



VVVF Drives and Electrical Protection in the Mining Environment

22nd Mine Electrical Safety Conference

MESC 2011

Overview



- Changes proposed in the present draft of AS2081 specify that protection devices are to have electromagnetic immunity to various sections of IEC61000.4.
- By definition, the loads that these devices protect must then have electrical 'noise' emissions in keeping with the same standard.
- Well proven techniques employed in MEN networks to ensure emissions for VVVF drives are kept to acceptable levels can be equally effective in an I-T network.
- Significant care in application is required to avoid fundamental degradation of the electrical protection afforded by the I-T network.

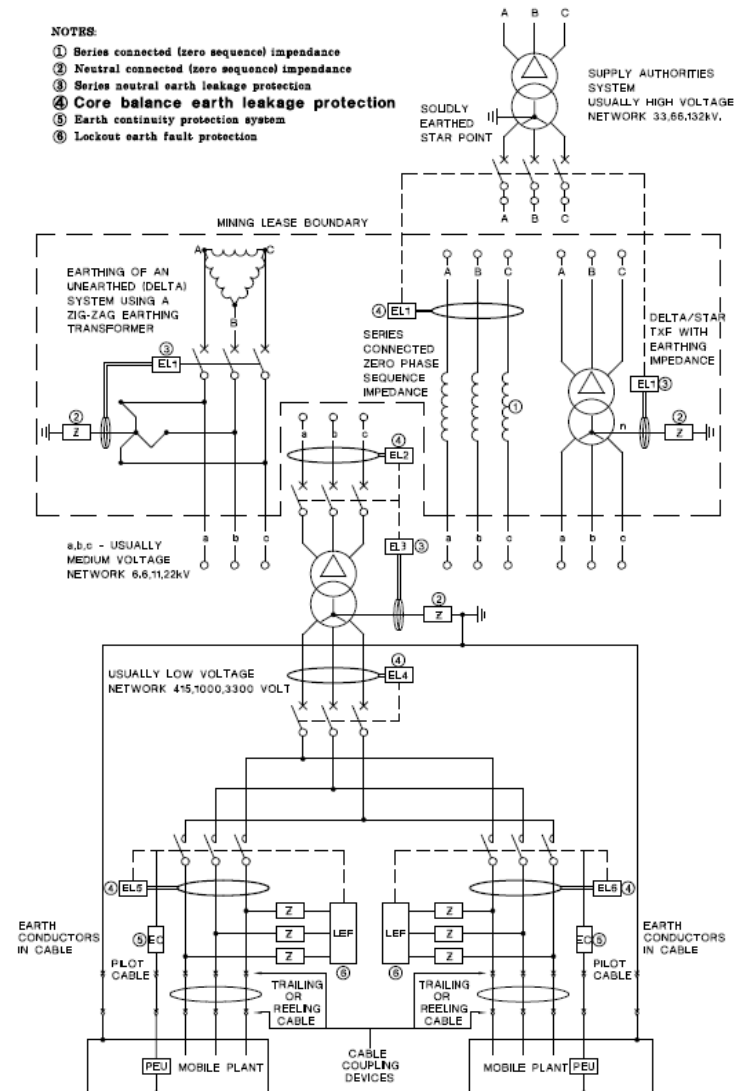
Presentation Topics



- Today's discussion is a 25 minute presentation split into three sections:
 - Understanding interference signals and earth loop currents peculiar to VVVF applications within an I-T supply network.
 - Typical interference mitigation techniques using power EMC filters.
 - Protection degradation issues for common mitigation techniques supported by actual underground measurement data

Provision of Power

- Earth fault current limiting impedances: AS/NZS 2081.5
- Personnel protection relies on a single primary star point and cabled earths to implicitly control touch & step potentials.

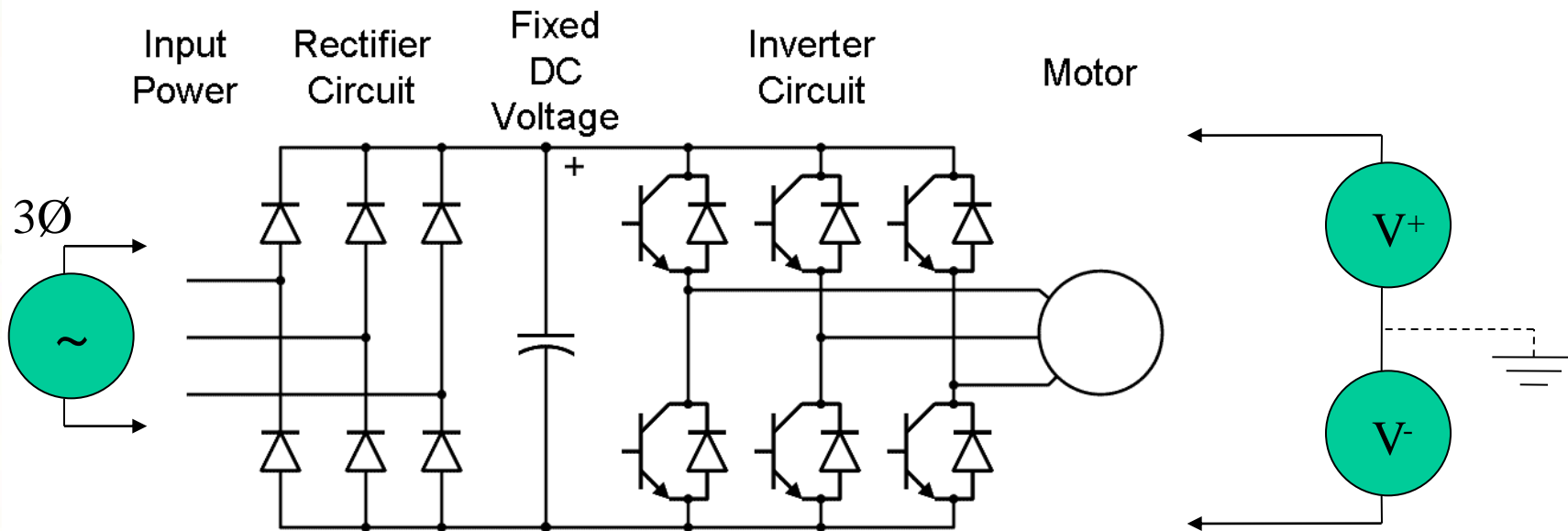


VSD Operating Principles



- All power converters rectify the AC mains to regulate a DC link with significant capacitance.
- Active (switched) power electronic output stage pulse width modulates the DC link voltage to synthesise a variable voltage, variable frequency output waveform.

