ELECTRICAL SHOCK AND FIRE HAZARD PROTECTION – CONQUERING THE LIMITATIONS

Originally published in “Elektron” September 1993.

1 Introduction:

The 1957 South African developments in sensitive earth leakage protection signalled a quantum leap in the science and application of devices specifically intended to improve the usability of electrical power, by dramatically reducing electrical shock and fire hazards resulting from imperfect or damaged electrical circuits.

Twenty five years of installation experience and evolution technology in these devices resulted in the 1982 edition of the SABS product standard SABS 767, which replaced the original 1964 document. By that time, sufficient understanding of application requirements and idiosyncrasies had been identified to enable documentation of the application and design limitations of Earth Leakage Circuit Breakers (ELCB’s).

A decision was thus made to include, as an Appendix C to SABS 767 - 1 982, a listing of the factors affecting the operation of Earth Leakage Circuit Breakers.

This was found to be necessary since, possibly as a result of the impressive track record of earth leakage protection devices, a degree of complacency had set in with a general lack of respect for electricity and its potential hazards if misused.

The preamble to Appendix C of SABS 767 suggested that Earth Leakage Circuit Breakers should not be considered as the ultimate in protection, since there were several sets of circumstances under which the safety characteristics of these devices could become reduced, and in extreme situations inoperative.

These circumstances included four points describing reduced safety viz:

a. Fault between line and neutral or two lines
b. Loss of neutral or one phase in a three phase supply
c. D.C. earth leakage components
d. Fault between earth and neutral

In addition, the question of nuisance tripping was included as a factor affecting the operation of Earth Leakage Circuit Breakers.

A further decade has seen technology developments in South African designed and manufactured Earth Leakage Circuit Breakers that have addressed the historical performance limitations of these devices, in the quest for ultimate protection.

2 Design Technology:

Core balance earth leakage protection circuit breakers have evolved in two separate technologies with power independent types that utilise highly sensitive electromagnetic releases being favoured in Europe.

Most other territories have or are tending towards power dependent types using solid state electronic technology.

The performance limitations identified in Appendix C of SABS 767 can be grouped into three basic categories:

a. Common to both design technologies

b. Mainly applicable to power dependent devices

c. Mainly applicable to power independent devices

This paper will explore the impact on performance of ELCB’s under the listed conditions and will identify the progress of technology developments in addressing these shortcomings.

3 Common Limitations:

3.1 Fault Between Line and Neutral or Two Lines:

The condition of a fault that occurs between the active conductors of an electrical supply system, without involving earth is a condition that is not addressed by core balance ELCB’s as we know them. Faults such as this that result in overcurrents, are normally detected and interrupted by the overcurrent protection device, the most common of which is the Moulded Case Circuit Breaker.

Protection against shock hazard is not provided since in this kind of situation, the person coming into contact with the active conductors is simply seen by the circuit as a load.

Shock hazard protection under such circumstances will require a totally different concept of both electricity supply and protection, with load signature

recognition being required.
Once the “Smart House” concepts of the 21st century begin to evolve, new technologies such as this could conceivably be addressed.

3.2. Nuisance Tripping:

From the very earliest days of the introduction of sensitive earth leakage protection, the most obvious identified problem was the inconvenience of “nuisance tripping”.

Nuisance tripping is a situation in which the ELCB trips and isolates the electricity supply without the occurrence of an earth leakage or earth fault.

In earlier times, it was assumed that only power dependent ELCB’s were susceptible to nuisance tripping by transient voltage spikes through peak voltage and dv/dt stress. This was soon shown not to be the case and in fact all ELCB’s were, for a variety of reasons, susceptible to nuisance tripping.

As a result, there has been much work and investigation into this problem, particularly in South Africa which has higher than normal lightning activity in the Highveld regions.

It was soon realised that ELCB’s were tripped spuriously by not only voltage surges, but also by current surges which resulted from voltage surges.

The research in the intervening decades has resulted mainly in strong action by responsible manufacturers in an effort to preserve the credibility of performance of their ELCB’s.

In recognition of the problem, product standards are also starting to include at least minimum nuisance tripping withstand requirements.

North American standards, such as UL have addressed the problem at its source by introducing withstand requirements for voltage surges.

European and IEC product standards, on the other hand, have, for the meantime, limited their attention to current surges.

Modern ELCB’s, including those of the major South African manufacturer, have evolved to a high level of withstand against nuisance tripping, to a degree that in many cases, system installation limitations and deficiencies are being highlighted. It cannot be claimed that research and development in this area are complete however, and work continues in this field in both the product itself and in product standards.

4 Factors Affecting Power Dependent ELCB’s:

4.1. Loss of Neutral or One Phase of a Three Phase Supply:

The most obvious performance limitation of power dependent ELCB’s was identified several decades ago as being the so-called “broken neutral” syndrome.

