High Reliability Electrical Distribution System for Industrial Facilities

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Abstract – **Continuity of service is most essential in data processing facilities. Insulation failure due to line to ground fault is the most prevalent cause of service interruption in such facilities. Solidly grounded systems create fatal and costly Arc Flash hazards that would cause substantial damage at the fault location. Resistance grounding limits the line to ground fault current. This practice has been in use for many years and is widely applied in industry. This paper explores the application of resistance grounding in data processing facilities, where the distribution systems are typically more complex and may involve multiple sources, such as multiple transformers, multiple generators or a combination of both. This paper proposes that the sizing of neutral grounding resistor (NGR) should be exclusively based on charging current. Application examples are presented and the concept of hybrid grounding in low and high voltage (HV) systems is discussed.**

Index Terms—**High Resistance Grounding (HRG), Hybrid Generator Grounding, Multi-Circuit Ground Fault Relay, Selective Second Fault Tripping, Stator Ground Fault.**

I. INTRODUCTION

HRG is recognized by the Canadian Electrical Code and considered to be the best practice in process industry [1], [2]. The advantages of HRG concept are: power continuity, negligible damage at the point of fault, insignificant arc flash hazard, low risk of single fault escalating into line to line of three phase fault, and minor shock hazard.

To implement HRG, a resistor is installed between the transformer neutral and system ground. An alarm is raised upon occurrence of a ground fault. Phase to ground voltage is used to identify the faulty phase. The alarm level is usually set for 50%, or less of the resistor let through current. This prevents false alarms caused by the unbalanced capacitive leakage current in unfaulted feeders [3]. In modern relays the zero sequence sensor signals pick up the fault first; moreover, the presence of unbalanced voltage is verified before the alarm is indicated. To avoid the possibility of nuisance alarms caused by inrush currents and non-linear loads, the Zero Sequence Current Sensor output is filtered and only the fundamental signal is extracted. These measures have been effective in avoiding nuisance alarms and trips in sensitive ground fault relays. This paper explores on resistance grounding applications and offers suggestions for performance enhancements for both LV and HV systems in hospitals.

II. HIGH RESISTANCE GROUNDING

Fig. 1 illustrates a typical application for a Δ/Y transformer with 480 V secondary. The 5A grounding resistor is placed between the transformer secondary neutral point and ground. All the feeders are monitored by a multi-circuit ground fault relay which identifies both the faulted feeder and the faulted phase.

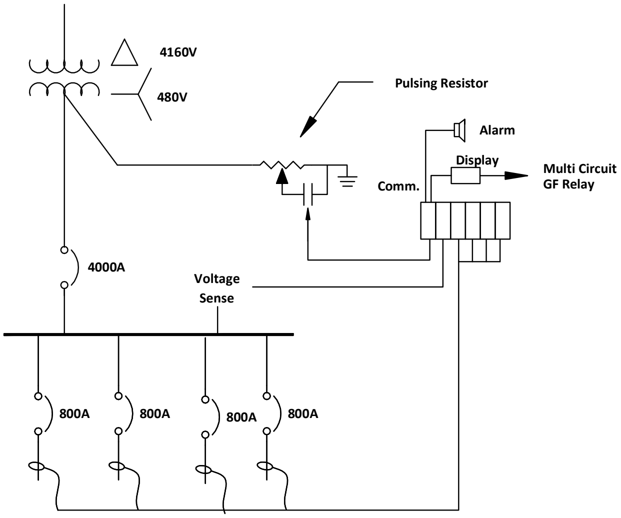

Fig. 1 Typical Δ/Y Installation

Four key points are to be considered when resistance grounding is applied:

1. All cables need to be rated for line-line voltage for the maximum duration of the line to ground fault.
2. Lightning arrestors and surge suppression devices will see the phase to phase voltage and they need to be adequately rated.
3. Capacitors should be rated for line to line voltages as well.
4. Circuit breakers and contactors need to be rated for breaking the line to line voltage across the pole of the breaker as well.

In a distribution system, there will be a 480V normal power system and a 480V generator power system. The most critical loads are fed from the emergency power distribution which is downstream of the transfer switches. The transfer switches get

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power from both the normal power system and the generator power system. In this scenario a ground fault occurs in the switchboard downstream of a transfer switch, Fig. 2. The cause of this fault could range from insulation failure due to overvoltage stress to tracking due to surface contamination, component failure, rodent intrusion or human error.

