AVOIDING PITFALLS DURING GROUND-FAULT LOCATION

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Introduction

When tracing ground faults in DC systems it is necessary to maintain system reliability. Due to the criticality, the troubleshooting process needs to be performed online and without disturbing the system. Ground-Fault tracing by signal injection has proven to be a highly effective method to locate faults, but its usage entails some obstacles that, if handled properly, will allow a successful and quick tracing and location of the faults.

Injecting a unique signal into a DC system provides a means to trace the fault. However, the injected signal can be affected by various system characteristics. Depending on the type of tracing signal and its frequency, the system capacitance and system noise can have various impacts on the injected signals.

The injected tracing signals can be either AC or pulsed DC. Since these signals change over time, capacitive circuits will provide paths for this tracing current. The cabling in DC distribution systems can provide significant capacitance. These additional current paths are in parallel with the ground fault, increasing the overall tracing current. Some capacitive paths may draw higher currents from the test instrument than the actual resistive faults. If not properly identified and handled in the measurement process, they can be considered as a faulted circuit and the user ends up chasing these "phantom faults." Furthermore, the magnitudes of the applied signal, be it AC or pulse, need to be carefully handled to avoid excessive current circulation that may cause related problems that can lead to a breaker trip.

For detection and tracing purposes, a current transformer (CT) is required. This CT is subject not only to the AC field from the test signal and the ripple from the system, but also to the DC field from the floating and loading conditions. If this DC field is large in magnitude, the CT may get saturated, affecting not only the measurement but also magnetizing the CT. This magnetization can lead to the inability to remove an iron-core CT from the energized circuit without causing damage to the CT or without the use of high levels of mechanical force.

The system noise, ripple from the charger or introduced by the loads, includes various harmonic and inter-harmonic components of the fundamental frequency, which can mask the tracing signal not allowing proper measurement of the stable AC magnitude or the unique DC pulse.

This paper discusses in detail the mentioned effects and how to handle pitfalls such as tracing of phantom faults, inability to identify the tracing signal, dealing with installed ground monitors, inadvertent breaker tripping, and inability to open and remove the CT used for tracing. The purpose of the document is to provide information to better understand the troubleshooting process while improving safety and effectiveness of locating ground faults using AC or pulsed DC signals.

Ground Fault Monitors

Ground Fault Monitors are essential on ungrounded systems to indicate when a ground fault has developed in the system. However, they can be a problem when tracing that ground fault. This is because ground fault monitors will often have their own path to earth, in essence they may be an intentional fault of high impedance to earth. If the impedance of the monitor to earth is less than the impedance of the ground fault, then most of the injected tracing signal will flow though the ground fault monitor and not the ground fault. If the ground fault itself is close to earth (a low impedance fault) then this may be of little concern, depending on the design of the ground fault monitor. However, the higher the impedance of the ground fault the more of a factor the ground fault monitor's earth connection becomes since it offers a parallel path to ground.

Best practices would dictate that when tracing a ground fault, the ground fault monitors should be disabled, pending the type of monitor, for example by removing a board, disconnecting the earth jumper, or adjusting the value of the impedance. In substations on 125V systems this will typically have no adverse effects on the circuit since this is a passive monitor. In some cases, it may cause some alarms, so it is prudent to include this in the communication to the system controller. On other types of systems there is a need to have a clear understanding on how the ground fault system works and is installed before any disconnection is performed, as it could cause a hazard. For example, on some 540 Volt UPS systems the ground fault circuity may be integrated deep into the electronics of the UPS. In these cases, it is recommended to verify the proper procedure with the manufacturer of the system, or it may be necessary to troubleshoot with the ground fault monitor on-line.

Stray Capacitance and Signal Injection

When searching for ground faults, a transmitter injects a current through the fault (fault current) and a receiver is then used to trace the path of the fault current. The injected current can be either an AC wave or it can be a pulsed DC output as shown in Fig. 1.

