White Paper

Type B Ground Fault Protection on Adjustable Frequency Drives

Abstract – This paper describes the IEC type A (AC only) ground-fault detection circuit and its limitations in accurately detecting electrical ground-fault currents in today's modern electrical installations. Discussed are the effects of waveform modifying power sources and the effect of the DC component on the efficacy of type A safety devices. Limitations of UL1053 standard for ground-fault sensing and relaying equipment are discussed. The paper will lead to recommending and applying IEC type B (AC/DC) detection technology for solving these shortcomings. This paper is based on T.Gruhn, J. Glenney and M. Savostianik "Type B Ground-Fault Protection on Adjustable Frequency Drives", in IEEE PPFIC Conference record, 2017, but lists additional information on preferred CT placement recommendations.

Index Terms — Residual Current Devices, Ground-Fault relays, Type A RCD Devices, Type B RCD Devices, DC Blinding

I. INTRODUCTION

Residual current devices (RCDs) or ground-fault relays have been around since the 1950s. The purpose of such a device is to reliably detect current leakage to ground regardless of its cause. Examples can be electrical current through an impedance path, an operator's inadvertent contact, insulation breakdown, a wiring error or degradation over time. The waveforms these RCDs are intended to detect are plain single or three phase sinusoidal AC with little or no power electronics involved. Applications have been getting much more non-linear over time and RCD's or ground-fault equipment must be upgraded in order to handle all ground-fault situations.

The type A relies on a zero-sequence current transformer (CT) to detect ground-fault current. In a single-phase system, two conductors are routed through the CT window. In a three phase system, all current carrying conductors and neutral (N) where used pass through the CT window. Current passing through the CT window in one direction is balanced by current flowing in the opposite direction, summing to zero. Only ground-fault current (I.N) will be detected, flowing to GND as shown in Fig. 1, bypassing the CT and inducing a current in the CTs secondary winding. The load (RL) shown in the

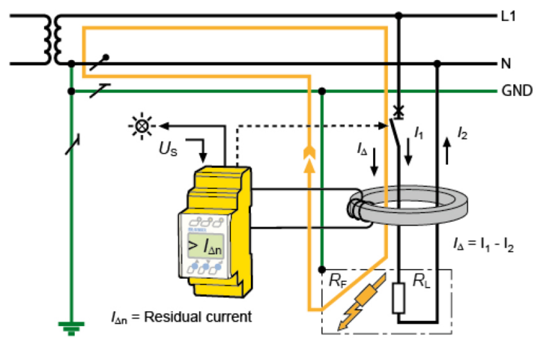

Fig. 1 RCD Measuring Fault Current

Fig. 1 is purely resistive. This is important for later considerations in this paper because a resistive non-controlled load will only draw sinusoidal AC currents.

II. NORMATIVE REQUIREMENTS FOR RCD TYPE "A" DEVICE

Many AC Drives may already be equipped with type A or type B ground fault detectors. This section should help engineers understand their differences and why they may have been selected for applications. Residual current devices of type "A" are designed for the following I.N ground-fault-current profiles in accordance with IEC 61008-1 and IEC 61009-1:

- Sinusoidal currents
- Pulsating sinusoidal currents
- Pulsating DC currents

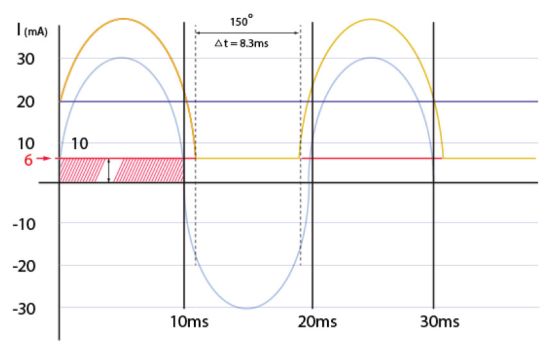

Fig. 2 IEC Defined I.N Ground-Fault-Current Profiles

Potential superimposition of a pure DC current is shown in Fig. 2. A DC component of 6mA adds to the sinusoidal curve. A typical US standard for such a ground fault device is UL1053. It does not however, address potential issues with waveforms or frequencies other than 60 Hz. Where do potential non-sinusoidal waveforms originate and how would they appear to an observer or even more important, a safety circuit?

