Electrical shock hazard protection

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The science of sensitive earth leakage protection was developed in South Africa, with the first commercial installation on a large scale taking place in 1957. A recent nationwide survey, however, revealed that approximately 5 % of installed earth leakage circuit breakers could be inoperative due to faulty installation or wiring, or due to faults in the units themselves. It is essential, therefore that these vitally important protection devices in electrical systems be checked at regular intervals by operation of the integrally mounted test button.

Introduction

Earth fault protection

The short circuit between one phase and earth is probably the most common type of fault on a low voltage (l.v.) electrical installation. It is surprising, then, that in many applications, very little thought is directed at confirming that this short circuit condition will be detected. The designer often assumes, without calculation, that the earth fault currents will be high enough to trip the overcurrent protection at the upstream moulded case circuit breaker (MCCB). It should be borne in mind that the magnitude of the earth fault current depends not only on the circuit impedance (resistance) but primarily on the type of earthing and the impedance of the earth return path.

To ensure that the magnitude of the earth fault current will be high enough to be detected by the overcurrent tripping elements of a typical MCCB, the neutral of the supply transformer should be solidly earthed and a copper earth conductor should be run with the power cables to all connected electrical equipment. The aim is to keep the value of the earth return impedance as low as possible. These factors are emphasised in the SABS Code of Practice for the Wiring of Premises (SABS 0142). When the earth return impedance becomes too high, the earth fault current will be too low for detection by the overcurrent protection.

Modern earth leakage protection circuit breaker

In these cases, separate earth fault protection devices with medium sensitivities are necessary. This is particularly true on motors where an internal insulation failure can result in serious damage while the fault current develops to a value high enough to trip the overcurrent protection device.

Earth leakage protection

It is vitally important to protect personnel against possible electric shock, both as a result of direct contact with 'live' conductors and indirect contact via metal enclosures during short circuit conditions. Although there are regulations aimed at reducing the possibility of direct contact, for example by means of barriers and enclosures, there are situations where it is necessary to use earth leakage protection in addition to the overcurrent protection.

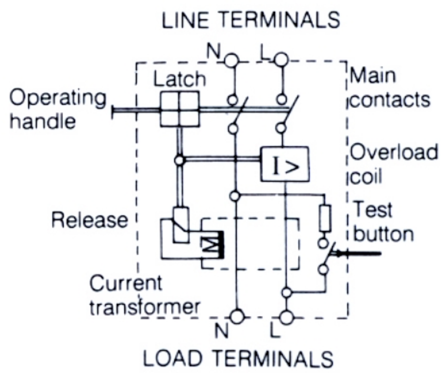

Fig. 1 Connections of a typical power independent device.

Wherever the integrity of the earth path cannot be guaranteed, earth leakage protection should be used. This is particularly necessary when portable appliances or equipment are operated from socket outlets where there is a danger of the earth conductor either breaking or becoming disconnected.

Mandatory requirements for earth leakage protection in circuits supplying socket outlets are laid down in clause 4.5.4 (d) of SABS 0142. Earth leakage protection is also necessary where electrical equipment is operated by personnel in wet or damp conditions or in closely confined spaces.

(See MOS Act (No. 6 of 1983) Electrical Machinery Regulation 9 and 10 . Portable Electric Tools and Portable Electric Lights respectively.)

Principle of operation

The principle of operation of a core balance device to protect against earth leakage is shown in Figures 1 and 2.

The current carrying supply lines (there may be more than the two shown) pass through the opening of an annular core. On a healthy installation, the summation of the currents in all the load carrying conductors, at any instant, will be zero (see Figure3).

A leakage of current to earth, from any conductor, will upset this balance. The magnetic field produced by the supply wires is changing with time, but the induced emf in the secondary winding is essentially zero because of the opposing current directions.

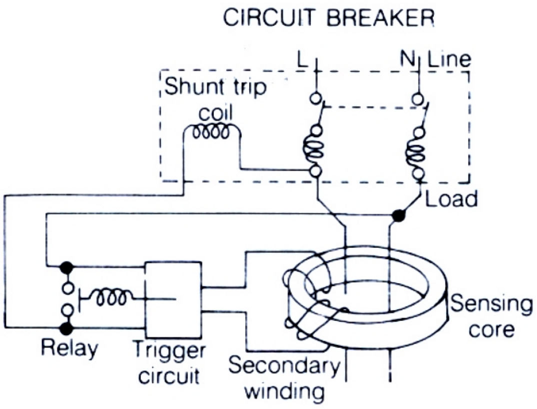

Fig. 2. Connections of a typical power dependent device.

However, if earth leakage currents occur on apparatus or wiring connected to the load side of the earth leakage protection device, one of the supply lines will carry less current than the other.

This asymmetry produces a net magnetic flux change in the sensing core which is picked up by the transformer action of the secondary winding and is proportional to the leakage current in the apparatus.