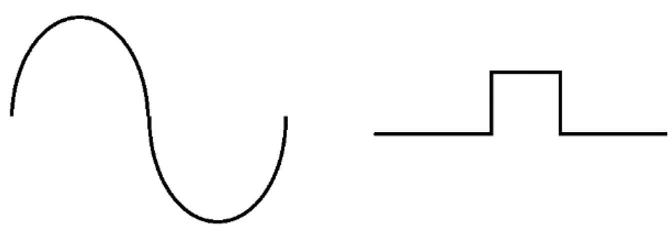

Fig. 1: AC and pulsed signals

A pulsed output often needs to be synchronized with the receiver during the test setup process. This is required due to potential noise on the system, as random noise can look like a pulse. This way the receiver can detect the test pulse and avoid identifying pulses from the noise circulating in the system. A drawback of this method is that if the noise magnitude is high, even during the synched pulse and detection instance, the noise can still interfere. In addition, if the sync is lost, then the receiver needs to be reconnected to the transmitter to reacquire the synchronization.

Be it AC or pulsed DC, the signal is applied to a large electrical distribution system. The main components of such a system are typically long runs of bundled shielded cables that consist of conductors separated by insulators, this all being a large capacitive network. Capacitance acts as a variable impedance when the excitation signal changes over time, so it will have impacts on both pulsed DC and AC signals.

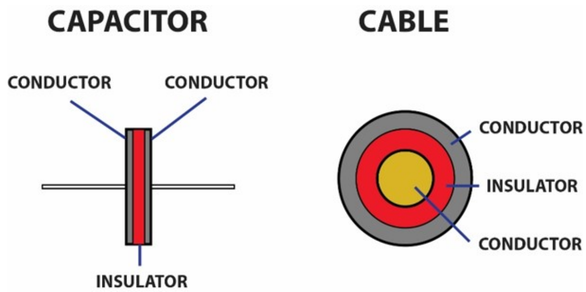

Fig. 2: Capacitor vs. Cable

The longer the cable, the greater the surface area of the conductors, hence the higher the capacitance. Even unshielded cables form a capacitor from the cable to earth: The cable is a conductor, earth is a conductor and the air—mostly, along with a little cable insulation—between is an insulator. This is known as stray capacitance (Fig. 3).

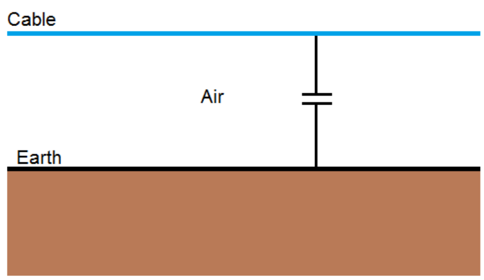

Fig. 3: Stray capacitance

Add to this the capacitance from the equipment connected to the distribution networks: relays, meters, remote terminal units (RTUs), coils, etc. The capacitance on these systems can get to substantial levels but will have little impact on the DC system itself since a capacitor does not pass DC current.

However, when tracing a fault with a sine wave, a current that changes in time circulates through the system. This means that in addition to the path to ground through the faulted circuit, other circuits with high capacitance will also draw the fault current used for tracing (through capacitive coupling of AC).

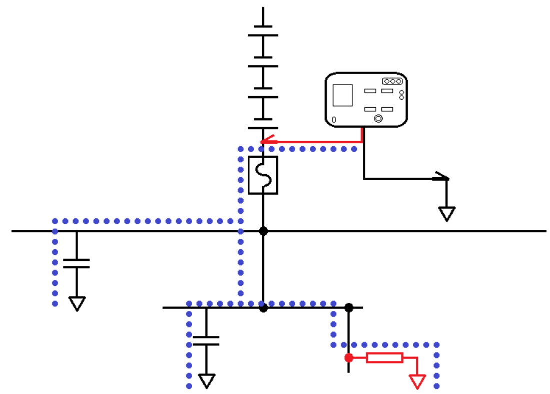

Fig. 4: DC circuits with capacitive and fault current

Therefore, if it cannot be determined what circuits have the real fault and which circuits are only drawing current due to capacitance then the operator can be tracing the wrong path all day long and never find a fault.

Capacitance causes a phase shift between the voltage and current. A capacitive pick up allows the test gear to determine this phase shift and the real and reactive components of the circuit can be established, determining how much current the real fault is drawing and how much is drawn due to system capacitance (Fig. 5). If there is only reactive current on the circuit then the circuit is only drawing current due to capacitance and the fault is on another circuit.

