Effect of multiple neutral earthing systems on consumers' installations

Originally published in "Vector" August 1983

An historical examination into electrical faults has revealed that the major causes of earth leakage trip-outs are faults in electrical appliances and flexible cords. The second most prevalent fault has been found to be inadvertent connections between the consumer's neutral conductor and earth.

The article describes an investigation into the effects of multiple neutral earthing systems upon the efficacy of sensitive earth leakage protection devices installed in the consumer's premises.

In the case of inadvertent connection between neutral and earth, this condition would only cause the earth leakage relay or circuit breaker to trip if the neutral conductor was at a potential high enough to drive the necessary 20 to 30 mA required to trip the device.

Depending upon the neutral conductor impedance between the system earth point and the consumer and the system load current being drawn, it is quite common for the neutral to rise several volts above earth, particularly in the case of single point neutral earthing, or where the last neutral earthing point is relatively distant from the consumer.

The relatively high incidence of these neutral-earth faults has been largely due to PVC insulation damage in conjunction with the high temperature and temperature excursions encountered in lighting fittings, roof areas, etc.

It is interesting to note that several Municipalities have reported cases of earth leakage devices having been found to be in perfect working order when tested in their workshops, after failing to operate when tested *in situ,* due to the limited (approx 40 mA) test current available from portable test equipment.

This mal-operation can be shown to be a direct result of the desensitising effect of the so called "shorted neutral" condition.

Specifications

This shortcoming has been considered serious enough to justify the inclusion in several national and international specifications of some reference, requirement, or test procedure. For example, Underwriters Laboratories of the United States, and CSA of Canada include a self-protecting requirement in the event of the neutral-earth impedance falling below some predetermined value.

The draft revised specification SABS 767 (Core balance earth leakage circuit breakers) imposes a limit on the degree of desensitisation at a particular loop impedance.

IEC and BSS have a clause titled 'Verification of the behaviour of residual circuit breaker in case of earth fault of the neutral conductor on the line side and on the load side of the device' (Clause 8.3.6.) under consideration.

Investigation into the problem

The Electricity Department of Johannesburg City Council, some time ago, conducted a series of tests to investigate the seriousness of this condition.

It was found that the desensitising effect on the earth leakage devices was dependent, in the main, on: (a) the impedance of the neutral conductor between the system earth and the earth fault; and (b) the impedance of the residual detector circuit when referred to the primary.

Neutral impedance

If the neutral conductor is taken to be a stranded copper conductor of 16 mm^2 cross-section, it can be shown that the neutral impedance (mainly resistive) would be approximately 0,006 Ω for a conductor length of 5 m up to, say, 1,2 Ω for a conductor length of 1 km.

Earth fault impedance

In the event of a neutral-earth fault on the consumer's installation, the impedance (again mainly resistive) of the earth path between the system earth and the earth fault, is unlikely to be less than the impedance of the neutral path and could conceivably be some multiple of the neutral impedance.

Residual detector impedance

Figure 1 represents the equivalent circuit of a core balance earth leakage detector with a neutral-earth loop impedance shown.

If the value Ir, is considered to be the current in the detector circuit at the point of tripping, then it can be shown that the current in the residual detector circuit and in the neutral-earth loop circuit divide as in a branch with parallel impedances.

It can be further shown that an effective detector impedance can be calculated and assigned to the detector circuit, depending upon the particular design of the detector. This is dependent upon the turns ratio of the device, and the tripping circuit.

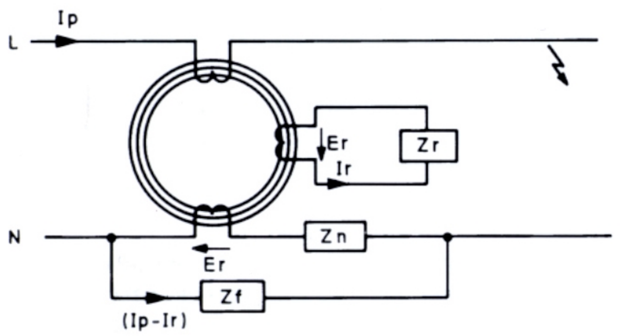

Figure 1 . Equivalent circuit of a core balance earth leakage detector.

Tests
A series of independent tests carried out by the Electricity Department of Johannesburg established the degree of this desensitising effect of a neutral-earth fault on various types of earth leakage devices, by plotting the actual no-load sensitivity against the neutral-earth loop impedance. This is shown in figure 2.

By considering the actual circuit impedances involved and the parallel branch division of these impedances, the actual load currents required to override this desensitising effect can be calculated and confirmed by test.

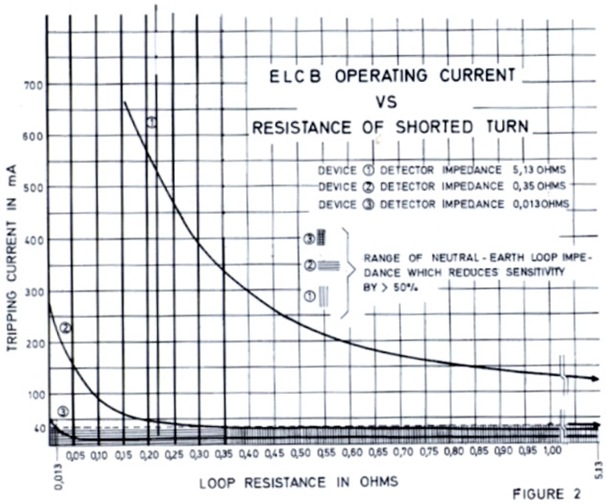

Figure 2. E.lc.b. operating current against resistance of shorted turn.