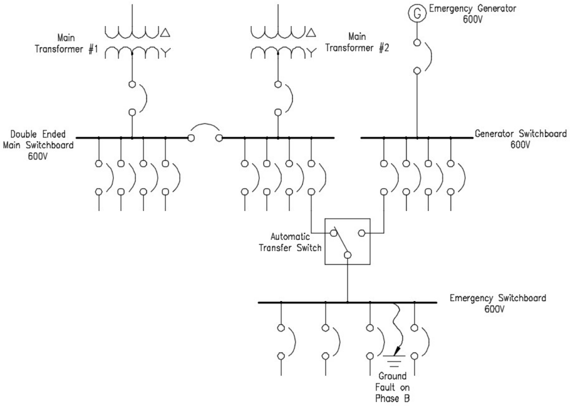

Fig. 2: Fault Scenario

In a solidly grounded system, the ground fault results in a large current flow which creates a significant damage inside the switchboard and the upstream transformer. The upstream breaker would trip in response to this large fault current. The loss of main power is sensed by the transfer switch and all the loads are transferred to the emergency generator. At this point, the occurrence of a second fault would further damage the switchboard and the emergency generator which would result in the generator breaker to trip as well. The loads will remain unpowered afterwards until a new source of power can be supplied. Full restoration of the system is conditional on the replacement of the switchboard which is a lengthy process.

In contrast to solidly grounded systems, in resistance grounded systems, the first ground fault will generate an alarm, the continuity of service is maintained, the main transformer is not stressed due to fault, the emergency generator is not exposed to fault current, and the damage to the switchboard is minimal only requiring the replacement of a single insulator. Therefore, the inconvenience to the facility is minimal.

III. LOW VOLTAGE – HIGH RESISTANCE GROUNDING

A. Locating Ground Faults

Monitoring all the feeders for the purpose of locating the ground fault is a major functional enhancement in ground fault detection systems. To achieve this, the fault current is modulated at a slow rate, 1 cycle per second. This is called pulsing. To perform the pulsing, a flexible zero-sequence sensor encircling all three phases is used to provide an oscillating signal to a hand-held multi-meter. Readings are taken on the faulted feeder starting from the switchboard. Two or three measurements are usually sufficient to show the fault location. Measurements can be done while system is energized and in operation. The portion of the fault current which returns via the ground path in the conduit is sufficient to start the oscillation required for ground fault locating [6], [7]. This technique can be used safely for systems up to 4,160V. Above this voltage range, switching of a resistor at high voltage is complicated and also high voltage systems are not permitted to operate continuously and the faulted circuit should be isolated promptly.

B. Selective Second Fault Tripping

As discussed earlier, the first fault in HRG systems does not need to be isolated; therefore, there is a possibility that during the operation of the faulted system, another phase to ground fault occur in another weak spot. Upon the occurrence of the second fault, the fault current is no longer limited by the resistor and has a larger magnitude. The zero sequence sensors will continue to monitor the fault current and if they detect a current much larger than that limited by the resistor, the system would identify the occurrence of a phase to phase to ground fault. One feeder breaker should be tripped to revert the system to a single faulted system.

Each feeder breaker is assigned a priority level based on its importance. The priority settings of the two feeders involved in the fault are checked and the lower priority feeder is tripped without any intentional delay.

Fig. 3 illustrates an example of a grounded transformer using a pulsing resistor. All the loads are monitored using zero sequence sensors. Shunt trip coils of all feeder breakers are connected to the second fault tripping contact of the multi circuit relay. The relay provides communications via RS 485 and sends a signal to indicate which phase is faulted and how serious the fault is. The relay continues to monitor the system and sends trips signal to one feeder should a second fault occur on a different phase before the first fault has been removed.