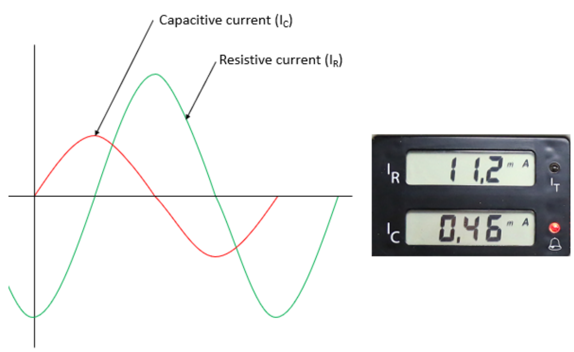

Fig. 5: Measurement of resistive and capacitive current

When a DC pulse is applied to a capacitive circuit a charging effect occurs, meaning that the pulse energy is stored in the capacitance dampening the pulse amplitude of the trace signal. Sufficiently high capacitance can decrease the pulse amplitude to a point where it cannot be traced. In this case the pulse amplitude or width would need to be increased, to allow for more charge time after which the pulse can be detected.

Fig. 6: DC Pulse

Fig. 7: Attenuated DC pulse

Inadvertent Breaker Tripping

When tracing a ground fault, the last thing anyone wants to do is trip a breaker and have a critical system go offline. When a ground fault occurs, it draws some amount of current. This current may or may not be flowing through a breaker tripping circuit depending on the path of the ground fault. If the current is flowing through a tripping circuit, then the injected tracing current will add to this current level. If the total current exceeds the threshold of the trip coil for a long enough period, then that breaker will trip.

If the ground fault is a low impedance ground fault (close to earth) then it will draw more current than a higher impedance ground fault. Therefore, a minimal amount of tracing current should be used to ensure there is no breaker trip. It is advantageous that with a lower impedance ground fault not much tracing current is needed. This level can be kept at minimal values to safeguard against trips.

If the ground fault is of a high impedance, then a higher tracing voltage will be required to maintain a sufficient signal current for tracing. If the system has over-voltage protection devices, then this should be considered, to avoid a potential trip.

The best practice is to always trace using minimal current. It is always best to set both current and voltage limits on the ground fault transmitter to safeguard against inadvertent trips.

Noise

Switching noise on systems such as from a SCADA can interfere with the tracing signals (Fig. 8) and it can make it difficult to locate a fault if the noise is in the same frequency range when an AC or DC pulsed signal is used. This can cause instability in the receiver measurement. When this measurement does not stabilize it becomes difficult to determine which lines are drawing fault current and which are not.

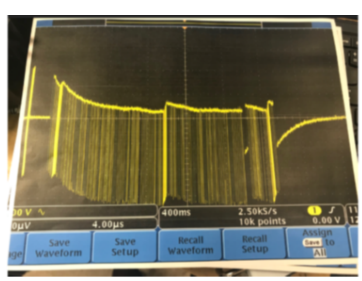

Fig. 8: Sample of noise from a SCADA in a DC system

Since this switching noise is typically at a higher frequency, a low frequency tracing signal is desired. The receiver can then use a low pass filter to measure the tracing signal, minimizing the effects of the higher frequency noise on the system.

In those cases where system noise still does cause measurement instability, it is possible to cancel out the system noise. The system noise current will typically circulate through the system, flowing from the positive side, through the load, and returning on the negative side. The injected tracing signal will flow only from the faulted side through the fault and return on the earth ground.

By placing the CT around both the positive lead and the negative lead, the noise that circulates on the positive side is cancelled out by itself when it returns through the negative side. However, since the tracing signal flows through the earth ground, that signal is not cancelled out. This will stabilize the measurement on any noisy circuit.

