Mining Earth Leakage Protection with Variable Speed Drives

Tim Wylie, Ampcontrol's Chief Technology Officer discusses the impact of Variable Speed Drives (VSDs) on earth fault limited networks.

There are established, well proven techniques employed in surface electrical networks to ensure interference signals from Variable Speed Drives (VSDs) are kept to acceptable levels. Many of these techniques are equally effective in an earth fault current limited network. However, it can be shown that EMC techniques routinely employed may significantly degrade fundamental elements of electrical protection afforded by the earth fault current limited network.

Protection Systems

Mining electrical systems have evolved various protection systems due to their unusual environments, equipment they use and the hazards they present.

A typical earth fault limited network will include:

- Earth fault current limitation, usually consisting of a resistor connected between the supply transformer star point and earth (NER)
- Earth continuity monitoring and protection
- Earth leakage protection
- Earth fault lockout protection

An element of the electrical protection scheme design is invariably intended to ensure that when people are exposed to touch potentials, the level of voltage and time they are exposed to before protection systems trip is limited to an acceptable level. What constitutes acceptable levels varies by jurisdiction, but within Australian mining applications is defined by AS/NZS 4871.1 2012 for 50Hz touch voltages.

A properly designed protection system also limits the risk of fire, arcing and hazardous arcing faults, but this is a secondary aim. To ensure the touch potentials are managed to acceptable levels the complete electrical system needs to be assessed and a protection scheme implemented accordingly.

These protection systems were originally devised to protect against touch potential hazards resulting from earth fault currents that are driven by the power supply (50/60Hz).

Consider, for example, that an earth fault occurs in a mobile machine with rubber tyres powered by a trailing cable. The earth fault current will flow through the fault to the machine frame and return to the supply transformer star point via the trailing cable earth conductors (primarily). The voltage drop caused by this earth fault current flowing through the total earth impedance will result in a potential rise above earth for the frame of the machine, and it is this potential rise that presents the touch potential hazard.

The system assessment must determine the earth fault limitation current and earth continuity relay trip settings

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that will protect personnel based on the achievable earth leakage clearance times, knowledge of the cable lengths and the resulting pilot and earth impedances (refer to figure 1).

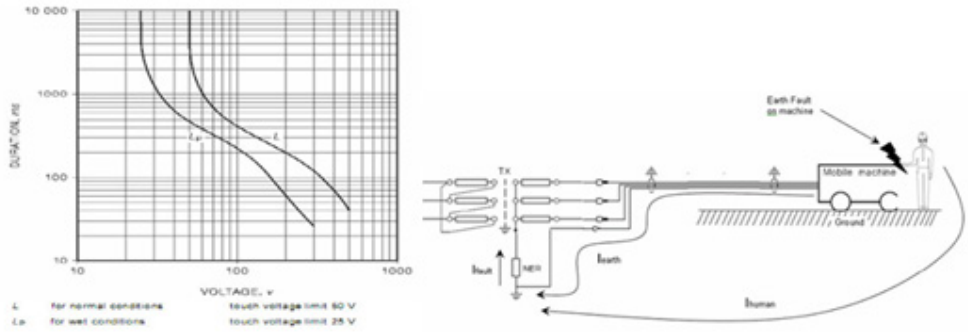

Figure 1: Traditional 50Hz duration vs touch potential curve and fault scenario for an earth fault limited system (ref AS/NZS4871.1:2012)

Variable speed drives

VSDs are now finding wide use in mining applications. Most of these drives use variable frequency outputs that are produced by rectifying the supply to DC and then inverting this DC voltage back into AC using a high frequency carrier and pulse width modulation (PWM) to produce variable frequency, variable voltage supply to the motor. They complicate the electrical protection design in several ways:

1. They introduce a new and complex voltage source into the power system. This may mean that earth faults can now be direct current (DC) in nature or may be driven by the inverter of the drive and so have a frequency that is primarily that of the drive PWM carrier frequency (say 1000Hz for example).
2. To minimise interference with protection and control systems, many drives employ Electromagnetic Compatibility (EMC) filters that consist primarily of a capacitive circuit between the input of the drive and earth. This provides a path for earth fault currents that represents an alternative path to the NER. In fact, it is the intention of the filter to provide this alternative path for the high frequency currents that flow (through the motor and cable stray capacitances) to earth under normal (non-fault) conditions. They will also provide an alternative path under fault conditions, particularly if the fault is driven by the high switching frequency drive output (refer to Figure 2).

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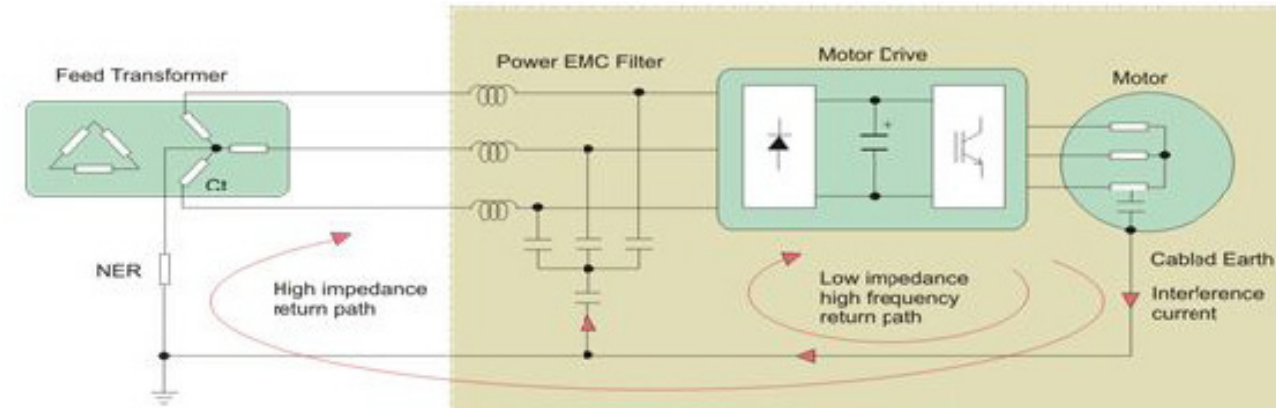