By means of the trigger circuit or the release in the secondary winding, the circuit breaker may be opened and the power shut off.

Physiological effects of electric shock

Earth leakage protection has been designed primarily for the protection of human beings using electrical apparatus. Throughout the world a considerable amount of experimental work has been carried out on the effect of electric current on the human body. It has been shown that the physiological effects of an electric shock depend on the magnitude of the electric current that flows through the body, the duration of that current and the path that it follows.

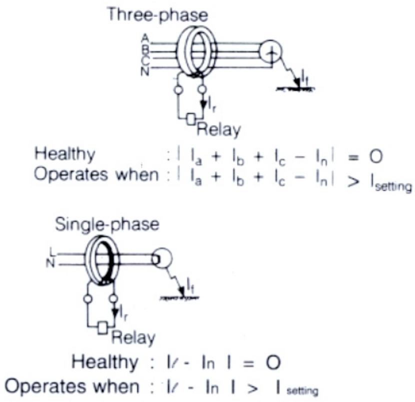

Fig. 3. Core balance earth leakage protection

Generally, the higher the current and the longer the duration of that current, the more serious the consequences.

The magnitude of the electric current that will flow through the human body under the influence of an electric shock, depends on the applied voltage and the electrical resistance of the current path through the body and other external resistances. The electrical resistance of the body is made up of the internal body resistance (which is low), the skin resistance (which is usually high but varies greatly from person to person), and the contact resistance (which depends on the type and pressure of contact, humidity and the state of the surface of the skin: sweaty, wet). The minimum value of overall body resistance for a current path between hand and foot is generally accepted as being roughly 500 Ω

The duration of electric shock depends on many external factors, but the longer the time, the more serious the consequences.

Current (m/A)		Effects on body (hand to hand path)
1	SAFETY ZONE	First sensation noticeable
2.5		Tingling on palms
5		First signs of cramp
7.5		Hands stiffening, 'let-go' still possible
1 0-1 5		Cramp increasing, limit of 'let-go'
25-30		Severe cramp extending to thoracic region: limit of safe current
30-50	DANGER ZONE	Blood pressure increasing: irregular heart operation
50-60		interference with respiratory system; loss of consciousness
60-75		Heart fibrillation

Table 1 . Physiological effects of an electric shock on the human body

The physiological effects of an electric shock on human beings (hand to hand path) are summarised in Table 1.

The physiological effects are also influenced by the path that the current takes through the human body. Currents flowing through the heart or through the lower part of the brain are particularly dangerous.

For example, a current of 200 mA hand to hand has the same effect as a current of 80 mA left hand to feet.

The physical condition of the person at the time of shock, such as the state of health (fitness, fatigue, worry), sex and age can also influence the physiological effects.

Consequently, the protection against electric shock offered by an earth leakage circuit breaker depends both on the current sensitivity level of the units and its disconnecting speed. In South Africa, SABS 767 ‘Standard Specification for Earth Leakage Protection Units’ specifies that the maximum nominal sensitivity should be 30 mA (tolerance of + 0 % - 50 %) and the maximum overall tripping time for differential currents greater than 60 mA should be less than 200 mS.

The time/current curve is shown in Figure 4. The aim is to prevent the possibility of heart fibrillation, as this is recognised as the major cause of fatalities. In choosing the sensitivity, it should be recognised that although it is desirable to have the lowest possible sensitivity to prevent injury, care must be taken to prevent unnecessary supply interruption due to normal leakage currents in electrical installations.

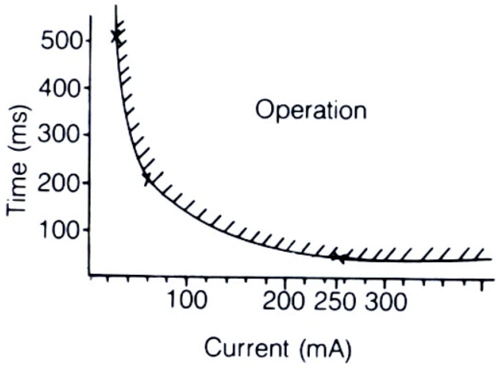

Fig. 4. Time/Current curve of earth leakage protection to SABS 767

Protection systems

Electric shock can result from direct contact with live conductors or indirectly by coming into contact with metal enclosures during short circuit conditions.

Direct contact

In situations where it is possible for a person to come into direct contact with live conductors, the full leakage current will flow through the body as shown in Figure **5(a). Typically this can occur when a faulty portable** appliance without an earth connection is used.