VSD Operating Principles

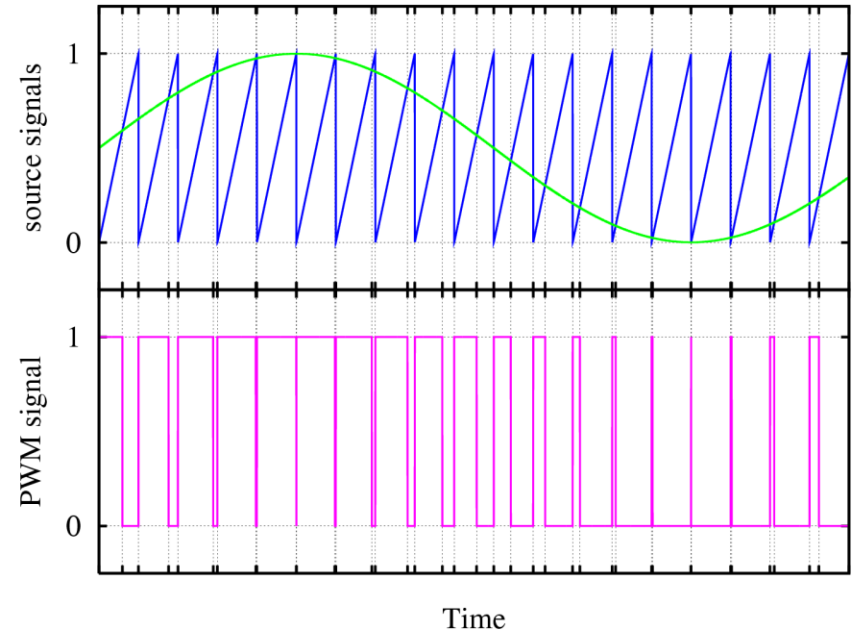


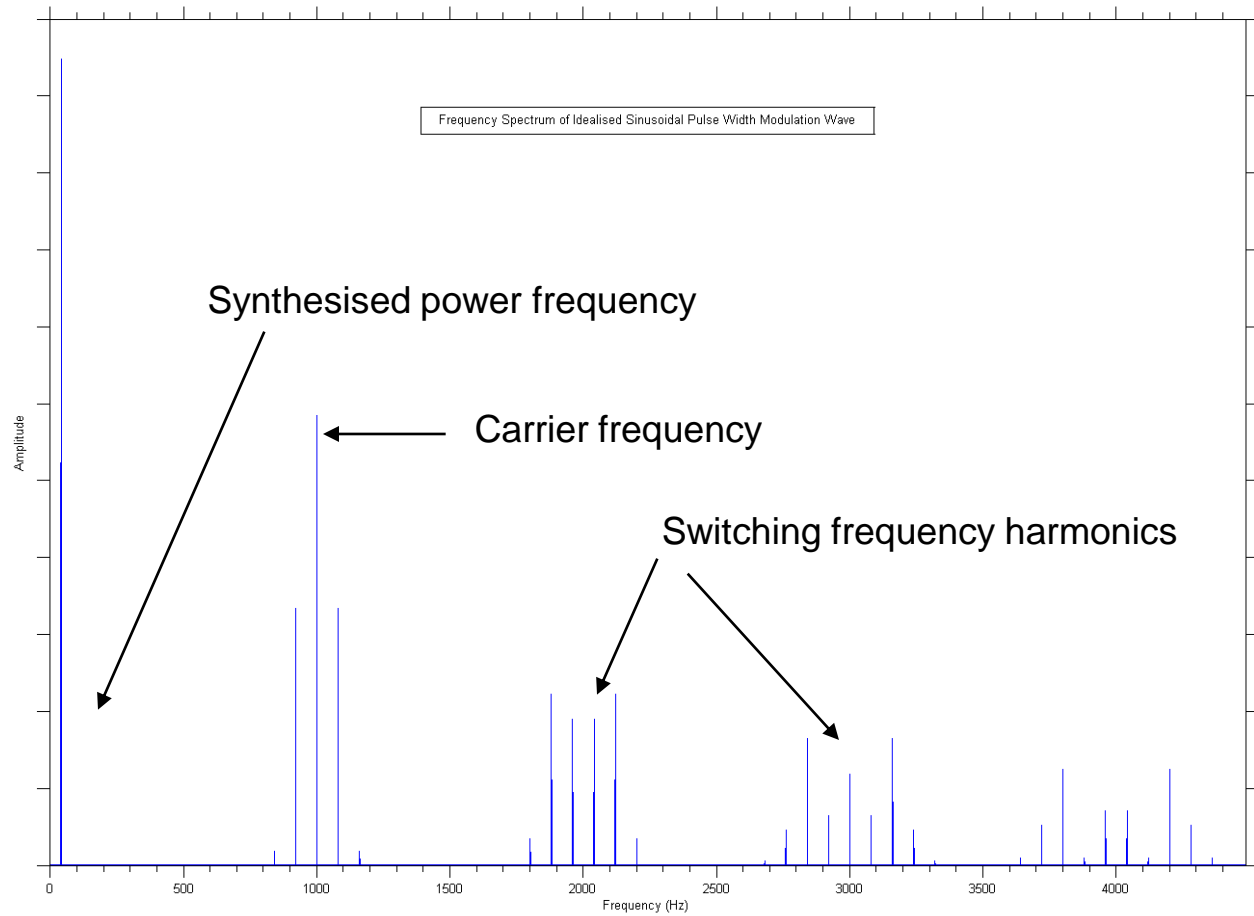
In a two-level inverter, the DC voltage on the link capacitance 'floats' almost symmetrically either side of the AC main earth, ie: V^+ and V^- relative to earth (common mode voltage source).

Pulse Width Modulation



- Output voltage waveform of a VSD consists of a train of switched DC pulses, characterised by a broad harmonic spectrum extending to very high frequencies.





Conducted Interference Modes

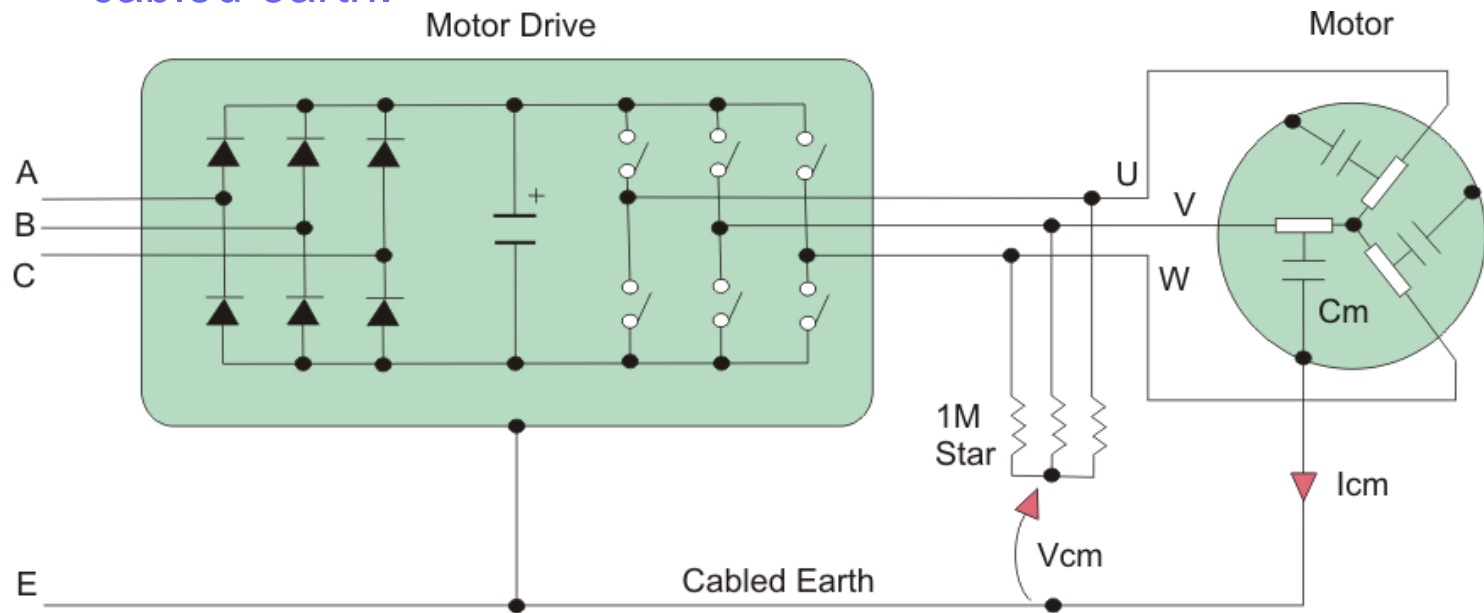


- **Differential Mode**
 - Creates a voltage between phases independent of the earth, current flows along one phase and returns via the other.
- **Common Mode**
 - Creates a voltage between each phase and earth, current flows through the earth (often via a parasitic capacitance) and returns to the source via the phase.

