DC System Grounds: Can You Afford to Live with Them?

Stationary battery and dc power systems used in switchgear and control applications are typically designed and operated as a floating from ground system which means that there is no intentional low resistance or solid connection to ground from either the positive polarity or negative polarity of the dc system. These types of systems used in switchgear and control applications typically operate at 125 Vdc or 48 Vdc. Telecommunication applications typically employ a 48 Vdc power system that is designed and operated as a positive grounded system (otherwise referred to as a +48 Vdc system) whereas the positive polarity bus is connected directly to an isolated ground system or a 24 Vdc power system that is designed and operated as a negative grounded system. In both cases, a very low resistance or solid path is intentionally established from one polarity of the dc system to ground. The stationary battery and dc bus link of an uninterruptible power supply (UPS) used in many mission critical applications will often be grounded as the result of no or very poor isolation of the line (phase) to grounded neutral ac input to the UPS rectifier. This paper discusses the many causes of unintentional grounds on floating dc power systems in switchgear and control applications and the effects these grounds can have on the operations of the dc system, personnel safety issues that can arise as the result of unintentional dc system grounds, and ground detection systems designed to identify the existence of unintentional dc grounds.

Sources of Grounds

DC system grounds can result when a conduction path is formed from either the positive polarity of the system to earth ground or the negative polarity to earth ground. Some common sources of low resistances to ground include moisture in conduit, junction boxes or switch/sensor terminations, wire splices soaking in water, degraded cable or wire insulation caused by aging, environmental conditions, wild habitat and constant abrasion from vibration, sharp objects piercing cable and wire insulation, wires that have pulled out of their terminations and touch ground or water, and failed capacitors or semiconductor surge suppressors. In generating stations and electric utility substations, water tends to be the greatest contributor to dc system grounds. Water will often form a bond between the exposed conductor and earth ground. As a result, the emergence of dc system grounds often tends to increase during rainy seasons.

Commercial ground detection systems associated with the dc system can also be a source of resistance to ground. Ground detection systems are designed with a reference to earth ground through a predetermined resistance in order for the system to monitor, detect, and determine the magnitude of a ground fault when one does occur. As a result, a dc power system equipped with a ground detection system that has a continuous reference to earth ground will always present a ground of some resistance on the dc system.

DC system grounds do not only occur in the field or at the connected loads. They can also occur on the battery itself. The electrolyte in flooded lead-acid and nickel-cadmium batteries and valve-regulated lead-acid (VRLA) batteries often used in switchgear and control applications is conductive. Cracks in cell containers, jar-to-cover seal
leaks, terminal post seal leaks, dripping of electrolyte from maintenance activities such as specific gravity measurements of flooded lead-acid cells, moving of cells during installation or replacement, and watering of flooded cells or rehydration of VRLA cells can result in a conductive path being established from the battery to the grounded battery rack.

**Impact of Grounds**

A dc system floating from ground is designed to allow for normal operation of the dc system and the connected loads with the presence of a low-resistance ground on either the positive polarity or negative polarity. Figure 1 show a relay control system with a single low-resistance ground on the positive polarity.

Multiple grounds can occur on the dc system at the same time. This situation becomes critical when the combined ground resistance becomes so low that high-voltage circuit breaker control schemes are unable to open or close breakers when required or dc system circuit breakers and or fuses open due to overcurrent resulting in de-energization of vital operating equipment. Figure 2 shows a relay control system with two low-resistance grounds. In this case, the ground path resistance may be low enough to energize the relay coil depending on the resistance of the relay coil, causing a misoperation of the associated equipment, perhaps a high voltage circuit breaker.

The floating from ground dc system and connected loads can operate normally with a single ground regardless of the resistance of the ground. However, if this ground resistance is small enough and a second ground that is approaching zero ohms (solid ground) appears, sufficient current may be available to inadvertently energize a relay coil that is in the de-energized state in normal operations or prevent an already energized relay from de-energizing when it is called upon to de-energize.

For a switchgear and control application, there may be numerous relay control systems, electronic input modules or programmable logic controllers (PLC) associated with the dc system. Each of these components should be evaluated to determine the minimum level of ground resistance that could cause misoperation of these components. This value is the dc system ground critical resistance that should never be exceeded. In the case of a circuit breaker control relay, the critical ground resistance can be determined by finding the resistance of the relay coil, the lowest dc voltage required to energize (or pull-in) the coil from the de-energized state, and the lowest dc voltage required to de-energize (or dropout) the coil from the energized state.

