White Paper

Unique Challenges for Resistance Grounding of High Harmonic Power Systems

Abstract - Neutral-grounding resistors (NGR) for industrial power systems are often selected without consideration of the nature of the loads on the system. Where a significant proportion of system demand is from adjustable-speed drives (ASD), unexpected performance problems, such as the NGR continually running hot without a detected ground fault, or NGR failure, can result. A significant factor is the use of ASDs that are not galvanically isolated from the power system—typical of six-pulse drive applications.

Index Terms - High resistance grounding, Neutral grounding resistor monitor, ground-fault protection, dc blinding, harmonics.

Introduction to the Harmonic Issue

ASDs create voltages that are harmonics of the power-line frequency, and these can drive harmonic-frequency current through line-to-ground system capacitance. ASDs draw non-sinusoidal current from the utility. This action may result in voltage distortion of the supply. When line-to-ground voltage or capacitance are not balanced in a three-phase system, a resulting zero-sequence current flows through ground and the NGR to the system neutral. Capacitive-current magnitude is inversely proportional to frequency— higher frequencies drive larger per unit current.

Capacitive reactance, Xc = 1 / (2pfC)
Where f=frequency
C=Capacitance

As frequency goes up capacitive reactance lowers and therefore current can increase.

The current measured in Fig. 2 equals zero on an ideal system with no faults and balanced capacitances between the three phases ground. If phase voltage magnitudes to ground are equal: VAG = VBG = VCG and phase-to-ground capacitances are equal: CAG = CBG = CCG then phase-to-ground capacitive currents are equal: IX_AG = IX_BG = IX_CG and ground-leakage current is zero: IGL = 0 A. The NGR current and ground-leakage current should be 0 A. However, power systems are not typically ideal. If capacitance or voltages are not balanced, ground-leakage results and NGR current is not zero: INGR = IGL≠ 0 A. The switching in drives causes voltage unbalance and drives circulating currents that cause NGR heating.

Third-order harmonics such as the third, sixth, and ninth harmonics, if present, are in-phase between the three phases and are additive—they do not cancel even in a perfectly balanced system. Their presence will result in zero-sequence current flowing through the NGR.

