FINDING THAT ELUSIVE GROUND FAULT

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Abstract

In PRC-005[1] the three parameters of a DC system that require attention most frequently are the verification of the system voltage, plus the inspection of electrolyte levels and whether a ground fault exists. Checking for that ground fault is relatively simple and many of the chargers incorporate a ground fault detection system which will generate an alarm if a ground fault is detected. The problems start when one tries to find where the ground fault exists within the DC system. This paper will provide a brief overview of the most common methods by which ground faults are identified and the potential that the methodology used has on finding the actual location of the fault.

Introduction

Ground faults are defined as an inadvertent contact between an energized conductor and ground. They can exist on all electrical systems both AC and DC. This paper specifically refers to ground faults and the way they impact a battery backed standby system in which neither pole of the battery is referenced to ground.

Ungrounded DC systems are typically found in utility applications involving the generation and transmission of electricity. In these applications, a ground fault can exist at any point within the DC power system and the associated distribution. Another standby power system in which a DC ground fault can occur are Uninterruptable Power Systems (UPS's). Here, the location of a DC ground fault is restricted to the battery and the associated cabling and circuitry between the charger, battery and inverter or within the battery itself.

Identifying a Ground Fault

Why is identifying and rectifying ground faults so important? It's simple, they can cause system disruption, equipment damage and pose a safety risk to any personnel working on the system. The electric utilities have long recognized the importance of detecting ground faults and most of their ungrounded batteries will have some form of ground fault detection associated with the DC power system. This can be as simple as two incandescent lamps with current limiting resistors, connected between each of the ungrounded battery poles to a common ground point. Under normal operating conditions, the lamps will be at the same level of brightness and if a ground fault occurs, the brilliance level of the lamps will become unbalanced and the one which has lost brilliance will be on the polarity with the inadvertent ground. This method of establishing a balanced ground reference and the detection of any subsequent imbalance, can be implement in many ways with different levels of sophistication and reporting and is the most common method in service today.

For UPS installations, where the UPS has an input isolation transformer, a balanced resistor network can also be used. For the newer generation of UPS without an isolation transformer, the challenge of identifying a ground fault condition is more difficult. This is because the operation of the semiconductors as a function of the rectifier circuit will provide a path to the system grounding of the three-phase supply. To identify a ground fault within the battery it is necessary to measure the current in both the positive and negative busses in a single Hall effect transducer, if no ground fault exists the currents will cancel each other out.

Using these methods and other proprietary approaches, the manufacturers of both AC and DC standby power systems will typically be able to identify any ground faults that occur within their systems. The challenge for the user is to find the actual location of these often elusive, inadvertent grounds. One of the more commonly suggested methods is to simply isolate the individual load circuits by removing or simply switching off the circuit protection devices. While this may have been an acceptable practice in bygone days, in today's 24/7 environment the loss of service that will typically result from such an approach is no longer acceptable.

Using Low Frequency AC as a Location Method

In the 1980's, Commonwealth Edison developed a system that injected a low frequency AC signal between the partially grounded conductor and ground. The signal could then be traced using an AC current clamp and an indicator to show the presence of the AC signal when the current clamp is placed around any cable which is in the path from the point of injection to the point at which the circuit is grounded. The device was eventually licensed to a major test equipment manufacturer who continues to manufacture their current generation of this product today. As with any good idea there are now other manufacturers with products based on the same concept but with specific features that help in the tracing of that elusive ground.

The majority of ground faults are the result of a breakdown of the insulation between a live conductor and ground either due to physical damage to the insulation or the ingress of moisture. They can also occur when a conduction path is created due to the leakage of a conductive liquid such a battery electrolyte, often by the associated corrosion caused.

When a ground fault is reported, its existence can be verified by measuring the voltage between each polarity and ground. The one which has the lower voltage can be assumed to be the one leaking current to ground. Now that the polarity on which the ground fault exists has been identified, if the ground fault detection circuit utilizes a balanced resistance network the next step is to disable that reference ground and the associated detection circuit. With an ungrounded power system as the monitor ground reference is not a protective ground, no electrical regulations are being broken by removing it. If this is not done, any attempt to follow a path to ground using a low frequency based location system will always lead to that reference ground and not to the actual problem area.

Setting Up

To use a low frequency tone-based locator, the first step is to set up the transmitter and connect its output between the compromised polarity and a good ground point. The point at which the connection is made should be as close to the power source as possible. The battery rack is typically a convenient point at which the connection can easily be made. The actual set-up of the test equipment is specific to each instrument but will typically include ensuring that the correct level of signal is being injected into the circuit. Once the test signal is set up, the operation of the portable receiver, which will typically consist of a clamp-on current sensor and a handheld display which can be checked by measuring the level of the signal being injected into the power system. On some systems, depending on how the meter indicates the signal strength, a simple calibration may be required to set up the receiver display to show a full-scale reading at the point of insertion.