Example: A 125 Vdc rated high-voltage breaker control relay has a measured coil resistance ($R_c$) of 5000 ohms. The lowest measured pull-in voltage ($V_{c}$) of the coil is 50 Vdc. The lowest measured dropout voltage ($V_{c}$) of the coil is 20 Vdc. The dc system source is comprised of a 58 cell flooded lead-acid battery and a 125 Vdc nominal output rectifier (battery charger) with a maximum expected operating voltage ($V_{EQ}$) of 135.0 Vdc when the battery is on an equalize charge. A simplified circuit is shown in Figure 3.
The ground resistance \((R_G)\) required to provide sufficient ground leakage current to energize the coil is:

\[
R_G = R_c \left( V_{EQ} - V_c \right) / V_c \\
= 5000(135 - 50) / 50 \\
R_G = 8,500 \Omega
\]

The ground resistance \((R_G)\) required to provide sufficient ground leakage current to prevent dropout of an energized coil is:

\[
R_G = R_c \left( V_{EQ} - V_c \right) / V_c \\
= 5000(135 - 20) / 20 \\
R_G = 28,750 \Omega
\]

To avoid a misoperation caused by the control relay in this example from energizing due to grounds on the system, the dc system ground resistance must be greater than 8,500 ohms. To avoid a misoperation caused by the control relay’s failure to dropout due to grounds on the system, the dc system ground resistance must be greater than 28,750 ohms. Therefore, the critical ground resistance established for this system would be 28,750 ohms.

**Grounded DC Systems and Personnel Safety**

A floated from ground dc system with no unintentional ground paths should have zero potential between the positive bus to ground and the negative bus to ground. Accidental contact of either the positive bus or the negative bus by personnel should not result in an electrical shock. However, should a low-resistance ground occur on the dc system, then a shock hazard can exist. A low-resistance ground on the positive bus can result in an electrical shock if personnel were to accidentally touch the negative bus. Likewise, a low-resistance ground on the negative bus can result in an electrical shock if personnel were to accidentally touch the positive bus.

**Methods to Detect and Eliminate Unintentional DC System Grounds**

Many types of dc ground detection systems are commercially available. Many of these ground detection systems are part of the battery chargers that are supplied for switchgear and control applications. The most common types of ground detection systems are balanced resistor ground detectors or switched resistor ground detection systems. Figures 4 and 5 show an example of each type.

The balanced resistor ground detection system is characterized by a medium resistance connected between the positive polarity and a measurement node, and an equal resistance connected between the negative polarity and a measurement node. A low-resistance measurement element such as a galvanometer which typically will provide a display in volts, is often connected between the node and earth ground. This type of ground detection design allows for continuous monitoring of grounds on a dc system. A ground will cause the voltage divider circuit to become unbalanced and a ground to be detected and displayed. If the voltage across the measurement element is zero, there are either no grounds present from the positive bus to ground and the negative bus to ground or there are balanced field grounds where the positive bus to ground resistance \((R_{PG})\) is equal to the negative bus to ground resistance \((R_{NG})\). This is one of the drawbacks of a balanced resistor ground detection system in that it will not detect balanced field grounds. Another drawback is that if one of the resistors in the voltage divider circuit fails open, then a constant ground resistance \((R_G)\) is present on the dc system. This could place a ground resistance that is lower than the critical ground resistance established for the dc system that can cause equipment misoperation.

Ground detection systems that employ ground lamps (incandescent filament) through a balanced voltage divider circuit provide half the system dc voltage across each lamp under a no ground situation. Each lamp will be dimly lit in this case. When a low resistance ground occurs on the positive bus or negative bus, the opposite polarity’s lamp will become brighter. This detection system relies on the eye of the beholder to determine the existence of a dc system ground.
A switched resistor ground detection system is characterized by a medium resistance alternately connected from the positive bus to ground and the negative bus to ground through either a manual switch or a semiconductor switching device. A high-resistance voltage measurement element is connected in parallel with the medium resistance. The resistance is generally not too large in order to quickly dissipate any capacitive charge between the battery bus and earth ground. A zero-volt measurement when the switch is activated to either the positive or negative bus indicates that no grounds are present on the dc system. The advantages of this type of ground detection system is that it can detect balanced field grounds and does not place a low resistance ground on the dc system should the medium resistance fail open. The drawback to this type of ground detection system is that it will not operate as a continuous battery ground detector.

In conclusion, to safeguard from misoperation of equipment due to dc system grounds, it is important to recognize when the first ground appears and understand what the minimum allowable ground resistance (critical resistance) for the dc system is. Once a ground is identified through a ground detection system, elimination of the ground or multiple grounds should be performed as soon as possible. This can be performed using commercially available battery ground fault tracers.

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