An ungrounded system, despite the drawbacks, does have one main advantage. After the first ground fault, assuming it remains as a single fault, the circuit may continue in operation, permitting continued production until a convenient shutdown for maintenance can be scheduled.

Benefits of proper system grounding

System grounding – the intentional connection of the neutral points of transformers, generators and rotating machinery to the earth ground network – provides a reference point of zero volts, which offers many advantages over an ungrounded system, including:

- Reduced magnitude of transient over-voltages;
- Simplified ground fault location;
- Improved system and equipment fault protection;
- Reduced maintenance time and expense;
- Greater safety for personnel;
- Improved lightning protection;
- Reduction in fault frequency;

Solidly neutral grounded systems offer partial protection

In solidly grounded systems, the neutral points have been intentionally connected to earth ground with a conductor having no intentional impedance. See Figure 4. This reduces the problem of transient over-voltages found on the ungrounded system and speeds the location of faults.

However, solidly grounded sys-

Figure 1

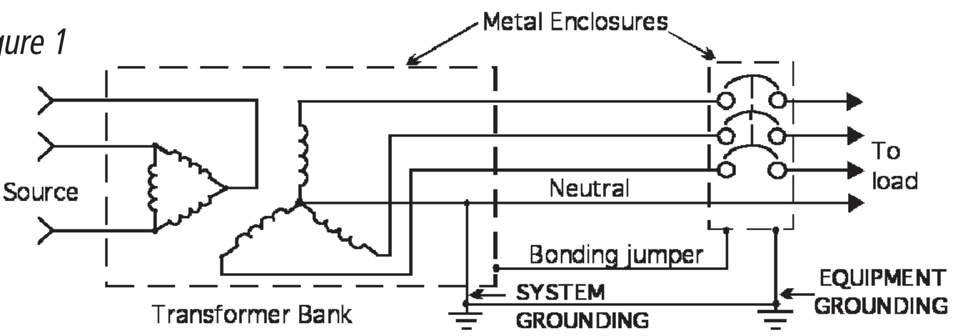
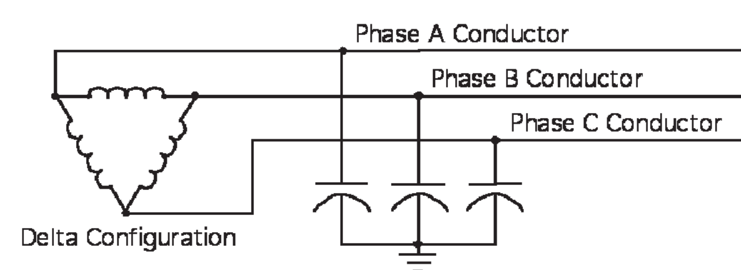


Figure 2



tems lack the current-limiting ability of resistance grounding and the extra protection this provides against equipment damage and arcing ground faults.

The well-known and well-documented destructive nature of arcing ground faults in solidly grounded systems is caused by the energy dissipated in the fault. A measure of this energy can be estimated from the formula:

Kilowatt cycles = V x I x T÷1000.

where V and I are the voltage and current respectively of the arc, and T is the duration of the arc in cycles.

The faulted circuits need to be tripped, with conventional time-current coordination. Often, it is difficult to selectively trip the circuit with minimum time delay and high equipment damage due to arcing ground fault is tolerated.

Ground fault relays with zone-selective instantaneous protection need to be used to provide maximum equipment protection, while retaining selectivity and coordination.

Advantages of resistance-grounded neutral systems

Resistance-grounding is by far the most effective and preferred method. It solves the problem of transient over-voltages, thereby reducing equipment damage. It accomplishes this by allowing the magnitude of the fault current to be predetermined/limited by a simple ohms law calculation:

I = E÷R

Where: I = Limit of fault current.
E = Line-to-neutral voltage of system
R = Ohmic value of neutral rounding resistor

In addition, limiting fault currents to predetermined maximum values permits the designer to selectively co-ordinate the operation of protective devices, which minimizes system disruption and allows quick location of the fault.

There are two broad categories of resistance-grounding: low-resistance and high-resistance. In both types of grounding, the resistor is connected between the neutral of the transformer secondary and the earth ground, as shown in Figure 5.

Low-resistance-grounding of the neutral limits the ground fault current to a relatively high level (typically 50 amps or more), in order to operate protective fault-clearing relays and current transformers. These devices are then able to quickly clear the fault, usually within a few seconds. This fast response time is important, since it limits damage to equipment, prevents additional faults from occurring, provides safety for personnel and localizes the fault.

The limited fault current and fast response time also prevent overheating and mechanical stress on conductors. It must be noted that, like the solidly grounded neutral system, the circuit must be shut down after the first ground fault.

Low-resistance-grounding resistors, typically rated 400 amps for 10 seconds, are commonly found on medium- and high-voltage systems.

High-resistance-grounding of the neutral limits the ground fault current to a very low level (typically under 25 amps). It is used on low-voltage systems of 600 volts or less, under 3000 amps. See Figure 6. By limiting the ground fault current, the fault can be tolerated on the system until it can be located, and then isolated or removed at a convenient time. This permits continued production, provided a second ground fault does not occur.

High-resistance-neutral grounding can be added to existing ungrounded systems without the expense of adding fault-clearing relays and breakers. This provides an economical method of upgrading older, ungrounded systems.

The resistor must be sized to ensure that the ground fault current limit is greater than the system's total capacitance-to-ground charging current. If not, then transient over-voltages can occur.