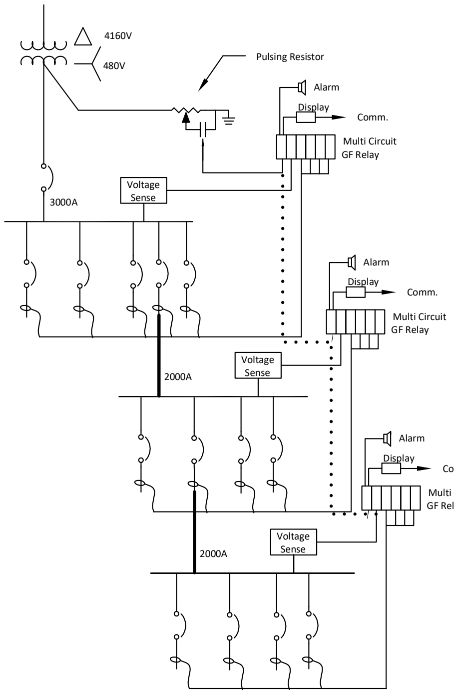

Fig. 3. Fully Integrated System

C. Distribution systems with multiple sources

Hospital's distribution systems are more complex than a simple radial distribution. Transformers are typically in double ended arrangements with two mains and tie, sometimes in triple ended arrangement with three mains and two ties, or connected in parallel. When systems are solidly grounded and the neutrals are distributed, providing ground fault protection becomes relatively expensive and cumbersome. By changing to a three wire distribution with high resistance grounding, ground fault protection is simplified. In distribution schemes with multiple sources, separate grounding resistors can be used at each source provided that the total fault current does not exceed the 10A limit required by the Canadian Electrical Code.

In case the number of sources is large or the selected resistor current is high, fault current higher than the 10 Amp limit is generated; in such cases, the solution would be to relocate the resistor.

A single grounding resistor can be applied at the switchboard instead of applying grounding resistors at the neutral of each transformer. In the case that generators are also involved, a second grounding resistor should be applied at the neutral bus of the generator switchboard.

Fig. 4 shows an example of two generator buses, each grounded with a resistor connected to the neutral point of the Zigzag transformer. The utility transformers are grounded using a pulsing resistor. In multiple source distribution systems, the minimum current flow is required to be greater than the charging current of the system. For most 480V systems the charging current will be below 1 Amp unless there is an outstanding amount of distribution.

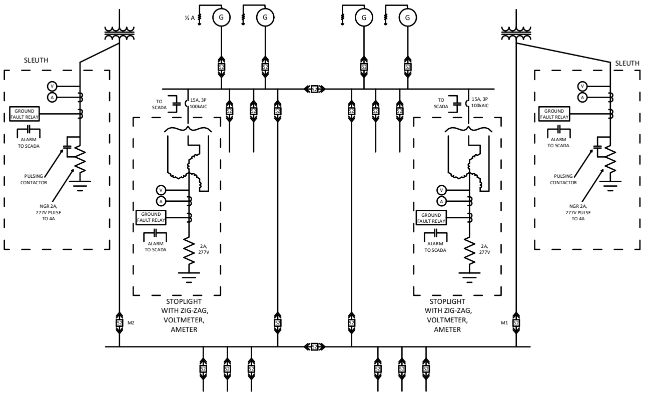

Fig. 4. Two Generator Busses

D. Emergency Power Integration

In solidly grounded systems with distributed neutrals, if the emergency generator is also grounded, the bonding path become parallel to the neutral and code violation occurs [5]. Two methods are proposed to avoid this issue:

1) Use four pole transfer switch,
2) Remove the generator ground so that only one ground on the service neutral is available.

When three-wire distribution is used, the issues with the emergency power system are resolved; moreover, the distribution system becomes more reliable when high resistance grounding is applied.

This approach allows the use of three-pole transfer switches and allows the emergency power system to be resistance grounded even if the normal power from the utility is solidly grounded.

Fig. 5 shows an example of a generator bus grounded by a zigzag transformer, all loads are three-phase three-wire and the utility supply is resistance grounded. Three-pole transfer switches are used.

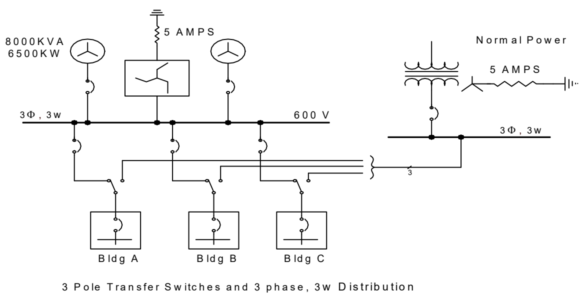

Fig. 5. Standby Generator and 3 Pole Transfer Switches

Fig. 6 shows another example of grounding the generator bus. The generator feeders are monitored by zero sequence current sensors which monitor the generator cables and the generator windings for ground fault.