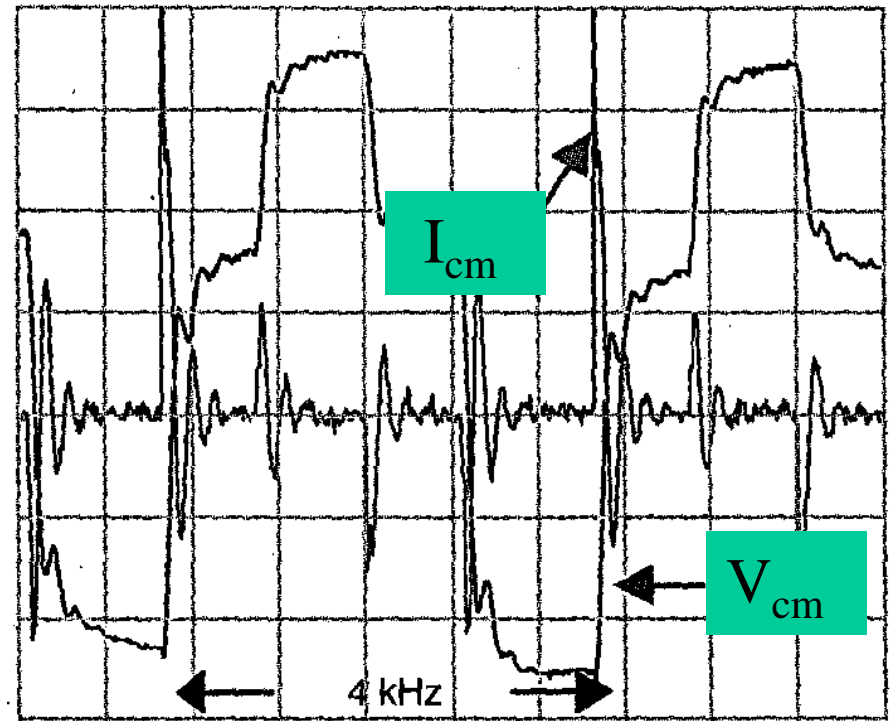
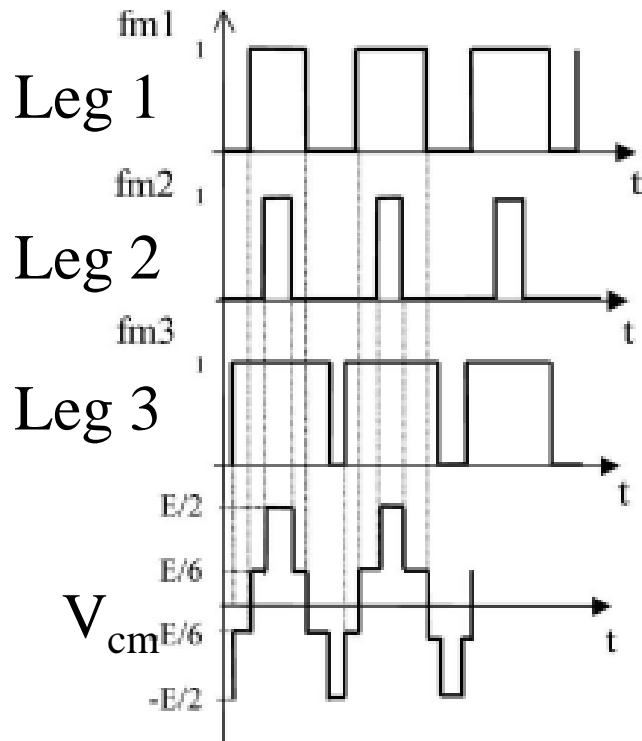
VSD Common Mode Voltage



- VSD common mode voltage can be practically measured between a high impedance star on the drive outputs and the cabled earth.



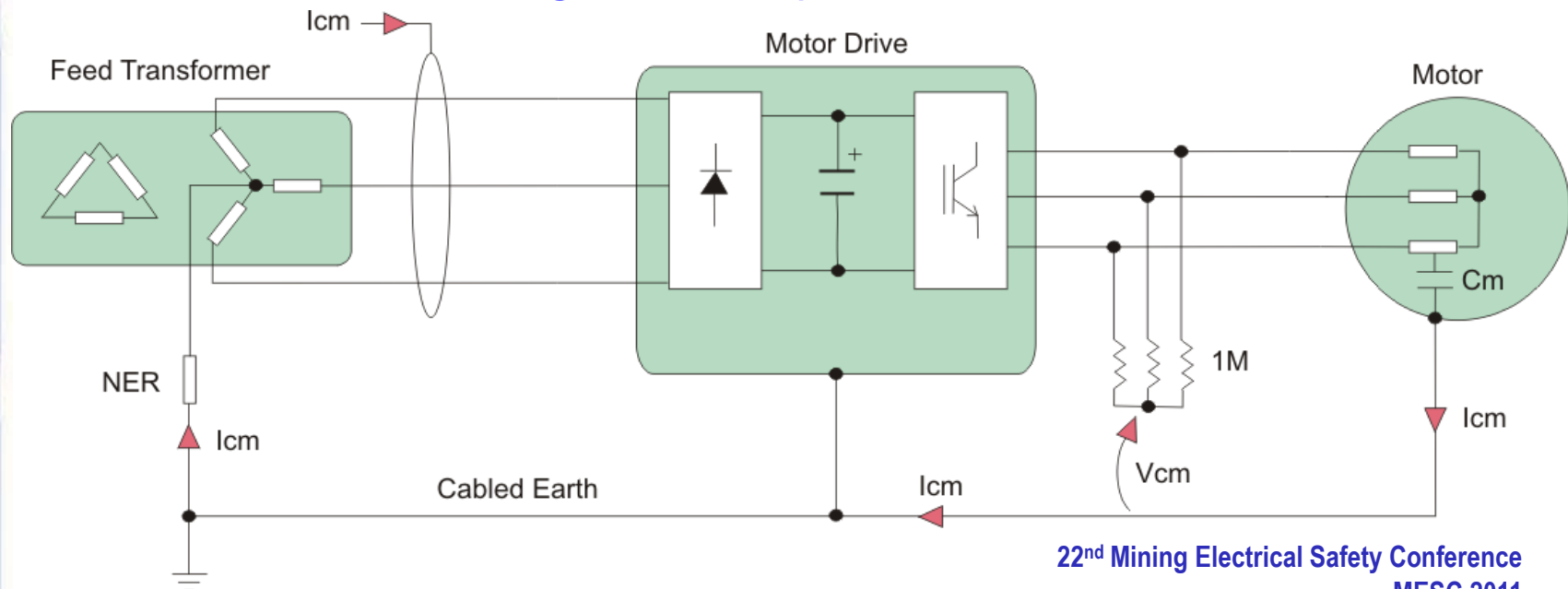
VSD Common Mode Voltage



Common Mode Voltages in an I-T Network



- No physical connection exists between the cabled safety earth and the drive DC link. The only return path is through the feed transformer neutral to return via the input phases to the drive, resulting in unacceptable interference levels.

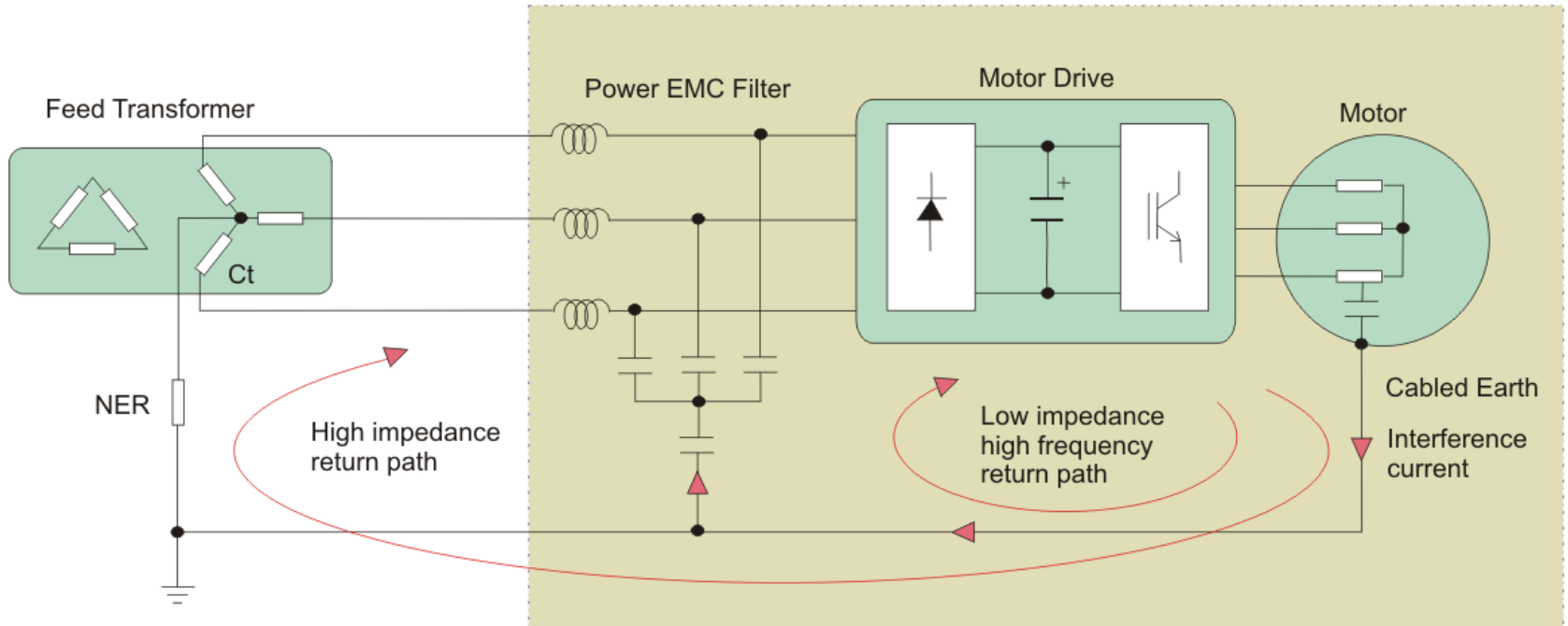


Can we Avoid Common Mode Current?



- High frequency common mode loop currents are a fundamental consequence of modern drive technology, they cannot be eliminated.
- Mitigation is all about controlling relative loop impedance, so controlling which path these currents take in returning to the source.

