

GROUND DETECTION CIRCUITS FOR STATIONARY APPLICATIONS (IN PLAIN DOWN TO EARTH LANGUAGE)

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SCOPE AND PURPOSE OF THE PAPER

Why do we bother to monitor the connection to building ground on the DC bus, anyway? Most simply, the answer is protection of the cable and – even more important – the safety of personnel. If an AC line cable connects to ground, current flows through the protective devices and disconnects the power protecting the cable. If the DC cables short from the battery, often there is nothing preventing the batteries from providing full short-circuit current to the cabling. If one of the DC bus connections gets connected to the building ground, this sets the stage for a short if the other pole gets shorted to ground as well. Personnel who assume that the floating DC bus is not connected to ground can be electrocuted while working on the DC bus, if while handling the live connectors they ground themselves.

We now have 100 years of experience with high voltage battery strings powering loads that are not referenced to earth ground. Over the years, equipment faults and resulting human injuries have inspired safer designs, and ground detection circuits have been invented to indicate introduced ground faults. Some of these early circuits used for monitoring floating DC buses are still being used today.

This presentation will provide users an overview of the different ground detection circuits typically found in the utility industry. The circuits are often applied in power generation, transmission, process control and any application where the battery's output is not bonded to the earth ground. Although some lower DC buses like 12, 24, and 48 volt are installed ungrounded, this paper will concentrate on the 130Volt bus used in the utility world. It will provide an understanding of the advantages and disadvantages of the different designs described.

The purpose of the presentation is not only is to describe the different circuits, but also to describe how to pin down a fault when it happens. I personally receive over 60 telephone calls a year prompted by an activated alarm or questions on ground detection faults in a system. The folks that usually encounter a fault are maintenance crews, who are not fully trained in the DC bus and its components. I hope that this presentation will equip engineers with the tools they need to educate these groups in advance. I am also hoping to provide a basis for the layout of future designs.

GROUND DETECTION IN STATIONARY UTILITY APPLICATIONS

The typical utility DC bus consists of a battery charger, a string of batteries, a DC distribution panel, and/or the loads. DC cabling runs can be found throughout a sub-station or power plant. Some systems contain redundant battery chargers on one battery. Other installations contain two redundant batteries and chargers creating two independent DC buses. Some have two 130V battery banks in series and feed, not only two 130V buses, but also a combined bus of 260VDC load. In the past, a sub-station would operate loads such as control relays, breaker coils, and some alarm lamps. A power plant can use the DC bus for lubrication pumps for the turbine, DC:DC converters, inverters, and countless other controls and alarms. The loads are nearly the same in a modern substation built today, except the DC bus is powering more electronic equipment containing DC:DC converters. Since the front end of these DC:DC converters have a filter stage with large capacitors tied to building ground for their input filtering, a fault in the DC:DC converter's filter can cause a ground fault or at least an imbalance to the DC bus voltage to ground.

Ground detection devices are often mounted and monitored in the battery charger. They can be installed in their own enclosure or mounted independently of other equipment. Some of the loads connected to the DC bus can contain ground detection circuits as well. Inverters along with other switchgear typically have built in monitoring of the DC bus to ground.

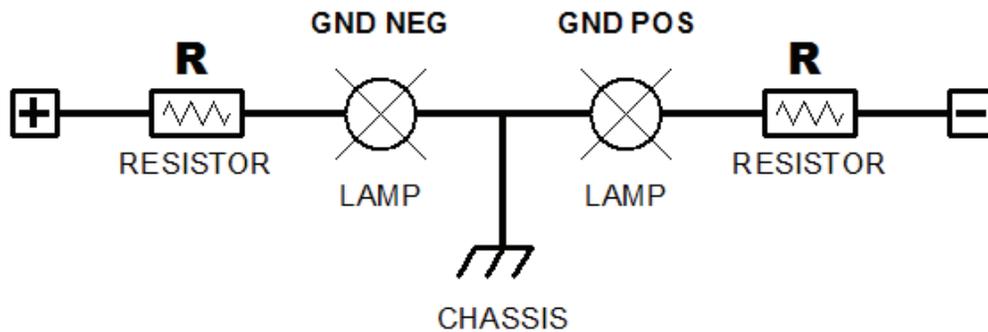
As these pieces of equipment get connected in to the system their ground detection circuits add in parallel and problems can arise, not only because the circuits interact, but also because the addition of more circuits increases the ohmic connection from the DC bus to building ground. Low impedance ground detection circuits such as relays activate high impedance ground detection faults. Measuring the DC bus with a modern digital multimeter (DVM) to building ground without any other ground detection circuit connected will indicate an imbalance. These are very high impedances but are measurable with the 10meg ohm impedance of the DVM. As soon as a circuit of some kind is added between the battery and building ground, the fault we are looking for is actually induced. In fact, in order to provide an indication, we end up adding the fault that we are trying to detect. In the end we add equal amounts to either side of the dc, so the ground impedances are balanced.