Phantom Grounds

Although these systems use a very low frequency typically between 10 and 20 Hz, any filtering capacitance in any of the load circuits may allow enough of the signal current to flow ground to falsely indicate a possible resistive path to ground, this is what is commonly referred to as a phantom ground. As many of the previous generations of control systems did not require any reference to ground, the problems with phantom grounds was limited. Today, with the increase of computer-based controls which are powered by switched-mode power supplies, all of which require additional capacitance to ground to limit high frequency emissions, the problem is more common. Again, the individual manufacturers have taken different approaches as to how to identify these false positives. In one case, the manufacturer adjusts the transmitter to balance out the capacitance in the circuit under test while another shows the phase change in the received signal caused by the additional capacitance as an indication that one could be following a phantom ground.

Finding That Ground

Once the test equipment is set up, the operator should move through the DC distribution network, following the strongest signal in the receiver. In many cases this will require the removal of covers from fuse or circuit breaker panels to allow access to the individual cables feeding the various loads. As many of these may feed further distribution panels, local knowledge or detailed distribution drawings are required, otherwise the task may take much longer and be more challenging than anticipated.

As good as these products are, there are often additional real-life operating conditions which present additional challenges to identifying that elusive ground fault, some of which the author has been subjected to during training sessions over the last couple of years. When a customer requests onsite training and is willing to pay for it, then you can be reasonably sure that the practical part of the training will be at a troublesome location, one that has beaten all previous attempts at identification and often with a number of different products.

Isolating the Detection System

Probably the most common problem is trying to isolate the internal ground fault monitors within the chargers themselves. When the charger uses the balanced resistor method of detection, that ground reference must be isolated, and depending on how that is implemented, it may be as simple as unplugging a separate sensor board or changing a link on the control board. On some chargers that may not be possible and the output of the charger may have to be physically isolated. If one is lucky, that may be achieved by operating the DC output breaker, on others that may require that the charger is physically disconnected from the battery and distribution. This requires that the battery will be able to carry the load. Caution; at one outdoor location the author experienced, when the charger DC output breaker was opened, the voltage at the battery dropped so rapidly it was clear that the battery would not carry the load so further investigation had to be abandoned. So it is always a good idea to somehow test the integrity of the battery before relying on it to carry the load.

More recently, at an electric utility training center, as part of a training course, the author was asked if he could demonstrate the use of a specific ground fault locator. The training center was set up as a substation complete with switched-mode chargers and batteries. The first step was to establish a ground fault condition in order to give the students something to find. Once the faulted polarity was identified and the transmitter set up, when the students tried to use the receiver the readings were all over the place. At that point it was revealed that this was what they saw every time they tried to use a ground fault locator with these switched mode chargers. As this was a training installation, they had installed a two pole disconnect switch between the charger and the rest of the DC system, so it was operated to isolate the charger and then everything worked as expected and the class successfully found the simulated ground faults. Because the chargers were not in the same room as the batteries, where they were making the connections, the response of the charger to the low frequency signal had not been observed, so before the transmitter was disconnected, the charger was reconnected and hearing relays chattering within the charger clearly indicated that there was interaction between the charger output circuit the low-level test signal. As there was no charger manual immediately available, we were unable to identify why this was happening. Concerned that this may be a characteristic of switched-mode chargers, the GFL test set that was used has subsequently been tested with other switched mode chargers and nothing similar has occurred.

Powering a Grounded Power System from an Ungrounded Battery

Another problem that can occur but not easily resolved, is when the communications equipment that is now a part of every substation, is powered from the 120 VDC station battery using DC to DC converters to reduce the 120 VDC down to a nominal 48 VDC. At more than one location, the only circuit with an apparent ground fault was the circuit breaker feeding a rack of communications equipment. The thing to remember is that all 48 VDC powered communications equipment is designed to work with the positive polarity of the power source grounded, so complete isolation between the 120VDC source and the derived -48VDC is necessary to isolate the ungrounded 120VDC source from inadvertent grounding. While a quick review of the specifications for the primary DC to DC converters in the identified racks stated that they were fully isolated devices so there should have been no physical path from input to output. In the same rack, there were a number of other separate grounding connections from various pieces of equipment but without a set of drawings there was no way to identify any specific connection as the potential source of the problem. So, the problem was handed over to the communication technicians to identify and correct.

Look Out for Murphy

On another occasion, after identifying the faulted polarity, isolating the ground fault indicator in the charger was a simple matter of removing a plug from the control board. It was then a simple matter of following the tone to a circuit breaker in an outdoor cabinet which was identified as feeding one of the high voltage switchgear control cabinets. When the panels were removed from the control cabinet to allow access to the terminating connections, the signal could not be seen at the point where the power feed was terminated.