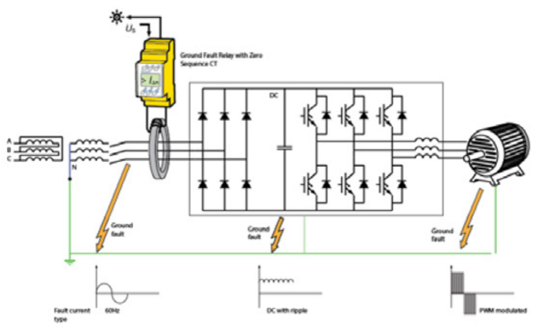

Fig. 3 Ground-Fault Waveform at Different Locations

III. RCD APPLICATION ON DRIVES

Figure 3. above shows a modern adjustable-speed drive application and the resulting fault current wave forms at three locations in the system.

Fault currents differ from 60 Hz: Drive front-end faults will cause a 60 Hz fault. A DC link fault will cause a ripple pattern. A fault on the load side of the drive (in the cable or motor) will produce a pulse width modulated waveform of varying frequencies. Both DC-link and load-end ground-fault currents will not be registered correctly with a typical type A RCD, or more commonly used bandpass filter ground-fault relays. The ground-fault currents will likely be undetected.

The UL standard for ground-fault relays, UL1053 mentions frequency twice, but not in regard to the response of the relay. The only mention of frequency in the standard is in the power supply requirements for the tripping circuit and in conversion of cyclic delay times to seconds should be based off of 60 Hz frequency. UL1053 defines the testing of ground-fault devices but does not offer any information on the test current frequency or the relay's ability to respond to dc faults. The only requirement for testing in section 34.1 (d) of the standard mentions that a simulated or actual controlled fault is generated and that the relay responds. It does not define the frequency or level or the fault or the shape of the waveform -which could have a negative impact on relay performance.

Carrier frequencies and filter circuit leakage: Modern drives have built-in filters to counter electromagnetic interference in the system. A good portion of the EMI stems from the carrier frequency of the drive, that is usually in the 8 to 16 kHz range, depending on the model. These filter circuits are usually in the form of Y or X capacitor-resistor networks. As shown from the frequency-spectrum plot in Fig. 5, a conventional type A RCD with little or no filtering on its CT input will be affected when exposed to these non-sinusoidal currents. Often the result is higher than anticipated ground-leakage current readings and nuisance tripping or nuisance alarming.

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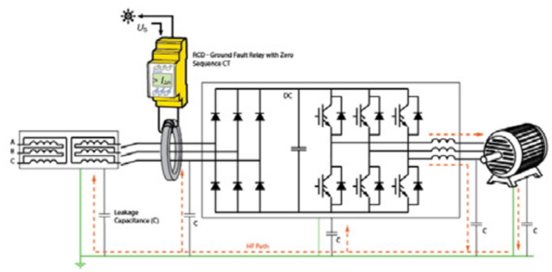

Fig. 4 RCD Detecting Carrier Frequency

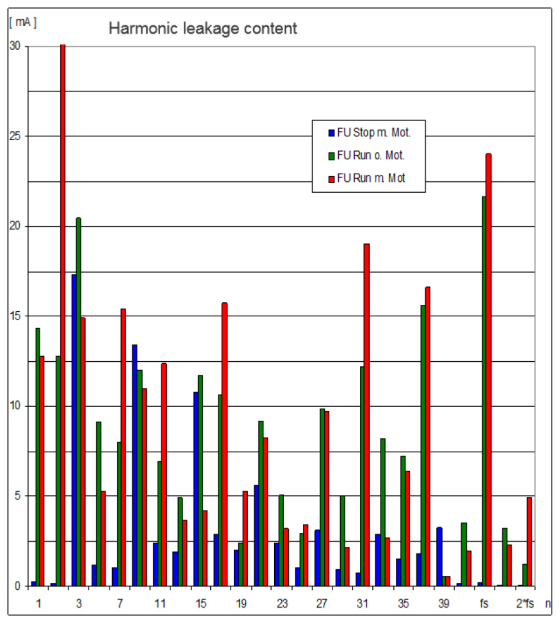

Fig. 5 Carrier Frequency Component Detection

DC Blinding: The term DC blinding has been used to describe an effect on a CT core that is being driven into saturation due to a DC current. It can cause a type A RCD to malfunction. A ground fault in the DC link, or after rectification will cause DC current to flow to ground. DC currents running through a conventional 60 Hz CT will cause what is known as core saturation. An AC ground fault is supposed to induce alternating flux in a CT to cause a secondary current to flow for fault-detection purposes. Once a CT core has been pre-magnetized by DC current and has been driven into saturation, it takes either higher current values to trip that circuit, or an action is entirely inhibited. The B-H or saturation curve as shown in Fig. 6 illustrates the effect. The ideal transformation takes place around the B-H centerline. (Top illustration.) Pre-magnetizing a CTs core with a DC fault current will shift the proper operation on the curve to the right and delay or even inhibit trips once saturation has been reached.