By strategic use and location of ground fault sensing relays, troubleshooting can be greatly simplified. High-resistance neutral grounding, combined with sensitive ground fault relays and isolating devices, can quickly detect and shut down the faulted circuit. This provides operating personnel with the added safety that's essential in hostile operating environments (such as in mining applications).

Another major advantage is the elimination of dangerous and destructive flashovers to ground, which can occur on solidly grounded systems.

As is the case with most systems, there are some disadvantages to high-resistance neutral grounding:

- After the first ground fault, the two un-faulted phases rise to the line-to-line voltage, as shown in Figure 7. This creates a 73 per cent increase in voltage stress on the insulation of the system;
- When a ground fault occurs, the neutral point of the system rises to line-to-neutral voltage above ground. As a result, the neutral cannot be used in the system for load connections such as single-phase lighting;
- Should a second ground fault occur on another phase before the first ground fault is removed, a line-to-line fault is created.

Summing up…

Ungrounded delta systems have many operating disadvantages. High transient over-voltages can occur that are not immediately evident. In addition, ground faults are difficult to locate.

Solidly grounded neutral systems provide greater safety for personnel, limit the system potential to ground, and speed the detection and location of the ground fault. However, the system must be shut down after the first ground fault.

Low-resistance-grounded neutral systems only limit the magnitude of the ground fault current so that serious damage does not occur. The system must still be shut down after the first ground fault. This level of resistance-grounding is generally used on medium and high-voltage systems.

High-resistance-grounded neutral systems limit the fault current to a tolerable level, permitting continued production, until the fault can be located and corrected at a convenient time. It also provides an economical method of upgrading older, ungrounded systems without expensive addition of fault-clearing relays and breakers.

For a detailed comparison of the performance of the different grounding methods under a variety of operating conditions and characteristics please contact Andrew Cochran at (905) 673-1553. ***EB***

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Figure 3

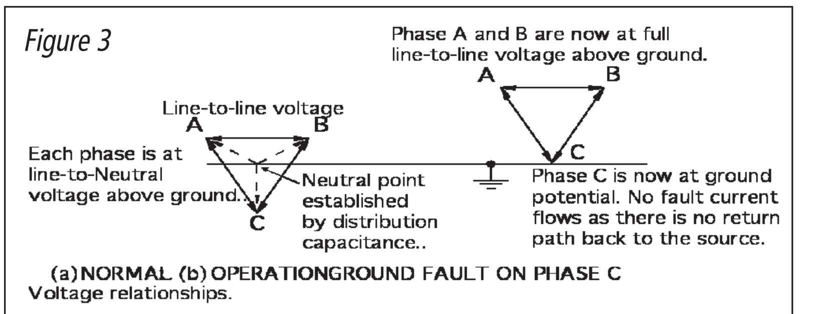

Figure 4

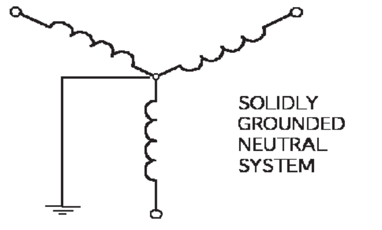

Figure 5

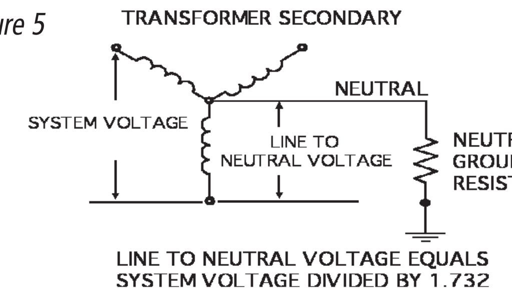

Figure 6

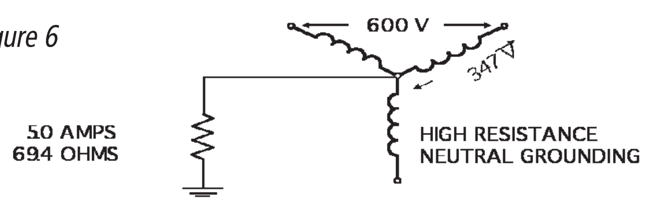

Figure 7

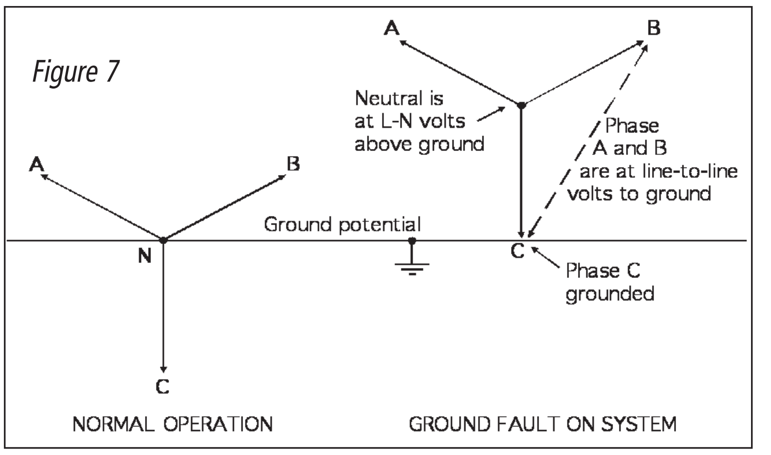

Figure 8