The cable in question was a two-wire cable with an outer sheath and along with the two conductors there was a bared tinned copper drain wire. A number of other similar cables were also terminated at that cabinet, each with a drain wire and as this was the last point on the circuits, the drain wires were twisted together and taken to a ground point. Placing the current clamp around these ground wires indicated that there was path to ground and it was on the drain wire of the previously identified cable. See Figure 1.

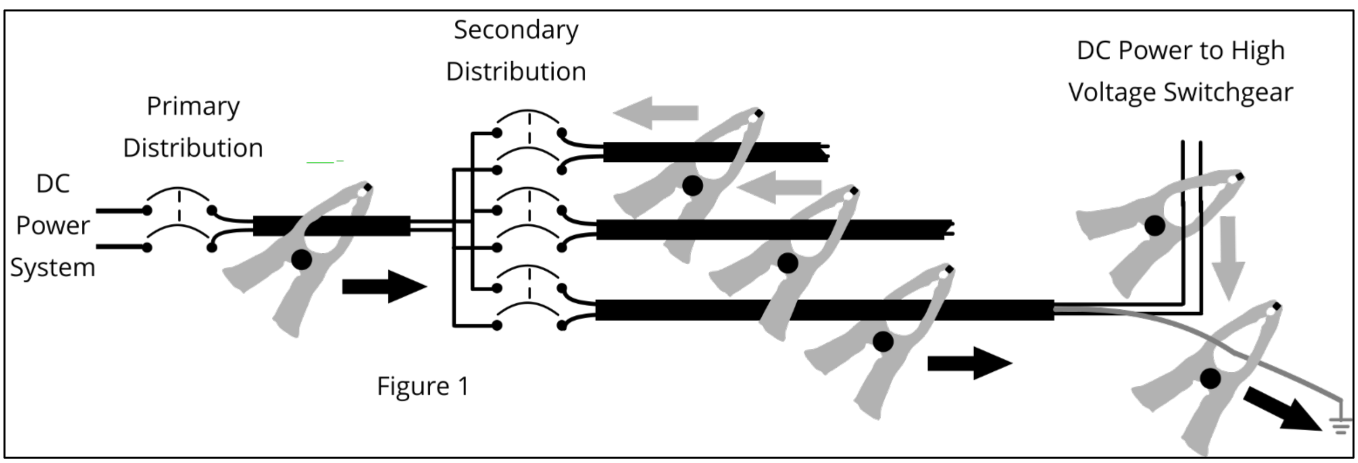

Figure 1.

Returning to the intermediate circuit breaker cabinet, no drain wire was visible on the cable so the assumption was that the bare wire had been cut back a little too close to where the outer sheath started and perhaps during installation the cable had been pulled and the cut end of the wire had gone back into the sheath. Then over time, it had penetrated one of the conductor’s insulation partially shorting it to ground. The drain wire for that cable was identified from the others terminated in the cabinet and cut to remove the ground fault until the cable could be replaced.

It would be nice to describe this example a complete success but what followed is a demonstration of how easily one can be misled. On returning to the battery and removing the transmitter connection, the voltage on the original faulted polarity to ground was checked and it still showed a reduced fluctuating voltage. The immediate assumption was that there was a second ground fault to locate, so the transmitter was again connected between the polarity and ground. The problem was that there was still not a clear signal from the receiver. After an extended period of wasted effort, the author remembered what he had been taught many years ago, "If after finding a fault and clearing it you appear to have a second one, always restore the equipment to its original configuration to verify that you do actually have a second fault."

When that was done, as soon as the ground fault monitor in the charger was reconnected, the problem disappeared. The problem was on an ungrounded power system without a balanced path to ground, as in the ground fault monitor, there is no reference to ground, so one won't get a valid reading. So, when you read on the internet that if no other form of ground fault monitor is installed, you can detect a ground fault by checking the voltage to ground from the positive and negative polarities and if they are balanced then no fault exists, this is "false news." For unless there is a ground fault detector there will be no ground reference against which the voltages can be compared.

Conclusion

In conclusion, the use of an injected low frequency based system is probably the best way to locate these elusive ground faults but like everything else, it takes patience and practice to get good at it, and no matter how good you are, there will still be challenges. Like the circuit you can't isolate, so you must wait for a shutdown. And of course, the truly elusive one that only happens when it rains.

Reference

1 North American Electric Reliability Corporation (NERC) PRC-005-6. *Protection System, Automatic Reclosing, and Sudden Pressure Relaying Maintenance.* www.nerc.com

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