Preferential Return Paths: Power EMC Filters

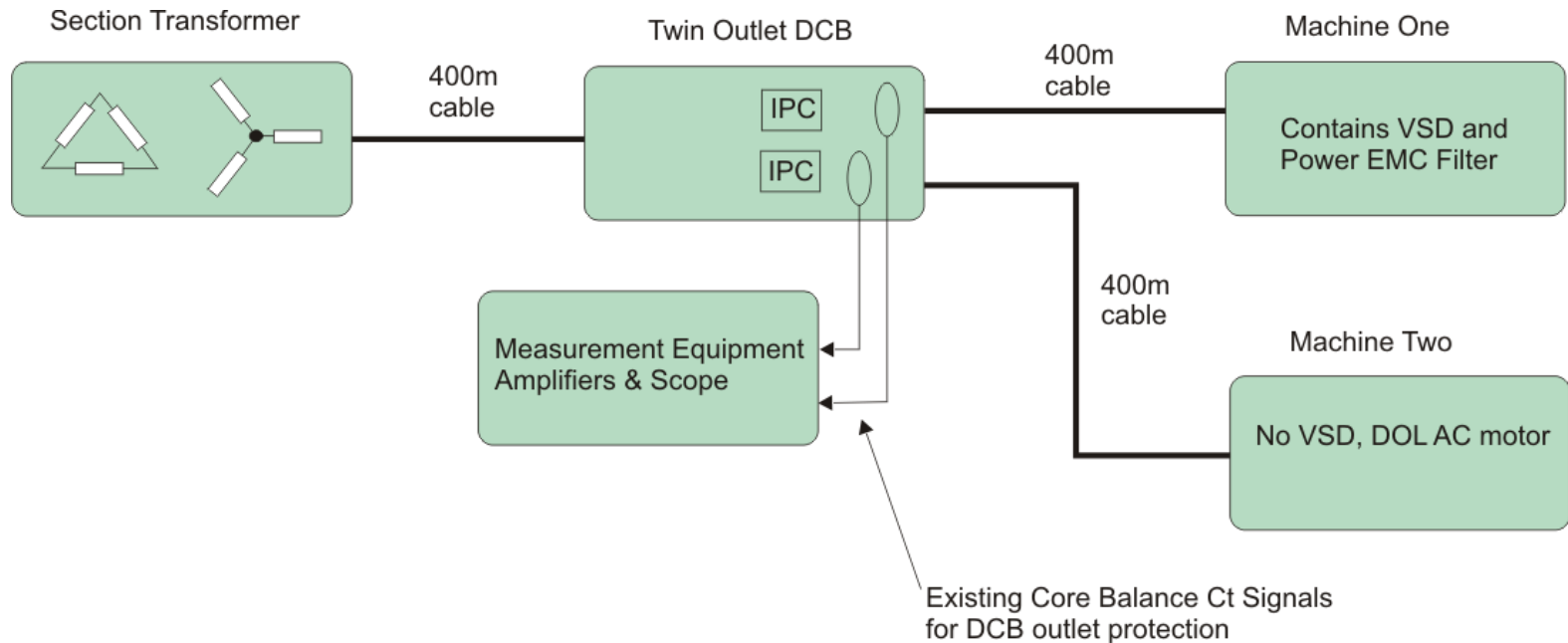


EMC Filters and the NER Limitation



- EMC filters provide an alternate (high frequency) star point, so have implications for earth fault current limitation otherwise provided by the NER and primary protection star.
- Under fault conditions, large circulating currents that can flow that are not limited by the NER due to a high frequency bypass formed by the power EMC filters.
- These currents are driven by a relatively low impedance common mode voltage source produced by the VSD power electronics, and can result in unacceptable touch potentials.