HOW GROUND DETECTION CIRCUITS WORK

There are two types of ground detection circuits. The first provides a visual indication of an imbalance to the ohmic connection between the DC bus positive to building ground and negative DC bus to building ground.

Visual Indicators Explained

The figure below shows the simplest visual indicator, where the lamps both glow with half voltage when no other ground connection is made. When the negative is shorted to the ground terminal, the opposite lamp glows to full brightness. The resistors are placed in series with the lamps to reduce the brightness during normal operation, and also to reduce the ground current that the indicator introduces into the dc system.



Ground Detection Lamps

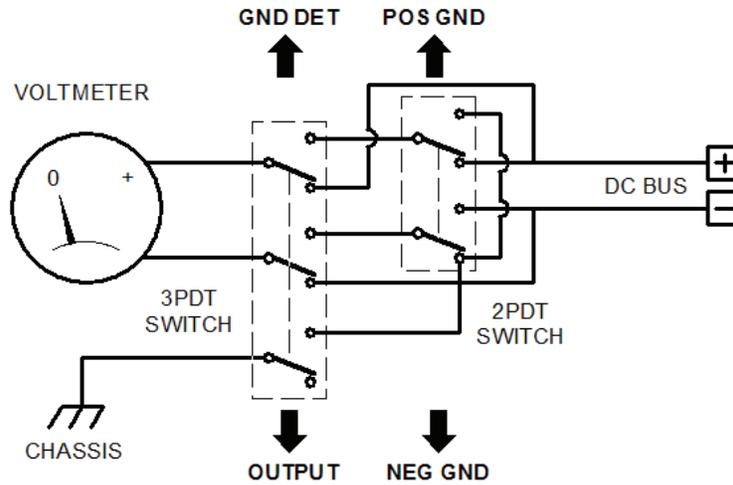
This basic design can incorporate a switch to turn the lamps on with full DC bus voltage in one position, or switch in the building ground to show an imbalance in the other position. A center off position allows the lamps to be disconnected from the batteries altogether. This disconnects the battery from the building ground while in the normal operation. This also prolongs the life of the lamp.

The option's sensitivity is dependent on the impedance of the lamps and the eye of the beholder to determine the magnitude of the added ground fault. The lamp needs to be an incandescent type, and a typical resistance of the resistor/lamp in a 130V system will be around 5K ohms. Depending on the size of the lamp, this design draws about 13mA when connected between building ground and to each side of the battery.

Ground Detection Metering

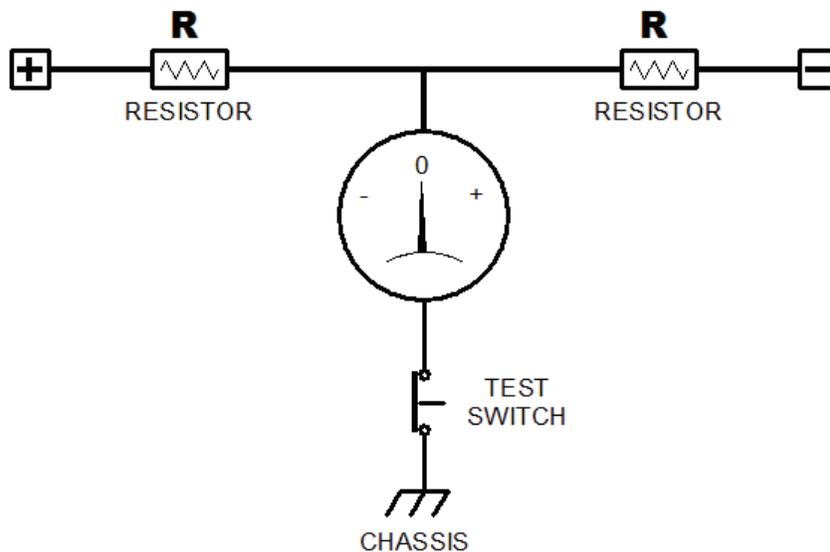
The second type of visual indication is a meter that is connected between building ground and the battery. There are two types of circuits. One version is a voltmeter that can be switched to either the battery positive and building ground or the battery negative and building ground. This left zero voltmeter will show two voltages when switched back and forth. A difference in the amount of indication tells the user if there is an imbalance. The meter is typically 1.0-2.0K ohm per volt. In a 130VDC system, the meter can either be a 150 or 200 Volt full-scale movement. This reduces the added resistance, of the previous design, from building ground to each bus to 200K ohms and draws less than a 1.0mA from the positive bus to the negative bus.