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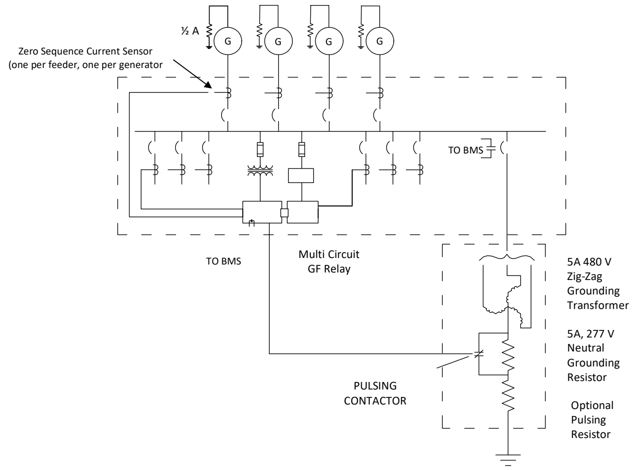

Fig. 6. HRG at the main bus

The emergency power system commonly consists of several generators in parallel with more to be added in future. On solidly grounded systems where generator neutrals are interconnected, in order to avoid parallel paths between neutral and bonding, the generator neutral is grounded in the generator switchgear. This causes circulating current between generator neutrals which requires generator de-rating which should be advised by generator manufacturer. In three-wire distribution systems, neutrals do not need to be interconnected. In such systems, grounding is applied at the generator switchboard bus through a grounding transformer and not at the generators. This results in the elimination of the current circulation and generator de-rating. When HRG is in use, the first ground fault will raise an alarm only and this enhances the reliability of the stand-by distribution system [8].

E. Examples of High Resistance Grounding at Data Processing Facilities

In this scenario, each transformer and generator in the substation is equipped with a 5A grounding resistor. Two generators are in parallel with each other which means under emergency and test conditions, the grounding system is rated 10A continuous which is acceptable by NFPA70 standard. In the event of one generator failure, the grounding system is 5A rated.

Three substations each 12.47kV: 480V are presented in this project. The resistors are rated at 5A but the pulsing feature, pulsate the ground fault current between 5A and 2.5A at 1Hz frequency for the fault locating purpose. All the feeders are being monitored so in the event of a line to ground fault, the faulted feeder can be identified. The automatic monitoring along with the pulsing capability facilitates the locating of the ground fault in the system.

When UPS systems are implemented in the distribution system, multiple modules are normally used in parallel and one extra module is set as standby. To provide further redundancy, a bypass switch is placed which can directly connect utility or generator output to the load. If there is an issue with the UPS output voltage or if the UPS voltage is reduced due to a downstream fault, the bypass switch will operate so the utility substitutes the UPS as the power source. A third level of redundancy is often provided using a second bypass switch connected to an alternate utility or generator bus.

The distribution systems are usually organized to provide two identical systems “A” and “B”. Each of these systems connects to the server providing power from two sources 120V each with 5kW contribution from each side. The servers have the ability of switching instantly from one to the other and take 10kW from one side should one side is lost. This is the forth level of redundancy being provided. The reliability and availability of such distribution systems can be improved by employing HRG at 480V or 600V. The L-G fault current is limited to 10A and no circuit breaker trip is required. Therefore, the continuity of service is maintained. A ground fault alarm is raised and ground fault is located by using the pulsing system while everything remains energized and operational.

Various UPS types and circuit arrangements are available:

1. Static double conversion with or without a transformer or with two transformers
2. Rotary
3. In-line UPS without full conversion

Double conversion UPS with a transformer isolates the grounding systems from the supply side and independent grounding system has to be provided. If an output transformer is used with Y configuration and a neutral is used internally in the UPS with multiple modules the neutrals need to be connected to a bus and four-pole breakers have to be used to provide isolation when one module is removed for maintenance,.

Rotary UPS requires independent HRG on the UPS output. Parallel modules operate through common UPS output bus. The UPS output common bus is grounded through Zigzag transformer and grounding resistor.

In-line UPS without double conversion has no isolation and the supply side resistance grounding prevails.

The major concerns in application with all of these arrangements are

1. What is the 3 I_{co} (the capacitive charging current of the system) contribution from the UPS? This is dictated by capacitance to ground connected in each phase in the UPS
2. Are these capacitances and any other components connected from phase to ground rated for full line to line voltage?

IV. HIGH VOLTAGE – HIGH RESISTANCE GROUNDING

A. High Voltage Application

Resistance grounding of high voltage systems reduces the line to ground fault current and the potential damage at the fault location. The general rule of applying resistance grounding is to ensure that the resistor let through current (I_R) is larger than the capacitive charging current of the system ($3I_{co}$) [4]. With this rule being applied most HV systems will have the let through current of 20A-100A.