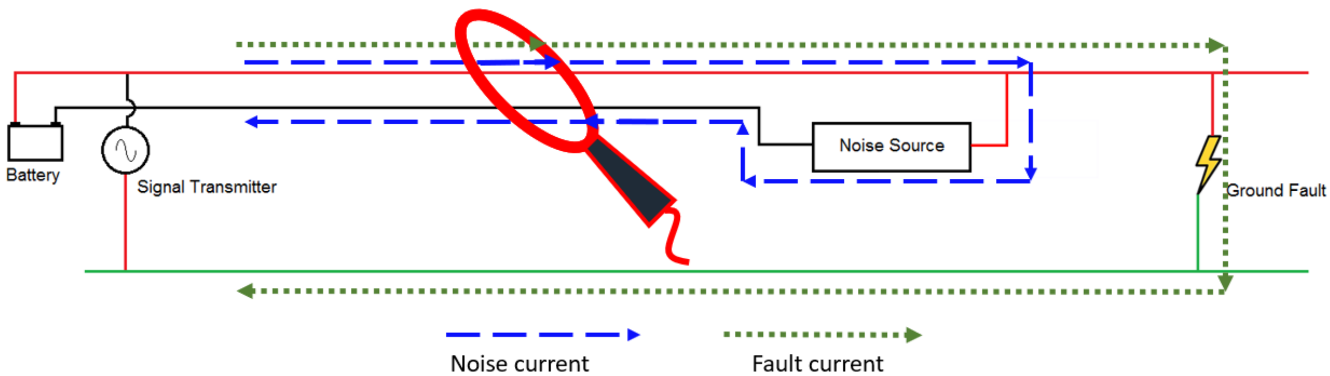

Fig. 9: Measurement of a circuit with noise and fault current. CT around positive and negative conductor.

CT Magnetization

When tracing ground faults on ungrounded DC systems different sections may have charging, load, or fault currents. It is not always a certainty that there will be no DC current flowing through any measured circuit. After all, a ground fault provides a current path to earth.

For purposes of tracing low level signals, a large pure iron core in the CT provides a high permeability making it a better option to measure the low currents used to trace ground faults but on the other hand it makes the core more susceptible to magnetization. If an iron core current clamp (Fig. 10) is placed on a line with DC current, it will cause the CT to magnetize. The iron core will have wire wrapped around it to transfer an AC signal. However, a DC signal will magnetize the iron core.

The higher the DC current the stronger the magnetization. This can make removing the CT from the circuit quite difficult. The CT can end up damaged in the process of removal. In some cases, the CT cannot be removed from the line until the DC current is no longer present and the CT is demagnetized.

Fig. 10: Iron core current clamp

One way to overcome the magnetization effect is to use current clamps that do not implement large iron cores. A Rogowski coil for example, uses an air core. Therefore, it will not magnetize. However, the permeability of an air core is quite low, so a Rogowski coil is poor at measuring these low-level low frequency signals. Using current clamps with smaller cores also help reduce the magnetization effects. However, the smaller the core the less sensitive the current clamp will be to low-level tracing signals.

Using a CT with flux gate technology can allow for the use of smaller cores. In this type of CT an active signal is generated. External magnetic fields will distort this active signal. These distortions can then be measured to determine the low-level signal. This type of CT reduces the magnetization effect while maintaining good low-level sensitivity.

Another option is to use a CT with a nickel alloy core. The advantage of these current clamps is they can use larger cores, providing higher permeability to obtain better sensitivity, while minimizing the magnetization effects due to DC current. Since these current clamps do not need to generate a signal, they are passive and do not require a power source, such as a battery.

Fig. 11: CT with nickel alloy core

Conclusion

Ungrounded DC systems are the backbone of protection and control systems in electrical substations and other installations. Connections to ground will develop due to aging, new additions, or maintenance activities, this is considered a fault in the system and needs to be corrected to avoid mis-operation of the protection and control system or to avoid deterioration of the battery.

Due to system operating norms and/or for the stability and reliability of the electrical system the process of finding the fault needs to be done online. Ground fault tracing with AC or pulsed signals provides an effective technique to detect ground faults without turning off any DC circuit in the system. However due to the characteristic of the signals used for troubleshooting or due to the characteristic of the system several pitfalls can occur.

This paper recommends disabling the ground fault monitor which is an intentional fault to ground and can interfere in the troubleshooting process. It also recommends the usage of a capacitive pickup to be able to distinguish currents of capacitive and resistive nature allowing easier identification of the circuits carrying resistive current. To avoid breaker tripping the implementation of voltage and current limits on testing equipment is recommended to avoid circulation of currents that could trigger tripping circuits. In case of noise interference with AC tracing signals, this paper recommends the usage of a low frequency signal and the measurement on both, positive and negative conductors of each circuit to cancel out the noise. Finally, this paper recommends the usage of current clamps with cores made from soft metal alloys which have high sensitivity to signals of low level and but will not easily magnetize under DC fields.