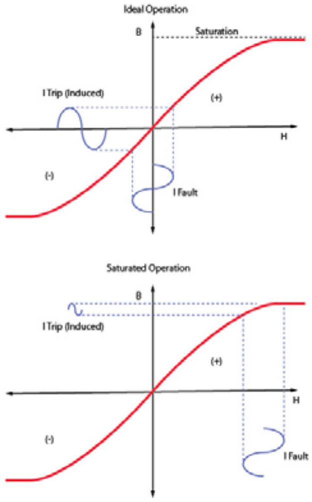

Fig. 6 CT BH Curves showing DC Blinding

Type B RCDs can be the solution for the aforementioned problems with type A devices. Type A CTs are passive and prone to inaccuracies. The CTs used with type B RCDs employ active compensation techniques, assuring measurement of true RMS values of AC, DC and mixed AC/DC waveforms from zero hertz to kilohertz.

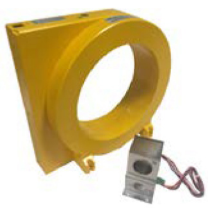

Fig. 7 Examples of Integrated Type B RCD

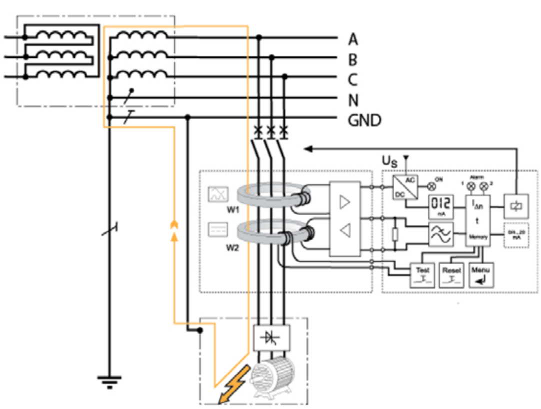

Fig. 8 Block Diagram of Type B Device

Figure 7 shows the interior of a typical type B RCD CT. The circuit board includes electronics for active measurement and digital filters. This type of CT requires an auxiliary power source to function. The measuring principle has a dual-core design, unlike the single-core passive type A CT. Its benefits are: High accuracy, true RMS readings, adjustable frequency drive (AFD) capabilities, DC and high-frequency measurement. In a variable-speed drive application, the CT is ideally mounted on the line side of the drive. In this configuration, it will protect the drive and the connected loads and cabling from ground faults.

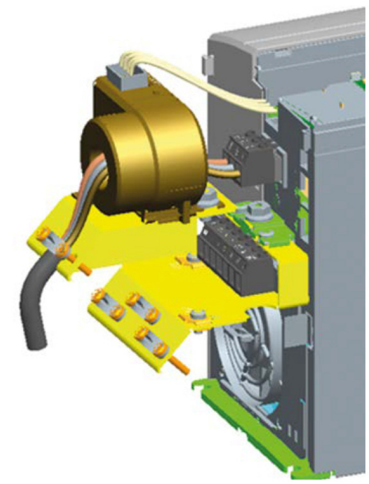

Fig. 9 Schematic of RCD Onboard Drive

The image in Fig. 9 shows a typical type B sensor installed on a AFD load side. When installed on the load side, only the outgoing cable and load are in the zone of protection.

IV. Correct CT placement for type B devices

There are multiple ways to place a current transformer into a power system. Most common placement in the industrial world for type A is installing a single CT around an individual conductor. The current transformer will be exposed to full load current (FLA) and sense high magnitude fault currents. Most are rated for 20 times their primary-current rating.