In power dependent ELCB’s, the supply to the amplifying and operating circuits is derived between line and neutral of a single phase supply, or between the phases of a three phase system.

If the neutral, or one of the connected phases of a three phase circuit is broken on the supply side of the installation, it is possible that, in the event of a leakage to earth from an apparatus, or in the event of inadvertent contact, certain designs of ELCB may not trip.

It was argued in many quarters that the statistical probability of accidents occurring in such circumstances was low, since several faults or failures were required to occur simultaneously for a hazardous situation to arise.

Furthermore, in permanently earthed electricity supply systems, a reliable earth is usually ensured, particularly where multiple earthing of the neutral (MEN) is introduced.

4.2. Functional Earth:

In recognition however, of the possible occurrences of hazardous situations without protection, however remote, this potential shortcoming has been entirely overcome by the introduction into modern ELCB’s, of a FUNCTIONAL EARTH connection.

The functional earth provides an alternative path for ensuring the continuity of supply energy to the ELCB even in the event of a total break in the neutral supply conductor.The low energy requirements of modern ELCB’s ensure safe and reliable operation of the ELCB even in extreme situations where the earth return path bond resistance is orders of magnitude higher than that normally accepted by mandatory or utility specifications or requirements.

The inclusion of the functional earth option has so far not been deemed to be necessary in North American product standards.

The requirements for the functional earth (FE) are currently under investigation in the IEC, even though this option has only been introduced by two or three European manufacturers.

Under normal operating conditions the FE circuit is quiescent and does not influence the performance of the ELCB, whether the FE is connected to earth or not.

The connected FE circuit becomes operative, immediately a total break, or high impedance in the neutral is detected. Functional earth connection provisions are now provided as a standard, by the major South African manufacturer of single phase ELCB's. Three phase ELCB's derive their supply energy from all active conductors, providing a high degree of redundancy.

5 Factors Affecting Power Independent ELCB's:

Power independent ELCB's rely for their operation on a limited energy source derived from a high permeability - high sensitivity toroidal magnetic core, operating an equally highly sensitive tripping release, which requires a tripping sensitivity of the order of one hundred micro VA. Any interference, be it from electromagnetic or physical sources can interfere with the delicate balance of this micro system with possible deleterious effects. In this limited energy system, the deleterious effects, at the best, could involve nuisance tripping, and at the worst could result in reduced tripping sensitivity leading to non-tripping conditions in extreme circumstances.

5.1 Energy Considerations:

In core balance earth leakage detection systems, the residual current is detected through excitation of a zero sequence toroidal transformer, through which all the ACTIVE conductors of the protected circuit are monitored.

Because of the very low energy levels involved, the zero sequence transformer needs to be constructed from high permeability materials. It furthermore, needs to be excited to a level that will ensure optimum energy transfer to the load that is being driven. Optimum energy transfer, is obviously a function of load impedance.

In power dependent systems, whilst the load impedance seen by the secondary winding of the zero sequence transformer is relatively high, this impedance when reflected to the primary of the zero sequence transformer, becomes very low, as a result of the high turns ratios employed. Good impedance matching under such conditions is relatively easy to achieve.

In power independent systems, the zero sequence transformer is required to feed into a relatively low impedance load. The resulting effective detector impedance is however relatively high, when reflected to the primary through the low turns ratios used in such systems. The impedance matching and power transfer characteristics of such systems are difficult to maintain under adverse operating criteria.

5.2 D.C. Earth Leakage Components:

Modern appliances, to an ever increasing extent, rely for their operation, convenience and cost on electronic control systems.

The quality of both design and components used in appliances can vary from very good to questionable.

The probability of introducing d.c. components into the load current by certain appliances, either under normal operation, or under fault conditions, is real.

In the event of a fault or leakage, uncancelled, unidirectional or d.c. components can result in severe performance deterioration of ELCB's, particularly when limited energy sources feed directly into electromagnetic detectors via low turns ratio zero sequence transformers.

This performance deterioration is a direct result of the change in effective permeability of the zero sequence transformer that results from a shift in the reference operating point on the magnetic induction loop of the zero sequence transformer.

The shift in the operating point on the magnetic induction loop known as the B-H curve results in a far shallower initial permeability slope, which in turn results in a lower output from the zero sequence transformer. The available output energy is further aggravated by the resulting change in the energy transfer characteristics of the system.

Whilst power dependent ELCB's are also subject to this phenomenon, the impact on their performance is far less due to their superior energy transfer characteristics.

Performance requirements for ELCB's when subjected to pulsating unidirectional d.c. currents that are superimposed on the ac. residual current have been established by international compromise in product standards produced by the International Electrotechnical Commission (IEC).

All responsible manufacturers who recognise the importance of such application and operating requirements in ELCB's now include these so-called "Type A" requirements i.n their product specifications. "Type AC" devices which do not meet the required performance requirements under conditions of superimposed pulsating d.c. fault currents are however still widely distributed in territories that have not yet realised or are prepared to accept the performance limitations in these devices.