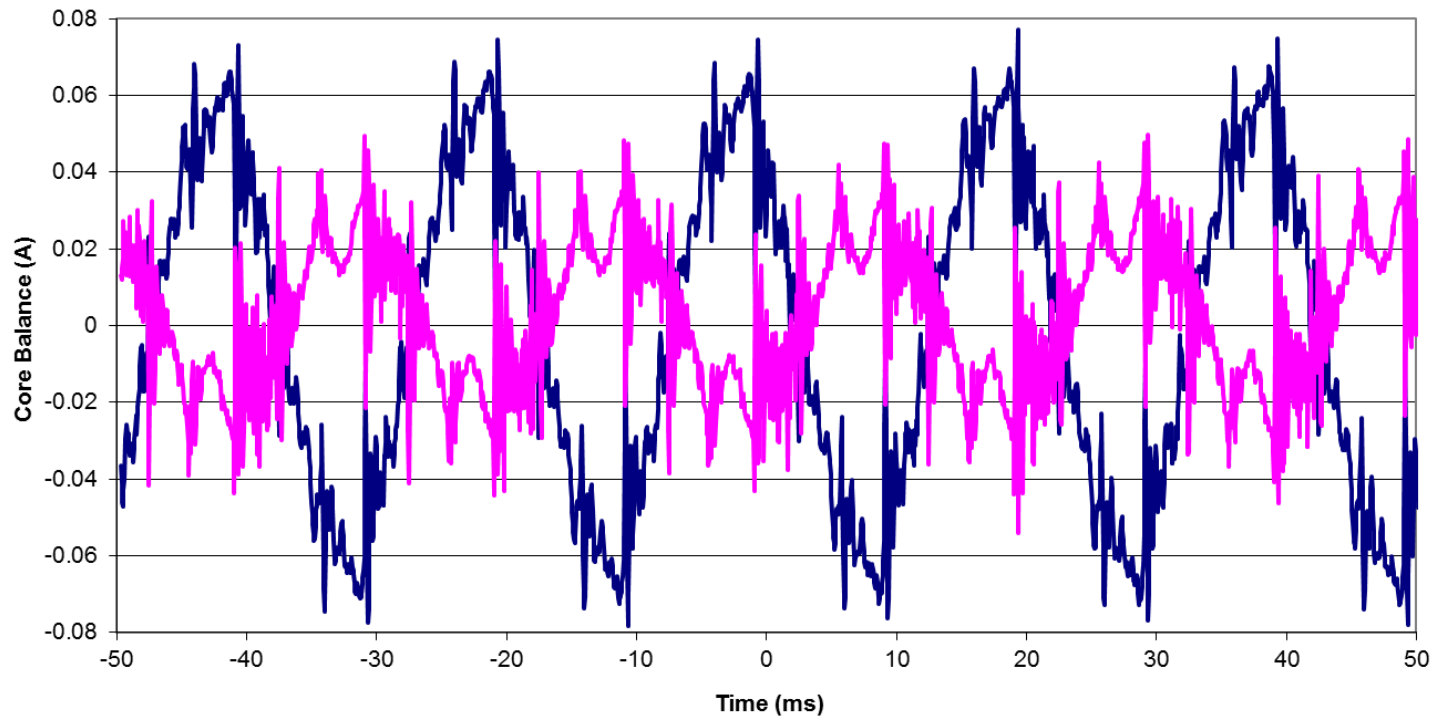
Some Underground Experiments



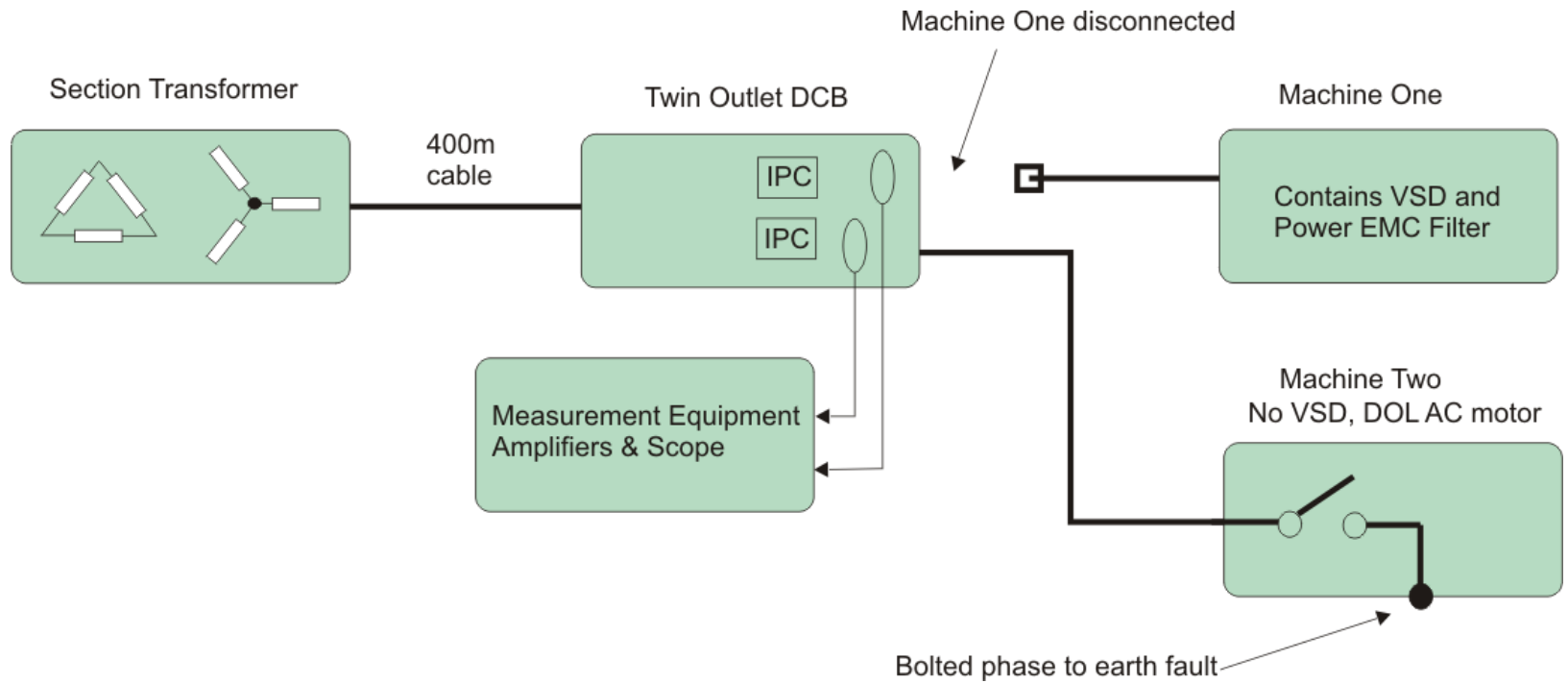
Background E/L: Both machines running



Background Earth Leakage 2



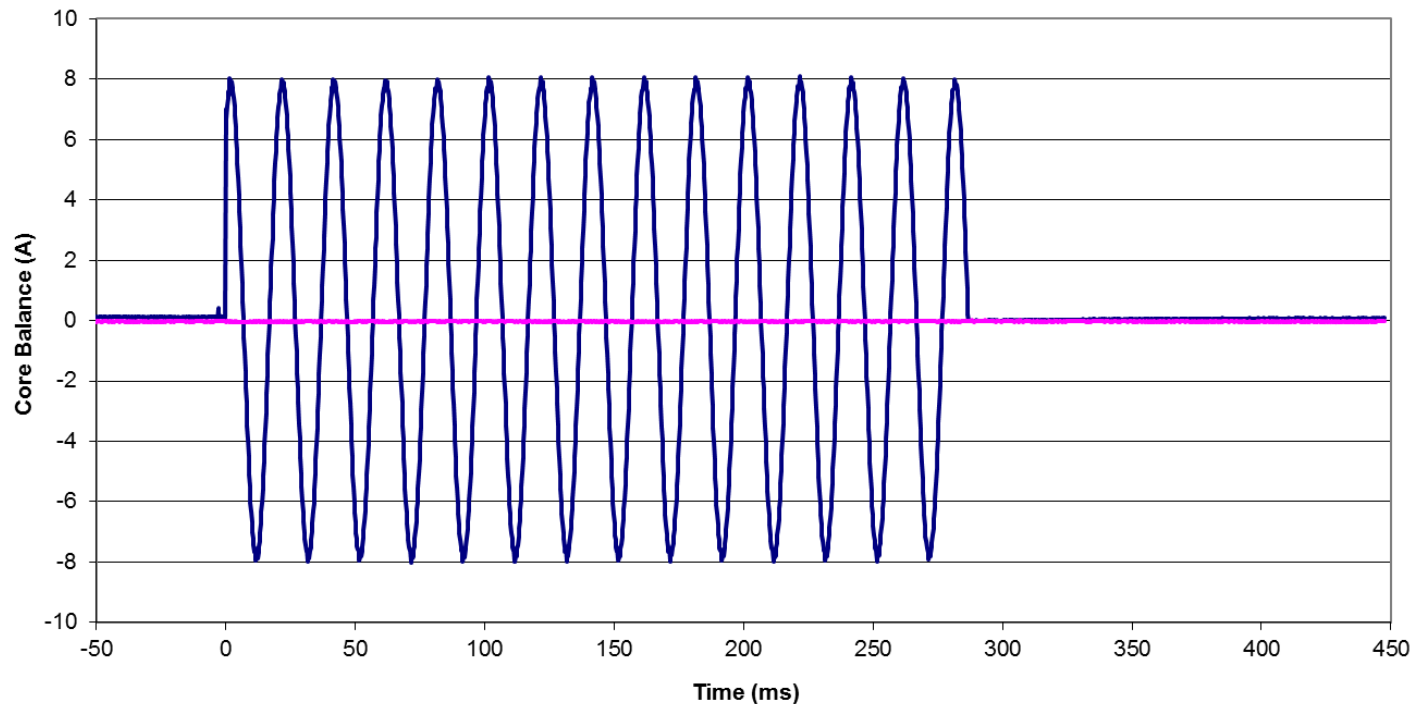
Bolted Earth Fault: Single machine, EMC filters disconnected



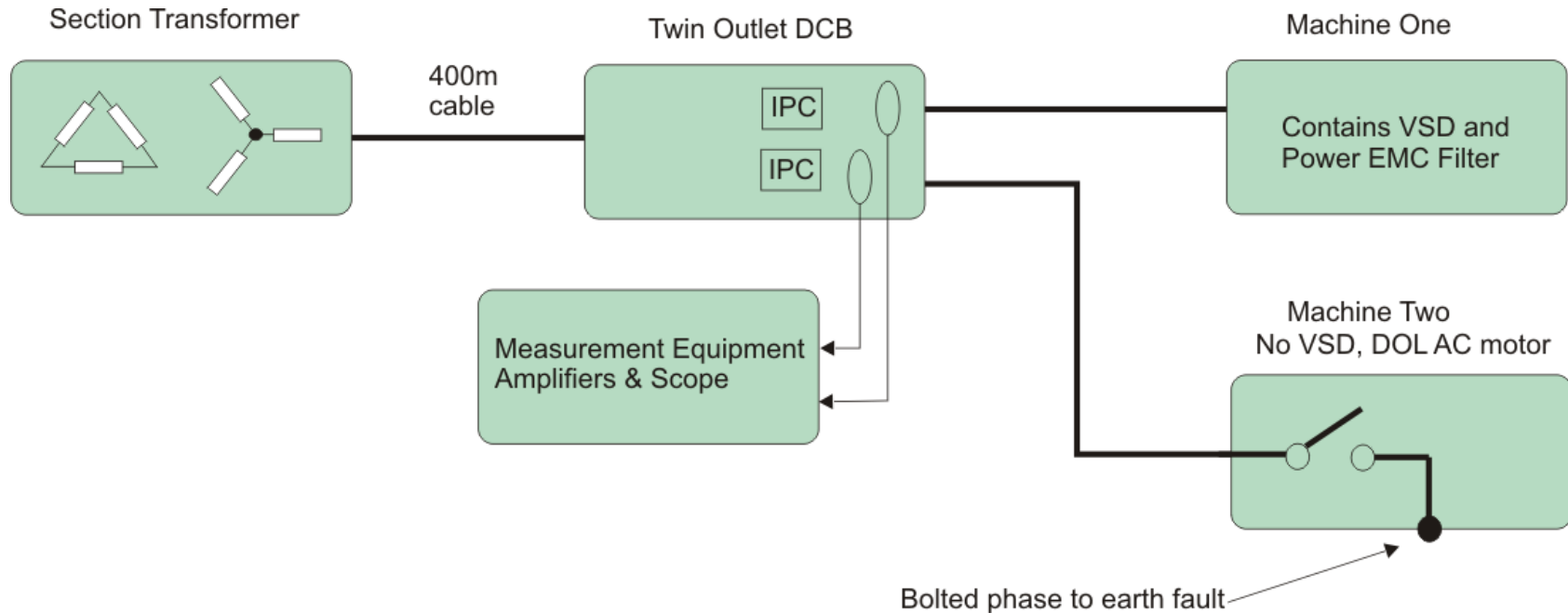
Bolted Earth Fault: Single machine, EMC filters disconnected