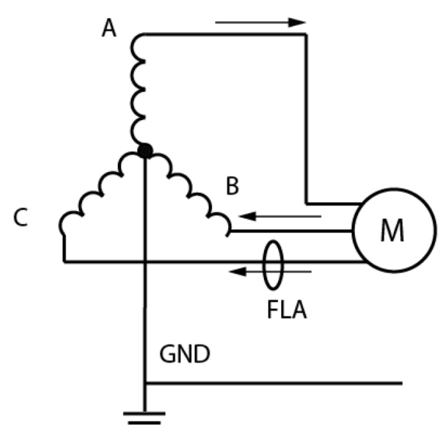

Fig. 10 CT Used for Load Monitoring

A variant of this is used for ground-fault measurements and it is called the "Holmgreen method". Here, individual CTs are placed around each conductor and will be exposed to full load current. The CTs are type A and rated for the main FLA and have a 1A or 5A secondary. The secondarys can then be connected in parallel and connected to a ground-fault relay. Type B CTs which are intended for ground-fault measurements are commonly not installed around single conductors only. In these applications the goal is to detect leakage and low level ground-fault currents; therefore the zero-sequence method is preferred. The zero-sequence or "residual current" method employs one single CT. All the current carrying conductors including the Neutral (if present) will be routed through the CT.

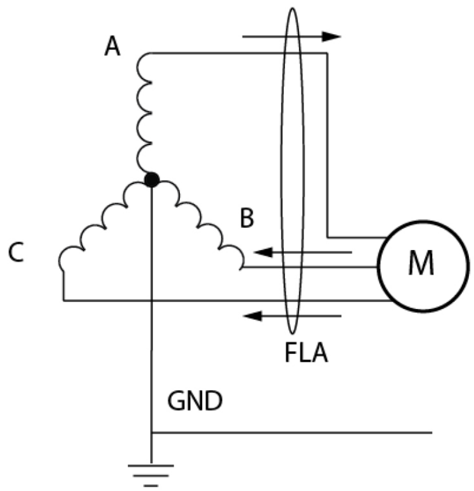

Fig. 11 CT in Zero-Sequence Placement

If the sum of all currents (A,B,C) is added vectorially, the summation is zero, the currents cancel each other out. Only a leakage portion to ground would subtract from the equation and show up as a leakage current or ground fault. Figure 12 graphically illustrates the zero-sequence principal. For illustration purposes phase A is red, B is blue and C is green. We can glance into the system at any given point in time, however for simplicity purposes we shall do so at the dotted line. The current values at this very specific moment add up to zero. (10 – 5 - 5 = 0)

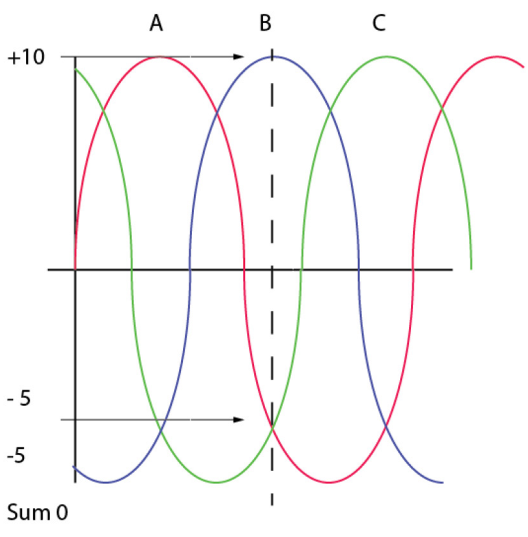

Fig. 12 Zero-sequence measurement

Further considerations for CT placement in drive applications are shown below. It is always preferred to install a type B current transformer on the line side of a drive. A CT will always sense faults downstream of its location, towards the load. Therefore, if the drive is placed downstream of the CT (Pos1) it will be in the zone of protection along with the attached cable and motor (for non-isolated drives). A CT at Pos 2 would only protect the motor and wiring between it and the CT. A further advantage of a CT placement at Pos 1 is the reduction of sensing unwanted higher frequency currents. A drive is usually equipped with internal filters that will reduce noise currents in the high kHz frequency range bleeding off to ground. In other words, the unwanted current portion is removed by the filter before it reaches the ground-fault device. Placing the CT at Pos 2 would expose it to the full spectrum of both, ground fault and unwanted nuisance currents, hence causing higher than normal readings and potential for nuisance trips, or a higher than desired pickup setting.