The figure below shows the typical circuit using a built-in analog meter. This meter is installed in the battery charger as the standard DC output meter; it adds little cost to incorporate the switches for the ground detection feature. Modern battery chargers are now using digital meters that are driven not by the battery voltage but by a scaled-down signal, and the displays generated via a microprocessor. These circuits are unable to easily switch in the building ground and produce the same effect, but electronic ground detection circuits have replaced these older ones.



Ground Detection Voltmeter

The next meter type is a Zero Center Ammeter with series resistors and a test switch. This design shifts the vane of the meter left or right, depending on the added impedance to the positive or negative to building ground. The ammeter is labeled with a voltage 150-0-150 or 200-0-200 Volts. The resistors are sized for full meter movement if there is a direct short between any one bus and ground. The meter is sized for a 2mA full-scale movement. The actual display is in volts, and represents the difference in the imbalance. What the deflection indicates is the difference in the impedance between the resistors used and the ground fault that has been added. The ground fault added can be calculated, but one needs to know the balanced grounding value in the system before the testing and all the component values in the ground detection circuit.



Ground Detection Ammeter

Another ground detection meter circuit is simply to connect a digital multimeter to the building ground and then to the positive bus, and then measure the negative bus. If there is no ground fault, the two numbers should be the same. The problem with this method is that the DVM has a very high impedance typically around 10M ohms. An imbalance of 2 Meg can display a large voltage difference on the meter even when the DC bus is not grounded. It's when another balanced ground detection circuit is connected to the DC bus where the DVM measurement becomes more telling of a problem.

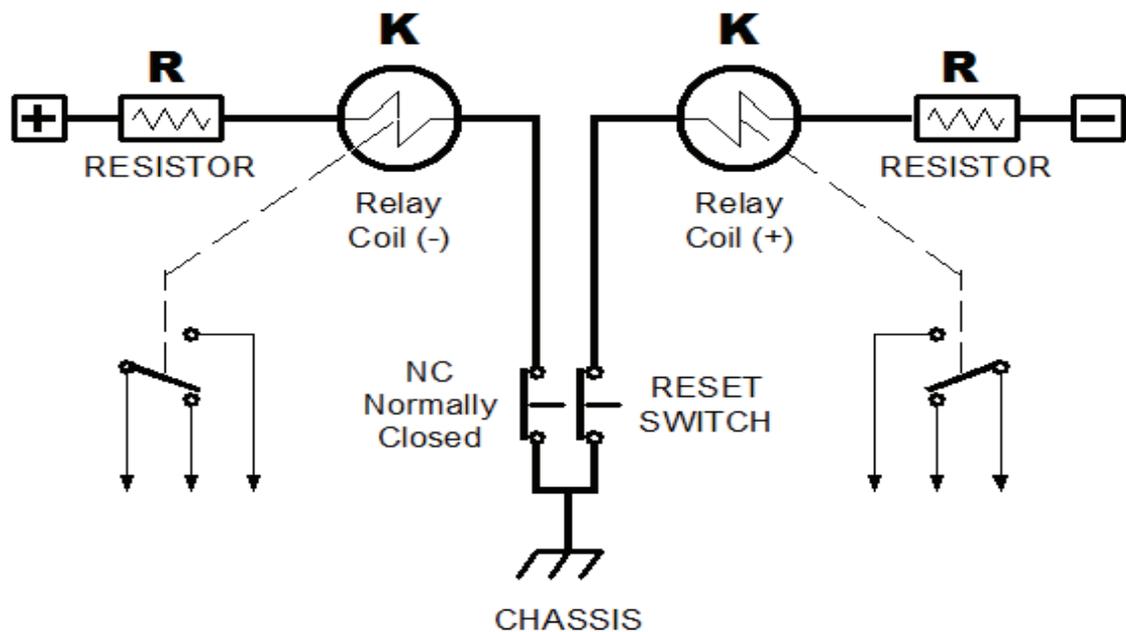
Again, these types of ground detection circuits only provide a local indication, and require interpretation by the observer. In most installations, the battery charger and battery are tucked away in the room that is only visited by a technician for preventative maintenance and inspections. A ground fault can be present for months before anyone even knows that it has occurred.

GROUND DETECTION CIRCUITS THAT ALARM TO REMOTE LOCATIONS

Ground Detection Relays

In this first design, the lamps in the ground detection lamp circuit are simply replaced with relay coils. The relays have series resistors sized for the coil current and the mechanical internal spring tension required to energize the relay coil when the DC bus is grounded. Once energized through a momentary ground fault, the relay often remains in alarm condition. This is because the holding or latching current is much less than the current needed to activate the relay. For this reason, a reset switch is provided to release the relay locally.

The figure below shows the layout of a ground detection relay circuit.