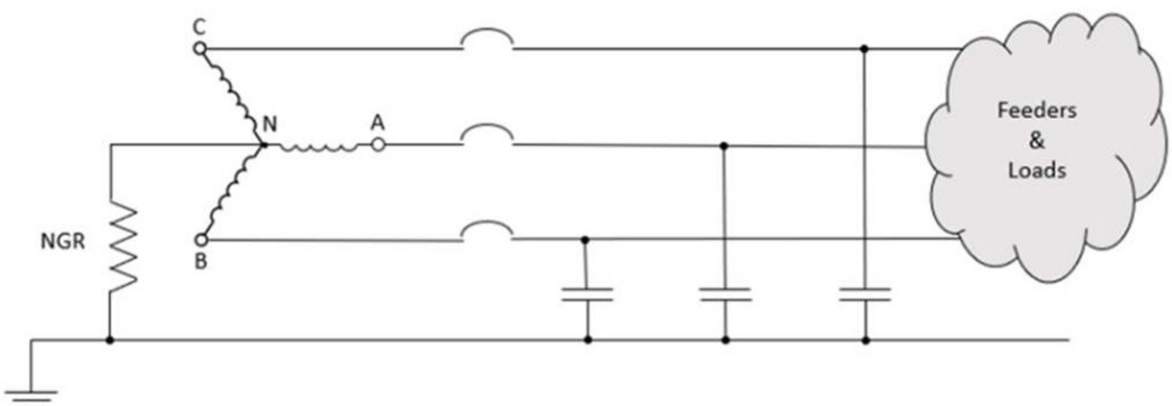

Fig. 1 Showing distributed capacitance on a system

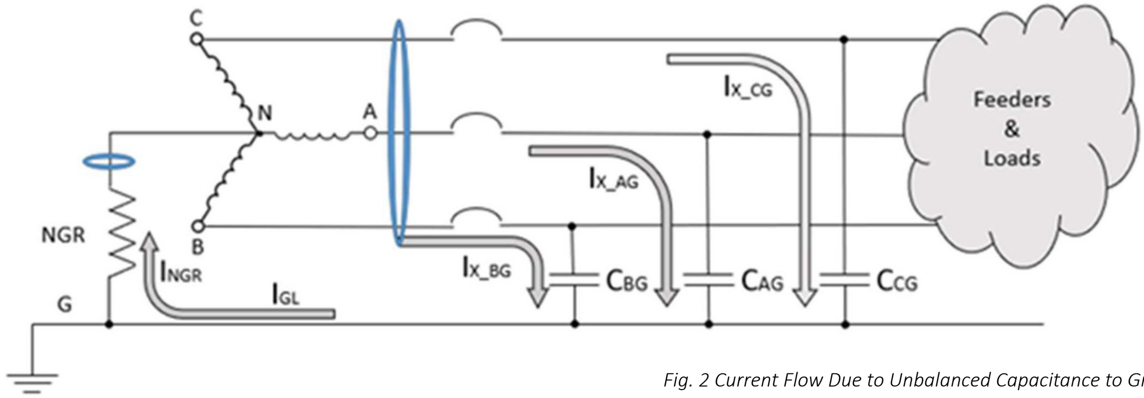

Fig. 2 Current Flow Due to Unbalanced Capacitance to Ground

Harmonic current, sometimes referred to as earth-leakage current or noise, in system ground conductors flows through the NGR with resulting, continuous, I2R heating. Current harmonics in excess of 15% are considered unusual service conditions and, when prevalent, should be brought to the attention of those responsible for the design and application of the NGR [1]. Over-sizing of the NGR may be required. Excessive harmonics can produce undesirable temperature rise that can result in failure or reduced life of even continuous duty rated NGRs.Generators with different winding pitches and connected to the same bus can be another source of harmonic current. [2]. The paper referenced describes an application in an industry that had mysterious failure of non-continuous-duty resistors. The ultimate cause of failure was undetected 3rd harmonic current flow between the generator neutrals.

The heating problem is further complicated if the system being monitored is an alarm-only system. Aversion to down time is often the driving factor in continuing to run a faulted system. If there is difficulty in locating the fault, as is often the case for intermittent faults or where ground-fault location is not automated, the fault can be left to persist for an extended period. Automated ground-fault location on older systems can be implemented by installation of additional ground-fault relays at key locations.

The frequency response of ground-fault relays and CTs often is not considered and are often optimized to monitor power-line frequency (60/50 Hz). They may therefore not be able to detect higher-frequency ground-leakage current.

Introduction to the DC Issue

Adjustable-speed drives and uninterruptable power supplies (UPS) include DC components. The ASD rectifies the incoming power frequency onto a DC bus. A ground fault in the rectifier or on the DC bus is a DC ground fault that will not be detected by AC-sensing 51G ground-overcurrent devices. UPSs likewise create DC to maintain a battery-backup voltage. A ground fault in the rectifier or in the battery system is a DC ground fault that will not be detected by AC-sensing ground- fault monitors.

The rectified DC voltage in an ASD is up to 1.414 times the incoming AC RMS voltage. A bolted DC-bus fault will drive 1.414 times the NGR rated current, requiring the NGR to dissipate double its power rating. Undetected DC ground-fault current can overheat the NGR—a potential personnel and fire hazard and cause of NGR failure.

To avoid the hazards of undetected DC ground faults, DC, or AC/DC-sensing ground-fault detectors should be used on a system with ASDs or UPSs.