Bolted Fault Earth Leakage 3



Bolted Earth Fault: Single machine, EMC filters connected

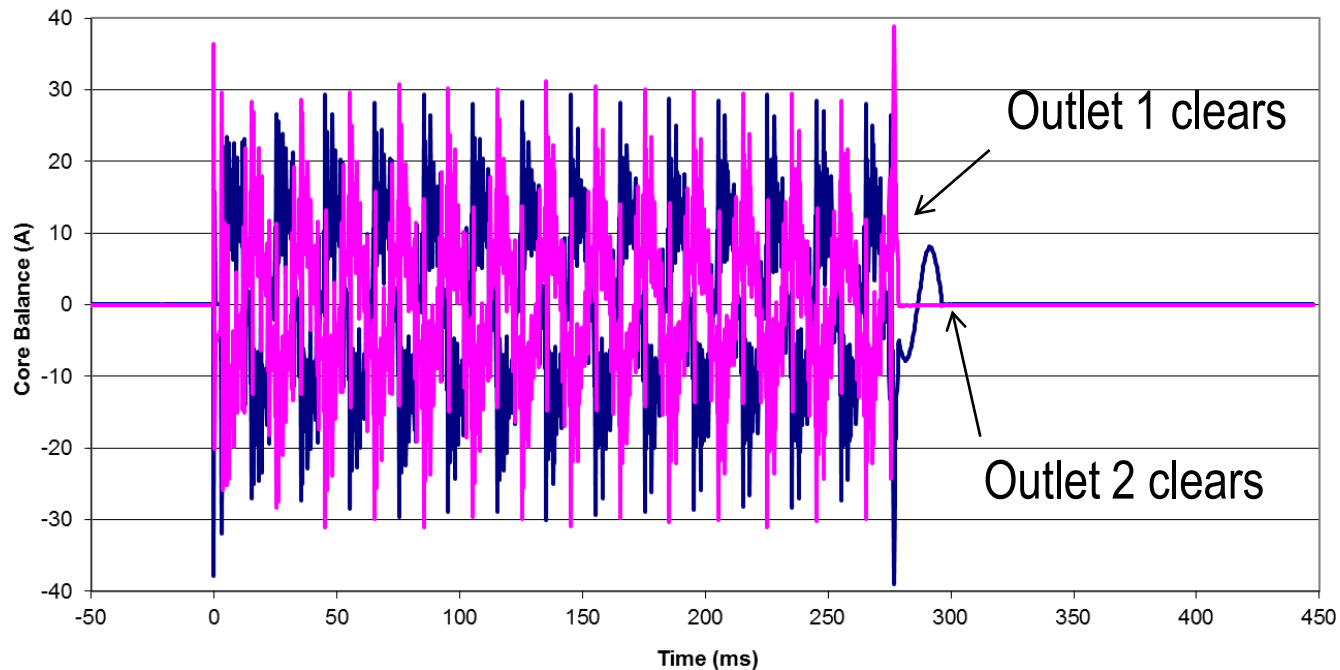


- Machine 1 connected but VSD is NOT running (only the EMC filter is in circuit).

Bolted Earth Fault: EMC filter connected



Bolted Fault Earth Leakage 2

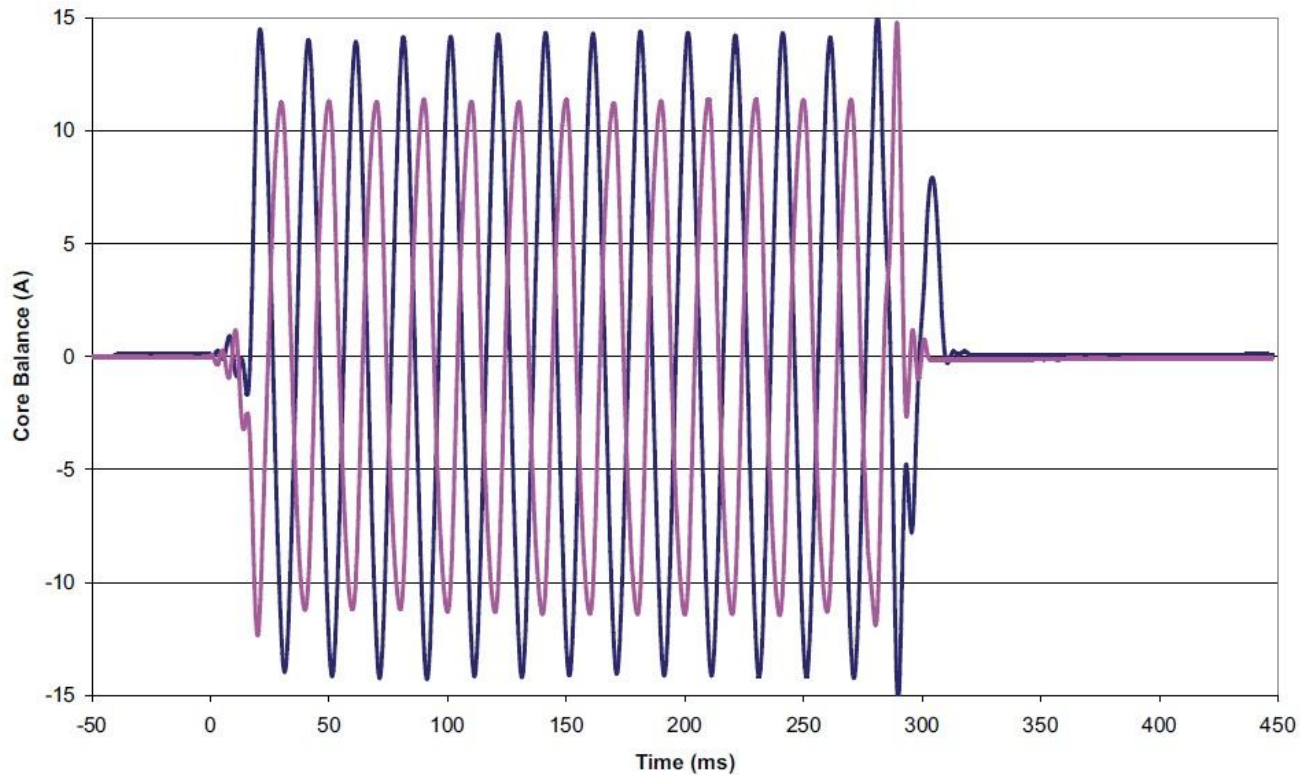


- Both outlets trip even though only one has a fault
- E/L current significantly exceeds 5A NER limitation until machine 1 (with the EMC filters) clears.