5.3 Fault between Earth and Neutral:

Core Balance ELCB's are zone sensitive devices that will detect residual currents occurring on the load side of the zero sequence transformer included in the ELCB.

Residual currents that occur due to leakage or fault, bypass the zero sequence transformer of the ELCB and return to the supply transformer via a path through earth or through the earth connection. The implication of this, is that ELCB's of the core balance type, require, for their successful operation, an identifiable connection between the transformer and earth, on the supply side of the ELCB.

Most public electricity distribution systems in South Africa are solidly grounded by connecting the transformer neutral terminal to earth. Private distribution systems sometimes use impedance earthing to restrict the level of earth fault current. In such cases, it is important to ensure that the earth impedance is chosen such that safety touch voltages cannot be exceeded.

In some parts of the world, utilities do not totally distribute the earth conductor and the consumer is required to ensure his own earth connection.

In an effort to limit the voltage rise of the neutral conductor in the event of neutral breakage, there is a trend towards theuse of multiple earth connections on the neutral (MEN).

Whatever the distribution system used, in the interests of safety, bonding of the neutral conductor to earth close to the consumer supply point, is becoming more common.

One consequence of this kind of safety installation requirement is that in the event of a fault occurring between the neutral and earth, on the LOAD side of the zero sequence transformer, a low impedance loop is created through the zero sequence transformer via the neutral and earth conductors, the fault connection, and the neutral-earth connection on the supply side.

The induced effect of this low impedance loop is to desensitize the ELCB and to allow currents in excess of the rated earth leakage current to flow without the ELCB tripping.

It has been found by both experience and test that detection circuits of ELCB's that have a high primary reflected impedance are far more susceptible to this kind of desensitizing effect, than are ELCB's having a low primary reflected impedance, as is the general case for power dependent devices.

One reason for this apparent desensitization is that the zero sequence current in the ungrounded primary winding of the ELCB induces a voltage in the grounded winding, which in turn causes a current to flow through the closed loop formed through the neutral and earth conductors. The phase of this induced voltage is such that it reduces the magnetic flux in the core of the zero sequence transformer and thus reduces the energy applied to the detector.

It is obvious that the anti phase induced voltage, which is proportional to the reflected impedance of the detector, will be higher for high reflected impedance devices.

5.3.1 Effect of Load Current:

It has often been assumed that even in the event of such desensitization of the ELCB taking place, the ELCB would be caused to trip through the division of load current through the neutral and earth conductors.

Whilst this assumption is true up to a point, it must be remembered that the load current will divide according to the inverse ratio of the neutral circuit impedance to the earth circuit impedance.

The amount of load current that is needed to result in tripping of the ELCB could, in some circumstances exceed many hundreds or even thousands of milliamps. During periods of low load demand, such as the early morning hours, such a situation could result in the major portion of this low load current flowing through extraneous earth return paths, without the earth fault being detected by the ELCB.

It has been well documented that currents flowing through uncontrolled return paths could, at levels exceeding about 300 milliamps result in potential fire hazards.

5.3.2 Product Standards:

The question of ELCB desensitization through double grounding of the neutral, has been a highly controversial matter.

North American product standards recognised the need to address the problem and have included stringent requirements for the past two decades.

The technical reasons for dismissing the problem in Europe remain tenuous and are only based on the assumption that the ELCB will be tripped through division of load current between the neutral and earth paths.

A weak compromise was made in SABS 767, in testing for shorted loop paths of 1.5 ohms impedance, which was considered to be a value that would not reject ELCB's on the South African market during the early 1980's, but would reject ELCB's whose performance was worse than that for the limit imposed.

6 Conclusions:

The degree to which the identified performance limitations of ELCB's has been recognised and addressed, has varied across the world and has no doubt been influenced by vested interests in the territories concerned . North American standards strongly address the question of double grounding of the neutral. They do not however, pay much attention to the question of broken neutrals, using the argument that their installation system always ensures a good earthed neutral conductor.

European standards address the question of d.c. fault current desensitization but have consciously ignored the question of desensitizing of ELCB's through double grounding of the neutral.

With installation rules influenced by vested interest, mainly power independent ELCB's are used in Europe. It is therefore not surprising that developments incorporating functional earth connections on ELCB's are limited to a few specific manufacturers.

South Africa has been fortunate in that despite relatively weak product standards requirements, the major manufacturer of ELCB's has, in recognition of the need to address the ELCB performance limitations listed in SABS 767, been successful in promoting market competitive ELCB's that have addressed all of the identified problems within the limitations of modern technology.

The current issue of SABS 767 has now passed its stage of maturity and is scheduled for revision in the near future. With home-grown technology having been developed and field proven to the extent that exists in this country, the time has come to delete Appendix C of that document and to incorporate meaningful performance requirements into that document in the quest for idealised safety against both shock hazard and fire hazards.

References

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