Magnitude of the problem
The desensitising effect of the neutral-earth loop is seen to be minimal on detectors which have a low detector impedance reflected to the primary side, according to the relationship:

1 TI 2

However, this is not the case for detectors which have a relatively high impedance reflected to the primary side, as can be seen from figure 2. Such devices can be desensitised from the nominal 20 mA level to many hundreds of milliamps, even with loop impedances as high as 0,25 or 0,50 Ω

Neutral earthing

Single point earthing
For the case of single point earthing, particularly with the earth point at the transformer neutral, the neutral conductor impedance between the point of the consumer's neutral-earth fault and the system earth, could conceivably be several ohms.

Multiple earthed neutral (MEN)
According to the AMEU draft code of practice for the application of multiple earthing to low-voltage distribution systems, the neutral and earth conductors are solidly connected at the tee-off point on the lv. distributor.
The probability is then that the distance between this earth connector on the neutral and any neutral-earth fault on the consumer's premises would probably not be less than say 50 m and could be up to a few hundred metres.

For $16mm^2$ copper conductor, the impedance between the earth point and the fault could then be expected to be between about 0,05 Ω and say 0,25 Ω

As can be seen from figure 2 the desensitising effect with devices labelled 1 and 2 could still be rather serious — certainly way beyond the limits imposed by SABS 767.

PME systems
The obligatory earthing of the neutral at the consumers' supply point obviously decreases the neutral conductor impedances between that point and the point of any neutral-earth fault, since the additional length of conductor to the tee-off point can no longer make a contribution.

This can only make the desensitising effect that much worse.

Black box analogy
It is interesting to consider the black box analogy of Figure 4 where A is the actual fault current, B the residual detector current and C is the neutral-earth loop current.

As one example, let us examine the case of equal division of the fault current between the detector circuit and the neutral-earth circuit, i.e. when the effective detector impedance is equal to the loop impedance. For the detector to operate at 20 mA (B), the neutral-earth current would also be 20 mA (C) and the total fault current would then be 40 mA (A = B + C).

Figure 4.

The intersection of the total fault current calculated in this way, with the tripping curves of Figure 2, approximates the calculated reflected detector impedance on the horizontal scale of Figure 2. The range of neutral-earth loop impedances which reduces the sensitivity by greater than 50 % is also shown in Figure 2 for three different types of devices having detector impedances of 0,013 Ω 0,35 Ω and 5,13 Ω

Load current

As load current is drawn on the protected circuit, the desensitising effect of the neutral-earth loop will eventually be overcome and the device will trip purely by virtue of the division of load current through the parallel impedances.

However, with certain types of detectors, the load current required to cause spontaneous tripping could be many amperes, or even tens of amperes, particularly when the impedance of the neutral circuit is low.

This can easily be seen from the relationship (see Figure 3):

$$Z_n + Z_f + Z_r$$

Where:

I_p = Load current required to operate the earth leakage detector.
I_f = Nominal tripping sensitivity of the detector

Z_r = Effective detector impedance (reflected to the primary).

Z_f = Impedance of the earth path between thesystem earth and the earth fault.

Z_n = Impedance of the neutral conductor between the system earth and the earth fault.

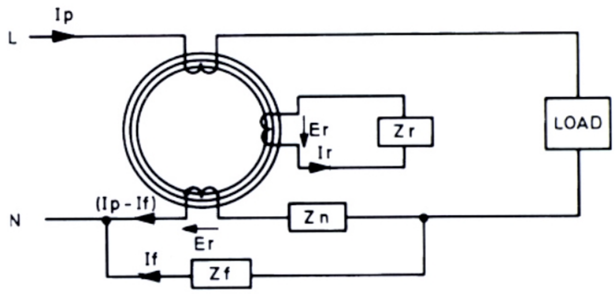

Figure 3. Equivalent circuit showing load current dependence.

Integrity of the neutral connection

It has been clearly demonstrated that the MEN system removes the hazardous conditions imposed on the consumer by a broken neutral in the PME system.

The multiple earth connections of the neutral in an MEN system provide integrity to the neutral return path. This in itself provides not only continuity of supply to the consumers, but ensures operation of earth leakage devices which require this supply.

In general, such devices are of the low-impedance type.

Conclusions

The neutral-earth loop condition results in desensitisation of earth leakage devices. This is aggravated by lower loop impedances encountered with MEN or PME systems, but this effect is minimal with the low-impedance type of devices.

The potential economic advantages offered by a multiple earthed neutral system should therefore not be discounted, since adequate protection can be afforded by the correct application of sensitive earth leakage protection devices.

Acknowledgements

The author is indebted to the Electricity Department of the City of Johannesburg for permission to include and reproduce references to a communication from that Department to the South African Bureau of Standards and calculations, tests and curves contained therein.

Acknowledgement is also accorded to the Engineering Staff of Fuchs Electrical Industries, who assisted with tests and advice.

Reference is made to the draft AMEU code of practice for the application of multiple earthing to low-voltage distribution systems.