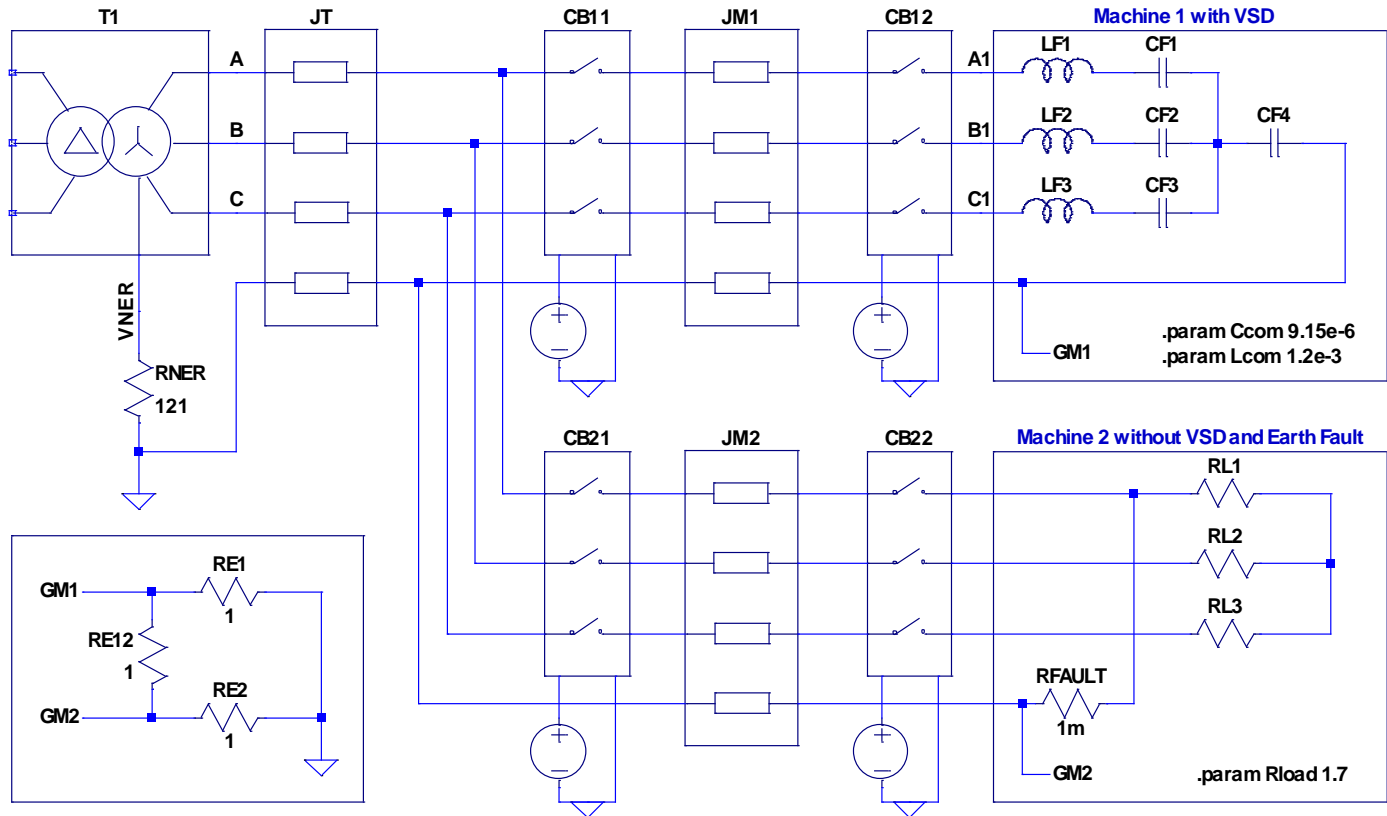
50Hz components

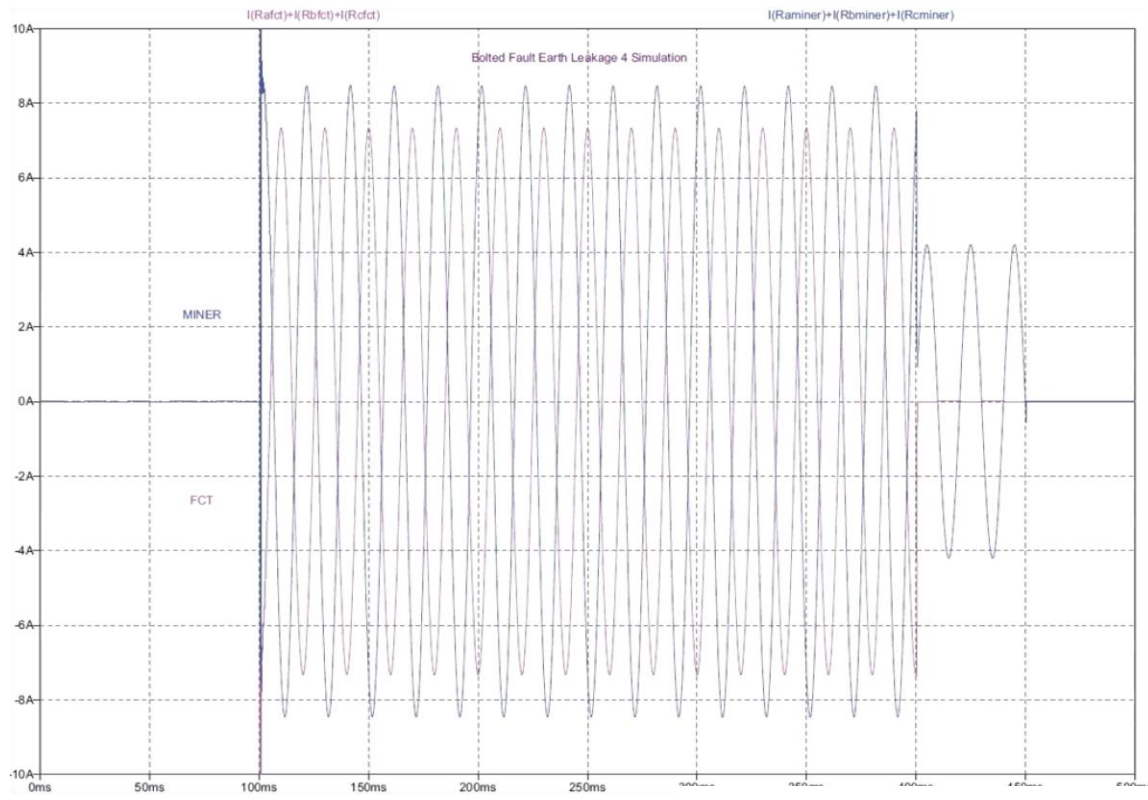


Bolted Fault Earth Leakage 2 Filtered

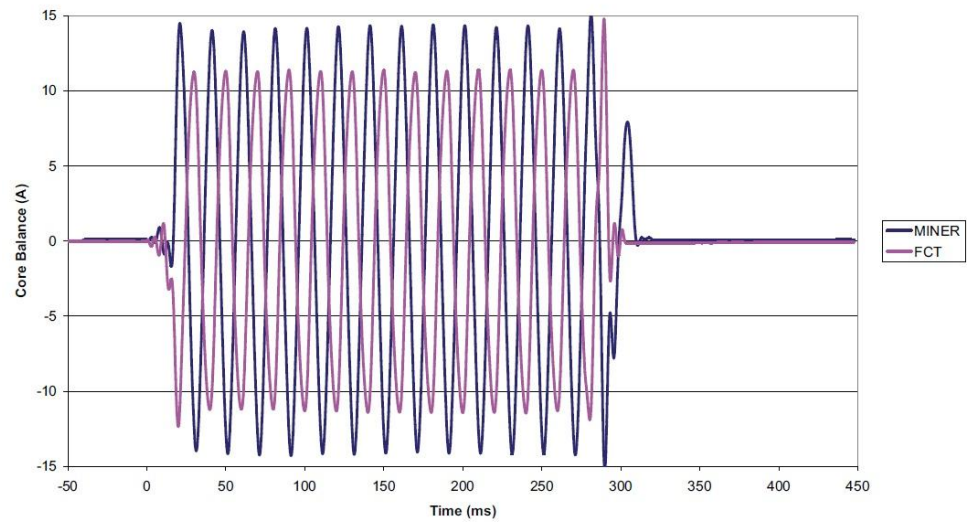


A simulation to match the experiment





Bolted Fault Earth Leakage 2 Filtered

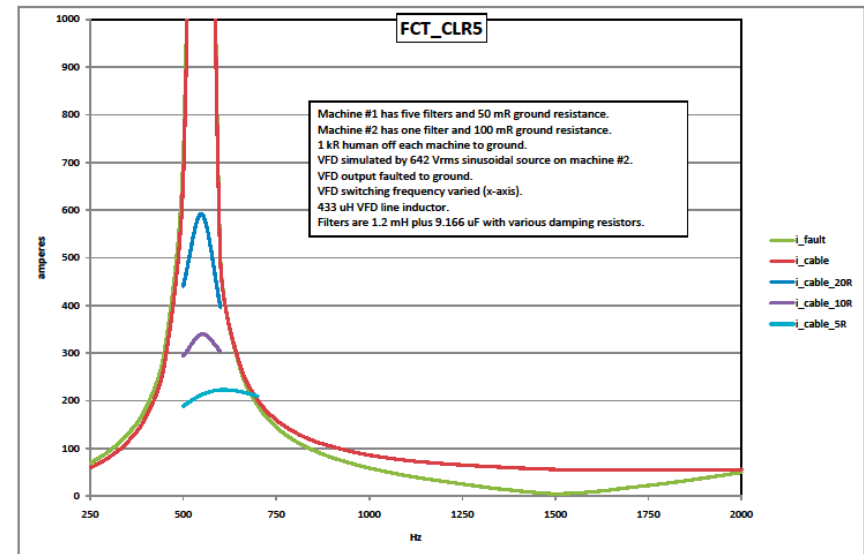
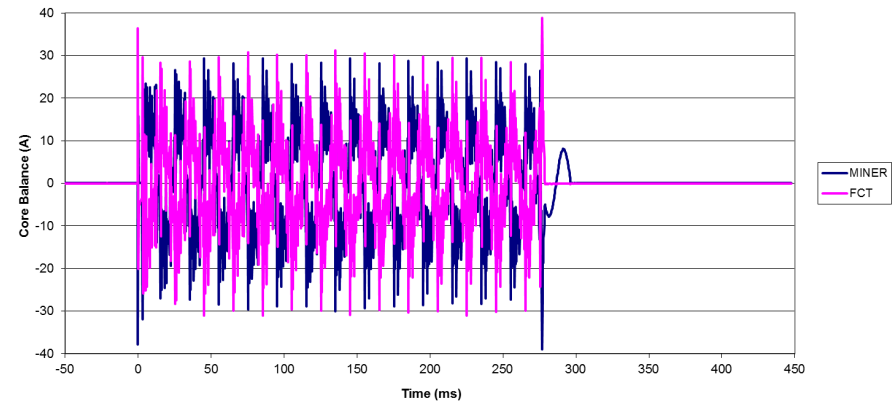


High frequency component? Where did it come from...