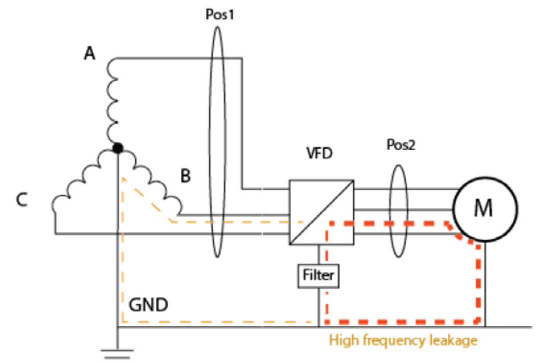

Fig. 13 Type B CT location Before or After the Drive

V. RCD APPLICATION ON DRIVES FED FROM RESISTANCE GROUNDED DISTRIBUTION

The problem of monitoring for ground-faults on drives is further compounded when these drives are applied on resistance grounded applications. The inadequate voltage rating of metal oxide varistor (MOV) protection internal to the drives is a more well-known issue with the application of drives on high-resistance-grounded systems. Many of the drive manufacturers publish information on what to do with MOV protection on such drives – since line-to-line voltage will appear from phase-to-ground when there is a single-phase-to-ground fault on the system. There is also another negative effect for ground-fault protection in that any ground-fault current that would be monitored would be greatly reduced by the current limiting nature of the neutral grounding resistor. Many systems in use today limit fault current to 10 A or even less. The Pulp and Paper Industry often uses currents of 5 A or less sizing the neutral grounding resistor to allow this maximum let-through value. Rectification by the drive as mentioned before can further reduce the alternating current peak-to-peak value measured by a type A RCD device. Users may have had single phase-to-ground faults that escalated to phase-to-phase faults when the first fault went undetected.

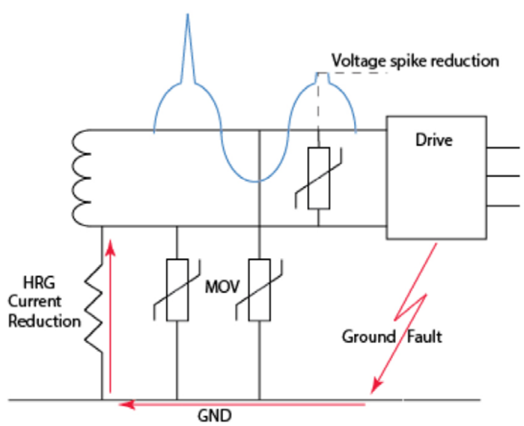

Fig. 14 HRG and MOV simplified

Early detection of rectified faults, dc faults, or high-resistance faults on a high-resistance-grounded system allows the user time to repair the fault and if done in a timely fashion will help reduce the risk for a second fault -which would be a phase-to-phase fault.

Even application of a UL listed ground-fault device, that is listed to UL1053, the standard for Ground-Fault Sensing and Relaying Equipment may not address the issues mentioned in this paper. Many individuals do not understand that there is no UL standard for ground-fault relays used on resistance grounded systems. Currently there is no North American standards for the operating frequency response of a ground-fault relay. Note that UL1053 scope is limited in section 1.2 to solidly grounded systems.

VI. CONCLUSIONS

Type A RCDs and listed UL1053 ground-fault relays may have shortcomings in applications that include non-sinusoidal waveforms. Type B RCDs are a viable and readily available solution to take their place and allow adequate protection even on high-resistance grounded systems. UL1053 may require amendment to provide requirements for frequency response and it or another standard may need to be written to address ground-fault protection on resistance grounded applications.

VII. REFERENCES

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VIII. VITAE

Torsten Gruhn started out as a certified electrical motor rewinder in Germany. He graduated from trade school and worked on everything electrical that can turn, produce or transform power. He obtained a Bachelor of Science degree in electrical engineering from the University GH in Paderborn, Germany with the emphasis on power generation, transmission and distribution. Main focus at his current position is new business development, sales and the support of ground fault protection equipment

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Mervin J. Savostianik, P.Eng. has a Bachelor of Science degree in Electrical Engineering from the University of Saskatchewan and is a registered Professional Engineer working with electrical protection manufacturers since 1997; as sales engineer, national sales manager, and now product manager. He has worked with many system designers and end users to find solutions for electrical safety including ground-fault relaying and neutral-grounding-resistor applications. Mervin is a member of the Institute of Electrical and Electronics Engineers (IEEE) and co-authored the previously published papers; "Why Neutral-Grounding-Resistors Need Continuous Monitoring" and "Considerations for Ground-Fault Protection for Low-Voltage Variable-Frequency Drive Circuits Supplied by High-Resistance-Grounded Power-Distribution Systems."

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