As the system voltage increases, the net capacitive charging current also increases and the total fault current ($I_R + 3I_{co}$) becomes significant. The system cannot continuously operate with the large fault currents (>= 10A) due to the danger of fault escalating to phase to phase or three phase fault. Further simulation and modeling is required to find the safe continuous fault current under which the system can run without damage. Present electrical codes [5]/application rules, allow the continuous operation of currents up to 10A for system voltages up to 5kV.

At voltages above 15kV, the fault current contributed by the distributed cable capacitance $3I_{co}$ will become larger than 10A; therefore, the resistance let through current is higher than the allowed value to keep the system running continuously. In this case, the faulted circuit must be tripped automatically which means that the resistor should be short-time rated. Time coordinated relaying can be applied to ensure selectivity.

B. Hybrid Grounding in HV – HRG on Generator and Additional LRG on the Main Bus

In HV systems, with large charging currents, hybrid grounding is a viable option. If the generators are low resistance grounded, the fault current will depend on the number of connected generators. This would make relay setting difficult. To solve this problem, high resistance grounding with 5A resistance is applied on each generator and the main generator bus is grounded using a zigzag grounding transformer connected to a low resistance grounding resistor. This low resistance ground is introduced in order to overcome the estimated capacitive charging current of the system.

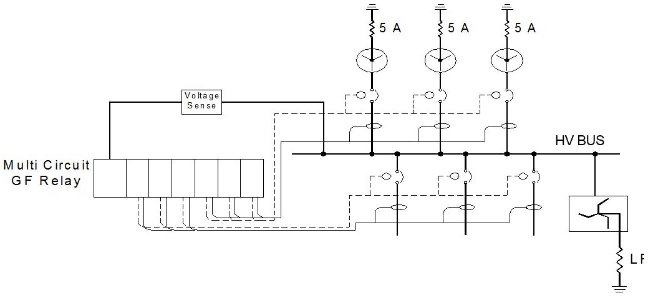

Fig. 7. Extended High Voltage Hybrid System

This approach allows the use of zero sequence sensors and ground fault relays to be applied for time coordinated protection of the distribution. Zero sequence sensors are also applied on the generator feeds and sense the ground fault towards the generator. Therefore, the stator winding is also protected as shown in Fig. 7.

C. Example of Low Resistance Grounding at a Major Data Processing Facility

This example involves replacing existing generators, generator switchgear and load management controls plus the addition of closed transition transfer switches. Each generator is equipped with low resistance grounding, with a resistor rated at 100 Amps. When the generators are paralleled the total ground fault current will be 400 Amps which matches the ground fault current available from the existing normal power system via grounding resistors on the 27.6kV – 4160V main transformers. The low resistance grounding limits the fault current in the event of a line to ground fault and this protects the shields on the extensive network of 5kV cables. It also protects the generators and significantly limits the arc flash hazard providing protection for the personnel.

V. UPS AND ASD (ADJUSTABLE SPEED DRIVE)

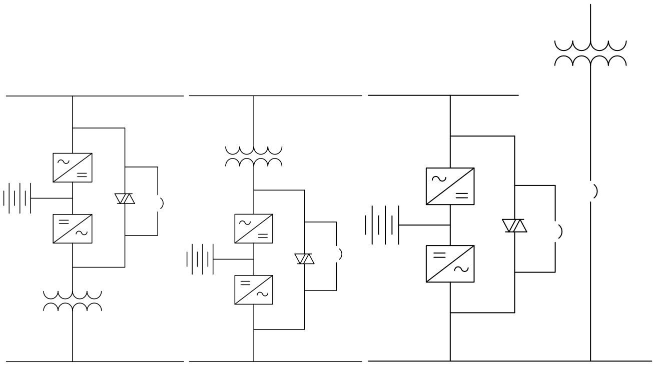

Fig. 8. UPS with transformer on output (a), Input (b), and Bypass (c)

Caution is necessary when choosing UPS for the data center. Figs. 9 through 13 show the common mode switching current and the zero sequence current due to ground faults at various locations. It can be seen that the UPS is not separately derived through the path of the ground fault current.