- The 50Hz induced fault is a transient (impulse)
- The spectrum of an impulse contains a large number of frequency components extending to very high frequencies
- The tuned EMC filter is a low impedance path to some frequencies

Bolted Fault Earth Leakage 2



But is there a larger problem?



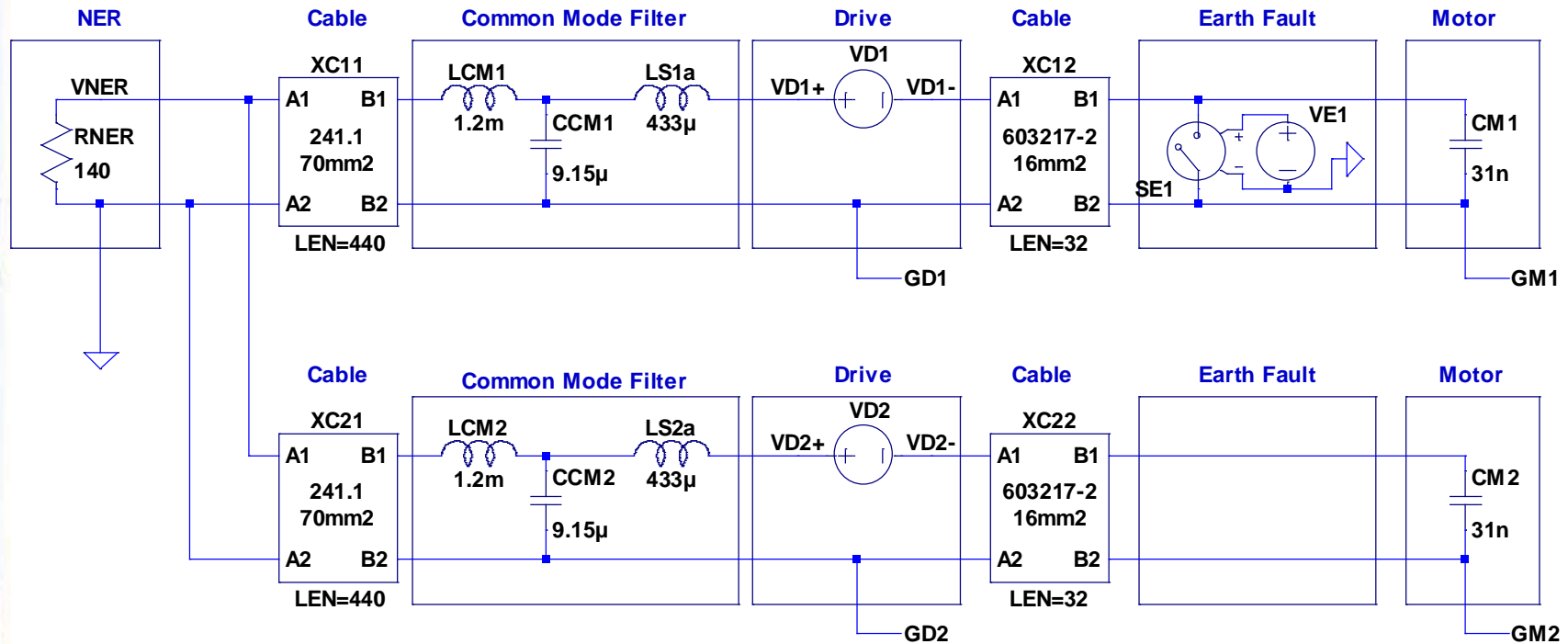
- If an earth fault scenario exists where a strong voltage source can produce frequency components at the filter resonant frequency, then we would expect large currents to flow.
- Given practical cable parameters, can this large current induce an unacceptable touch potential between two machines in close physical proximity but connected by long cables?

An Example Fault Scenario

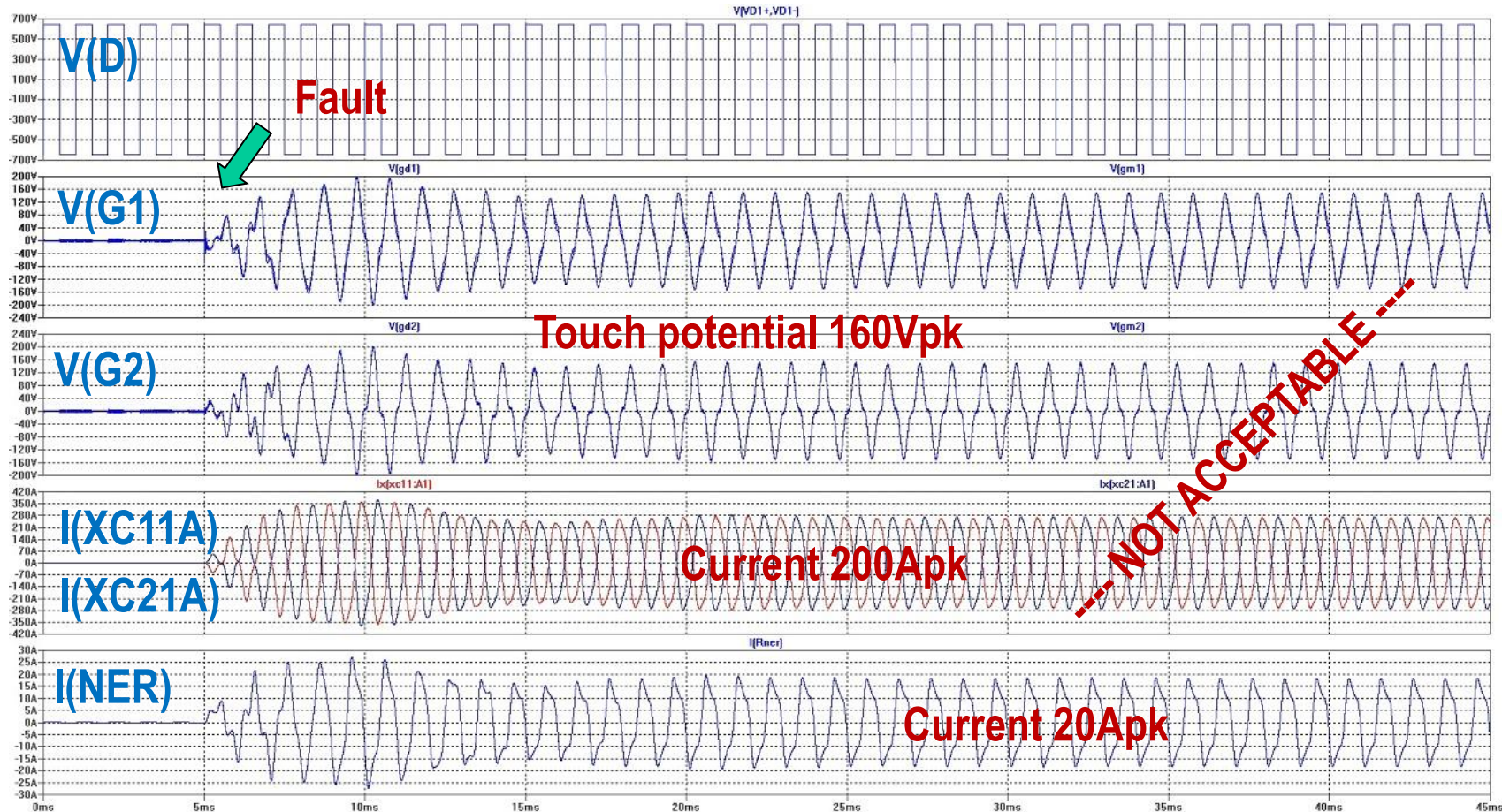


- The following simulation is common mode. We consider a bolted phase fault to earth occurring on the output of a variable speed drive.
- The fault current is driven by the VSD common mode voltage source. This is a low impedance source, capable of supplying large currents continuously due to the VSD construction.
- Parasitic capacitances are included, with detailed cable models provided by Olex.
- Consider the case of two machines, parallel fed off the same section transformer, both machines contain VSD's and power EMC filters.

Parallel Connected Equipment: Two machines, both with operating VSD's



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Summary Observations



- EMC filtering will be required for machinery containing VSD's to meet the emission limits in the new revision of AS2081.
- Equipment manufacturers can not control the type of parallel connected machinery, and can only validate design parameters based on the properties of their own equipment.
- The presence of one or more parallel connected VSD on an I-T network can significantly degrade electrical protection.
- Any analysis must consider frequencies well above 50Hz power frequencies and its harmonics (near DC to several kHz).

Further Assistance and Information



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