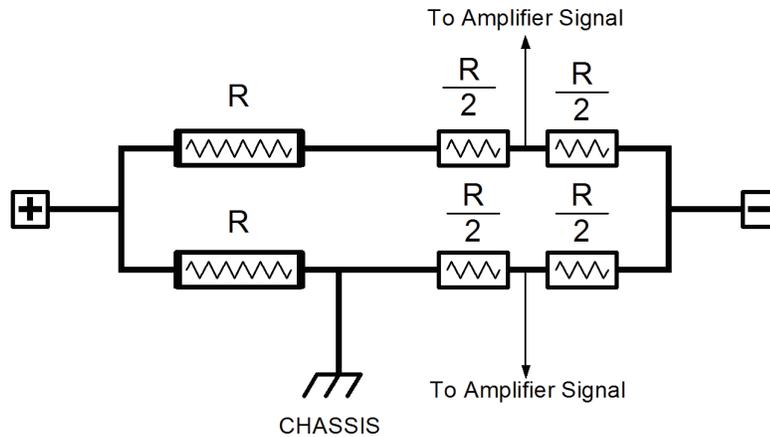


Ground Detection Relays

The value of the ground detection relay coil is near 10.0K ohms for a 130VDC system; the resistors are near 5.0K ohms each. The ground fault needed to energize the relay coil is near a short. This is based on typical 10A contact rated relay. Different relay coils would have different coil resistances as well as different pull-in characteristics.

Electronic Ground Detection Circuits

This design provides a balanced bridge with equal resistor elements, which is fed into an instrumentation amplifier or comparator circuit. Once the bridge becomes imbalanced, the detection can activate a relay driver or drive a lamp.



Electronic Ground Detection Circuit

The advantage of this design is that the effect on the DC bus can be minimized, because the resistance added to the system has much higher impedance than the designs previously described. Also, the sensitivity of this design is adjustable. Setting the alarm to activate at lower impedances can prevent false fault indication in dirty environments. If the load is more sensitive to ground faults, the circuit can also be adjusted to detect small changes to the imbalance of the DC bus to ground.

QUICK COMPARISON OF GROUND DETECTION CIRCUITS

The chart below compares the different ground detection circuits.

CIRCUIT DESIGN	SENSITIVITY	COST	REMOTE ALARM	ADJUSTABILITY
GND DET LAMPS	LOW	SMALL	NO	NONE
GND DET VMETER	MID RANGE	SMALL-MODERATE	NO	NONE
GND DET AMMETER	MID RANGE	MODERATE	NO	NONE
DVM	VERY HIGH	-----	-----	-----
GND DET RELAYS	LOW		YES	NONE
ELECT.GND DET	MID RANGE	HIGH	YES	YES

GROUND DETECTION IN THE REAL WORLD

Power plants and sub-stations are initially clean, new and free of grounding material, but as time passes, dirt and other contaminants pervade their environments. Batteries, often stored unprotected, can spill electrolyte onto the support racks and enclosures. This conductive electrolyte, combined with carbon dust and other conductive material, can cause an imbalance and a ground fault.

Placing two battery chargers together on one battery is a common way to achieve a higher level of redundancy of the DC bus. This connects both ground detection circuits in parallel and simultaneously cuts the sensitivity in half and doubles the current flow from the battery to building ground. A quick way to restore the same sensitivity is to disable the ground detection circuits in one of the battery chargers. Some DC bus configurations can create a false fault when more than one type of ground detection circuit is connected in the system. An imbalance can also be created in applications where two batteries/battery chargers are tied together at the negative with two separate positive feeds to the separate loads. Each battery charger contains its own ground detection alarm circuit that is in parallel with the negative but not with the positive.

Troubleshooting Ground Detection Circuits

Once a ground fault has been detected, measure and record the two voltages between building ground to positive and building ground to negative, and then measure the total DC bus voltage.

- If the first two measurements are equal (half the bus voltage), then the alarm is false and the ground detection circuit may need an adjustment or be checked for defective parts in the circuit.
- If there is full voltage with one measurement and zero volts with the other, then there is a direct short to the bus on the side that measures zero.
- If there is a slight difference between the first two measurements, then there is a partial short to building ground. Depending on the ground detection circuit you have, you will need to make calculations to determine the resistance of the ground fault that has been detected.

Once we have determined the severity of the fault we can examine the loads that might contain those resistances. Often it is easy to shed the loads one at a time to find the partial short through the distribution panel. If the ground fault to the DC bus is a direct short, remove the equipment connected to the DC bus one at a time, in the following order, to determine the location of the fault:

- First, remove the battery charger; this often removes the ground detection circuit itself. Once the DC bus leads are removed, a DVM can be used to measure the voltages between the DC bus and building ground to see if the bond to ground has been reduced.
- If the short to building ground is still present, then reconnect the battery charger and use its ground detection circuit and shed the loads one at a time.
- The last place to look is the batteries. If the battery charger can support the loads, lift the leads of the batteries and use the DVM to measure the DC bus to building ground.