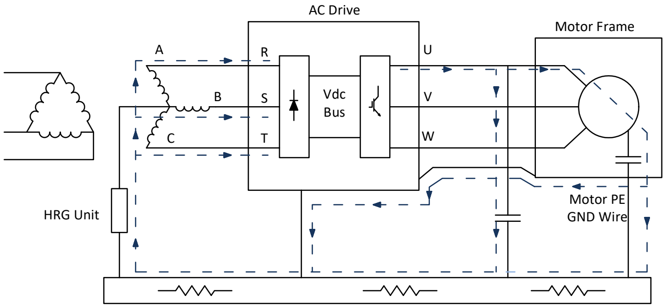

Fig. 9. UPS or ASD indicating common mode current due to switching supply

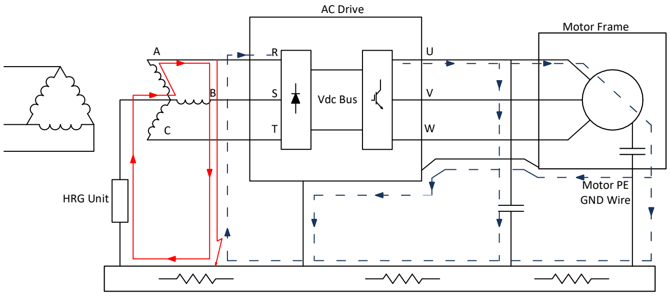

Fig. 10. UPS or ASD indicating common mode current due to switching supply and zero sequence due to ground fault on Line side

Fig. 11-13 show that UPSs and VFDs work with high resistance grounded systems. The fault current always returns back to the source. The benefits of high resistance grounded outweigh the alternative of solidly grounded systems.

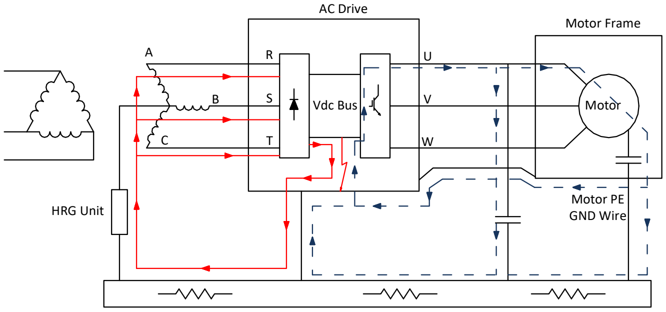

Fig. 11. UPS or ASD indicating common mode current due to switching supply and zero sequence due to ground fault on DC Link

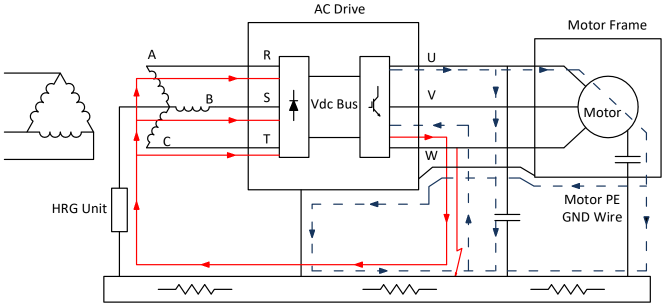

Fig. 12. UPS or ASD indicating common mode current due to switching supply and zero sequence due to ground fault on Load side

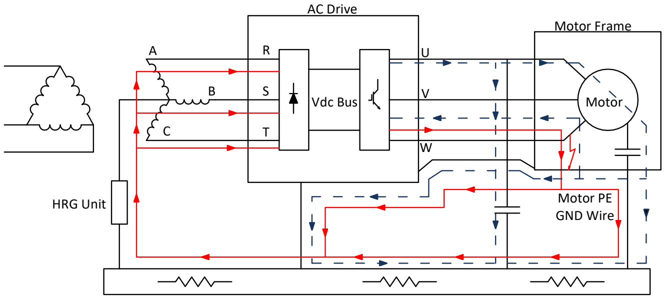

Fig. 13. UPS or ASD indicating common mode current due to switching supply and zero sequence due to ground fault at motor

VI. CONCLUSIONS

On low voltage systems (up to 5kV), high resistance grounding provides a safer and more reliable distribution system. In the presence of line to ground fault in such systems, the arc flash hazard is eliminated and power continuity is maintained. Use of NGRs with low temperature coefficients, monitoring the NGR continuously, and using a pulsing system to located the ground fault would increase the performance of the distribution system. In many applications, the neutral grounding resistor is applied at the main bus and the incoming supply feeder is monitored for ground fault very cost effectively by applying multi circuit relays.

On high voltage systems, the let through current of the resistor should be higher than the net capacitive current. The duty of the resistor depends on the current level and voltage of the system. It is recommended that the distribution systems with multiple sources be resistance grounded at the main bus. Distribution systems with multiple generators can be hybrid grounded using HRG at the generators and additional LRG on the main bus. Older LRG generators can be retrofitted with hybrid grounding.

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