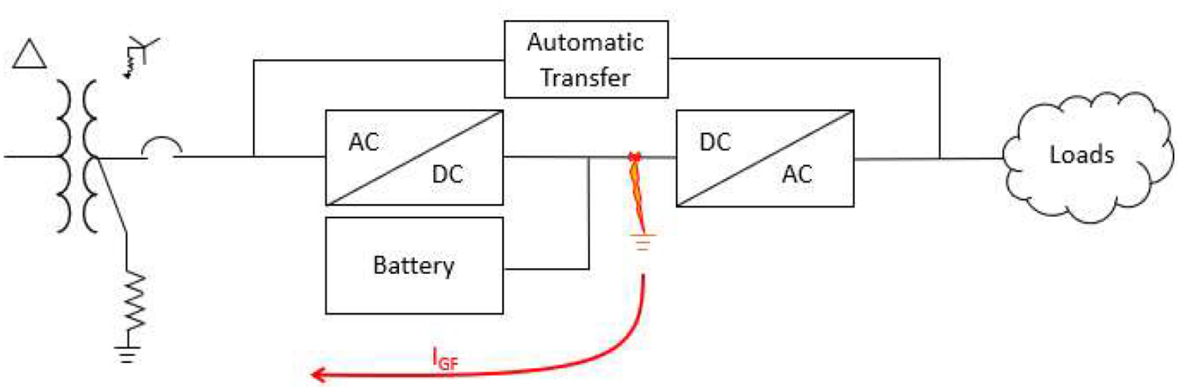

Fig. 3 UPS schematic showing dc bus fault

Limitations of Current transformers

Ground-fault protection for resistance-grounded industrial power systems most often consists of zero-sequence current transformers (ZSCT) connected to analog or digital ground- fault detection (or protection) relays. This configuration, due to the nature of ZSCTs and design of the relays, is inherently AC ground-fault/leakage current detection and can be effective for detecting AC ground faults.

Detecting harmonic-frequency leakage current that can cause continuous NGR heating is typically within the capability of an AC-sensitive ground-fault monitor. However, since the current is noise, the typical system-design approach is to select a device that filters the noise, or to set the detection level above the quiescent current level. Neither approach limits NGR heating. The same harmonics could be causing other issues such as abnormal transformer heating.

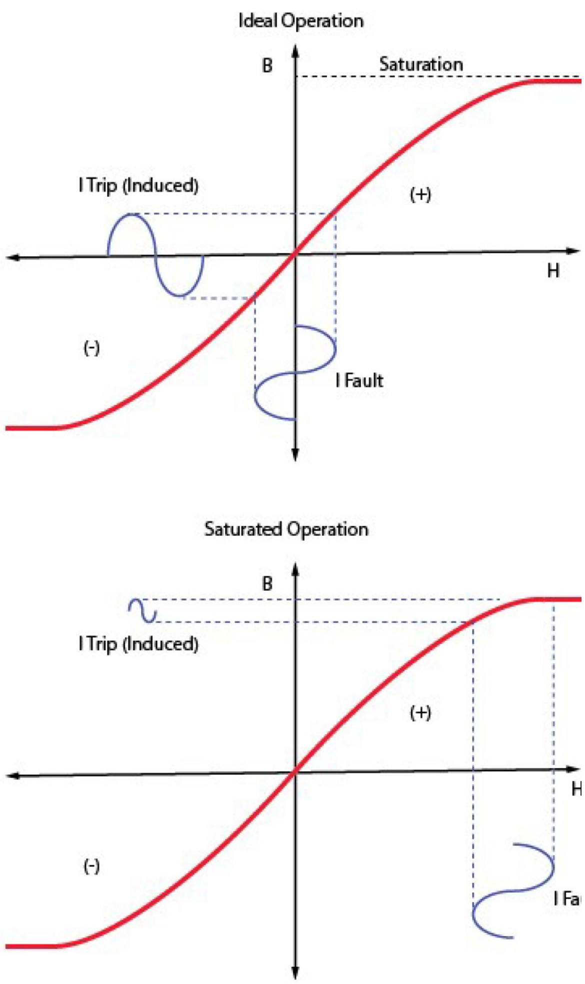

Fig. 4 CT BH Curve showing DC Blinding

Many power systems in pulp and paper facilities include significant ASD loads. Six-pulse ASDs, and those with active- front-end topologies, do not galvanically isolate the drive and its load from the power system. A ground fault in the rectification or DC-bus drive components is a DC (or predominately DC) ground fault.