Figure 2: alternate earth leakage current path via the power EMC filter associated with the VSD

It has also been shown that when one or more drives and filters are in use, and an earth fault occurs, there can be circulating currents between the drives and filters and/or the fault location. The fault current magnitudes may then greatly exceed the nominal current limitation value (typically 5amps in Australian mining networks) determined by the NER. These large currents may cause touch potentials that greatly exceed the expected values.

3. Most earth leakage protection relays approved for use in mining applications are designed to detect power frequency (50/60Hz currents and low order power frequency harmonics), not DC or high frequency currents that a VSD system may generate under fault. As a consequence conventional relays may not trip or if they do trip they may take longer than expected.

The overall result is that with standard earth leakage protection relays and electrical system assessments based only on consideration of faults driven by the supply system power frequency, protection performance is unlikely to be adequate when VSDs form part of the connected loads.

In December 2011, the Australian mining regulator in NSW released a safety bulletin (SB11-04 available from resourcesandenergy.nsw.gov.au) on potential electrical hazards associated with operation of variable speed drives on earth fault limited networks. The bulletin sponsored numerous electrical system and protection studies as well as several large scale, practical experiments that have now verified the fault mechanism and predicted shortcomings in previous practice and electrical protection.

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Improving protection

Key to improving protection is realisation that for fault limited systems incorporating VSDs, the protection design and associated calculations must extend beyond the power supply frequency (50/60Hz) and the traditional power frequency harmonics. In such instances, individual calculation to determine requirements at the frequency or frequencies in question will be required.

In Australia AS/NZS 60479.1 and AS/NZS 60479.2 are referenced in relation to the effects upon the human body of other supply frequencies.

What this means is that when VSDs (or other non 50/60Hz sources) are used in a fault limited electrical system, the standard approach needs to be modified and interpreted to ensure that protection is adequate. The key factors to consider are as follows:

1. The sensitivity of the human body to electric shock varies with frequency. In general, for frequencies above the power frequency (50/60Hz), for a given exposure time, the allowable touch voltage magnitude increases with frequency. For example, at 10kHz, the allowable touch voltage (actually the let go voltage) is about 5 times that at the power frequency.
2. When EMC filters are used (with an internal shunt capacitive path to earth), this forms a path for earth fault currents that is an alternative to the NER. When considering touch potentials at a mobile machine (for example), strictly speaking we must examine the impedance of the filter at the frequency of interest (say the drive carrier frequency) in order to determine the earth fault current that will flow when a fault occurs in the machine. The earth leakage tripping time, (or other fault clearance / current limiting time), must then be used to ensure the touch voltage and exposure time form a safe system. Some EMC filters may have fuses or current limiting circuits that act quickly to limit the earth fault current that flows during any earth fault. Care must be taken when multiple filters are connected to a single supply. In this case there are many modes of possible earth fault that need to be considered and actual earth fault currents may exceed the current seen by any single filter.
3. We must have an earth leakage relay that will accurately sense earth fault currents of any frequency that can be generated by voltage sources within the electrical system. Voltage source inverters (a common topology used in modern variable speed drives) contain powerful common mode voltage sources capable of producing earth fault currents from DC to at least the drive carrier or switching frequency (typically as high as a few kHz).

With complex environments that contain multiple drives and filters a careful analysis of the system is required. The characteristics of the filters, drives and cables and the system circuit must be known. Information about the possible frequencies that the various drives can produce (carrier frequencies) will also be required, and often this information is not immediately available or on hand with the end user or system operator. In some cases, transient simulation of the system will be required in order to estimate the maximum currents and so touch potentials that may occur under fault conditions. It is likely that unique protection settings will be required for each application to avoid potentially hazardous scenarios.

It is acknowledged that this may be a challenging process and it could take some time for end users and operators to develop the required engineering knowledge and familiarity with simulation tools.

Ampcontrol is available to assist users in detailed simulation and protection studies, and has developed new, wideband relays, the ELV-PRO and ELV, specifically to address the issues around VSDs and earth fault limited networks.

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A traditional approach to VSD protection has been to deliberately blind or desensitise the protection system to high frequency leakage currents. Both the ELV-PRO and ELV relays include a number of advanced operating modes where protection characteristics that differ significantly as a function of frequency may be selected. The settings allow increased trip levels at higher frequencies to take into account the reduced sensitivity of the human body to touch potentials at these frequencies. Conventional wide bandwidth earth leakage relays do not compensate high frequency artefacts associated with VSDs and so commonly suffer nuisance trips unless the trip level is significantly elevated. This can compromise the proper management of touch potential hazards. The relays pre-programmed characteristic as a function of frequency allows the user to maintain high earth leakage sensitivity at the power frequency (50/60Hz) without experiencing nuisance tripping.

In addition ELV-PRO provides trip event information and diagnostics in both time and frequency domains to accelerate fault finding, enable proactive identification of earth leakage degradation of system and loads, automatically record and validate protection system routine tests and maintenance, as well as providing real time information as to normal operating earth leakage signatures and so enable fine tuning of earth leakage protection sensitivity, and proactive identification of leakage degradation.