Introduction to the low-Frequency Issue

ASDs in some applications are used with a low output frequency, such as conveyor or escalator creep speeds, or for tensioning a conveyor belt. The frequency of a ground fault on the load side of a drive, in the motor or cable to the motor, is the drive-output frequency, and in these cases, it can be in the 2 to 20-Hz range.

ZSCTs are AC devices and therefore their output is strongly attenuated when the primary current is below approximately 30 Hz—even if a bolted ground fault is present, the detection device may not measure its magnitude as being above the alarm or trip setting. As well, DC current flowing in the ZSCT primary can saturate the core, blinding the CT even to power-line-frequency current as shown in Fig. 4.[3] When the CT is monitoring the system neutral-to-ground connection, such as by an NGR monitor, even AC ground faults may not be detected when DC- blinding is present.

An NGR converts DC current and low-frequency current to heat energy, just as it does power-line frequency AC current. When AC-sensitive ground-fault detectors are used, a DC ground fault will remain on the power system indefinitely and without the knowledge of a system operational issue, until the NGR, the ASD, or some other component fails catastrophically. A device, or devices capable of detecting a DC ground fault is required to detect ASD and UPS internal faults and low- frequency load-side faults. Current sensors with powered cores are available for such monitoring.

Limitations of ASD ground-Fault Protection

The manuals for many ASDs have recommendations for using the drives on ungrounded and resistance-grounded power systems. These are primarily recommendations to remove input transient voltage suppression, but there are additional considerations. High-resistance grounded (HRG) systems are often used because of the benefit of current limitation. The ground-fault current limitation of an HRG system can create a gap in protection if the drive's built-in

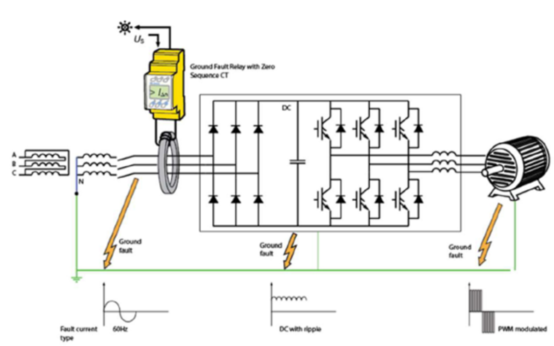

Fig. 5 Ground-Fault Waveform at Different Locations

ground-fault protection is not able to detect the low level of available ground- fault current, as limited by the NGR. The problem can be further exacerbated by resistance of the fault path and rectification caused by the drive -resulting in much less detectable current. If the drive is to be providing protection of the connected load it is important to know the drive topology.

ASDs with 12-pulse or higher rectifiers may be galvanically isolated from the supply and ungrounded from the input- transformer secondary windings to the load. CT-based ground-fault protection will not function properly on an ungrounded secondary and a ground fault here will not result in NGR current.

As mentioned earlier in the paper, the frequency response of the ground-fault detection is also critical for protection. The end user must determine if frequency response of the protection is adequate for the application. Consultation with the drive manufacturer to insure the ASD provides the level of protection required on a resistance grounded system should be part of any good design.

Conclusion

Resistance grounded applications that include sources of harmonics could be subject to abnormal conditions that can cause NGR failure. Monitoring for these conditions and monitoring NGR health can give advanced warning of the condition and allow time for correction.

Implementation of such solution can provide protection for any non-galvanically isolated UPS or ASD and give enhanced protection beyond that which the UPS or ASD can provide. Type B ground-fault devices that respond to wider frequencies than standard current transformers can enhance protection.

REFERENCES

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