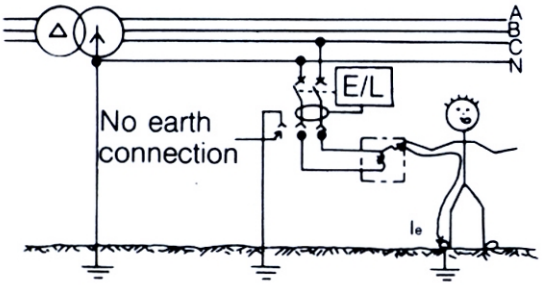

Fig 5 (a) Earth leakage protection for direct contact

Indirect contact

Another possible cause of electric shock is through indirect contact, where the voltage on exposed metalwork can rise above earth when a short circuit occurs between a phase and the metal enclosure as shown in Figure 5(b).

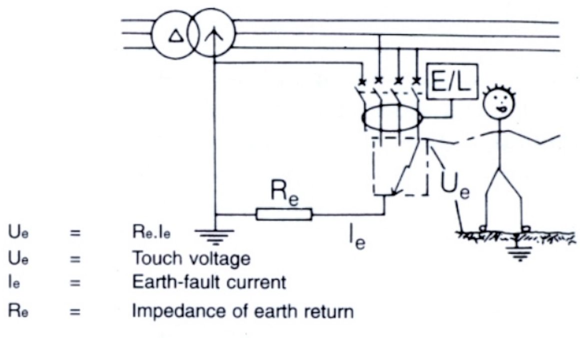

Fig. 5(b). Touch voltage for indirect contact

In this case it is not the actual fault current that flows through the person, but he is exposed to a voltage developed by the current flowing through the earth return impedance. This is commonly referred to as the ‘touch voltage’ and it is evident that its magnitude is dictated by the impedance of the earth return path.

On installations where the impedance of the earth return path (R_e) is low, the touch voltage will be low and it is sufficient to rely on the overcurrent protection to detect and interrupt the fault without danger to personnel. (This requires calculation or measurement of R_e to confirm the safety aspects).

When the earth return impedance is too high or when the integrity of the earth return path cannot be guaranteed, for the safety of personnel, it is necessary to use earth leakage protection of medium sensitivity to detect the earth fault condition. The values of touch voltages commonly accepted as safe are:

50 V in dry environments;
25 V in damp environments (for example, mines);
12 V in wet environments (for example, pumpstations).

The choice of sensitivity of earth leakage relays used for these applications depends on the impedance of the earth return path, the minimum earth fault current and maximum safe touch voltage acceptable for the application.

The sensitivity should always be chosen to be less than half the minimum earth fault current to ensure that the protection trips for all earth fault conditions. Once this has been decided, the maximum value of the touch voltage may be calculated. For touch voltages above the safe limit, it is essential that the earth leakage relay should trip the circuit as quickly as possible.

Limitations of earth leakage protection devices

The impressive track record of earth leakage protection devices in itself is a partial root of cohiplacency and the possible lack of respect for electricity and its potential hazards. Earth leakage circuit breakers are not a panacea, therefore common sense safety precautions should be taken i.e. to isolate circuits before undertaking electrical work. In recognition of this remark, the SABS Standard SABS 767 Part 1 includes the following Appendix ‘C’.

Appendix C Factors affecting the operation of an EL circuit breaker

C- 1 General

The use of an EL circuit breaker is a great asset in the prevention of accidents caused by earth leakage and inadvertent contact with live electrical apparatus. However, it must not be considered the ultimate in protection since there are several sets of circumstances under which the safety characteristics can become reduced or inoperative. For information the circumstances referred to are given below.

C-2 Circumstances of reduced safety or inoperation

a) Fault between line and neutral or two lines. An EL circuit breaker operates using a current transformer as a sensor for measuring current differences. If a fault occurs between two active conductors (line and neutral or two lines), the currents are balanced and cannot be detected by the current transformer. The EL circuit breaker will not trip.

b) Loss of neutral or one line of a three-phase supply. In some designs the supply to the amplifying/operating component is taken from the line and neutral of a single-phase system or between two lines of a three-phase system.

If the neutral or one of the connected lines of a three-phase circuit is broken, it is possible that, in the event of a leakage to earth from an apparatus or in the event of inadvertent contact, the EL circuit breaker will not trip.

c) Fault between earth and neutral:

1) This has the effect of bypassing some of the current which would normally flow through the EL circuit breaker neutral. The effect varies with the relative resistance of the earth fault; in some cases the switching-on of sound apparatus could cause tripping, and in other cases the EL circuit breaker will allow increased currents to flow before tripping.

2) In the event of a fault on the line side of an apparatus, the induced effect of the loop formed by the earth and neutral causes desensitisation of the EL circuit breaker, and allows currents in excess of the rated earth leakage tripping current to flow without the EL circuit breaker tripping.

d) A DC earth leakage component. The effect of a DC earth leakage component is to change the magnetisation characteristics of the iron core and thus the operating characteristics of the EL circuit breaker. The DC earth leakage components can be introduced into the system by apparatus using rectified AC power.

C-3 Nuisance tripping

EL circuit breakers in certain localities appear to suffer from nuisance tripping, i.e. tripping when there is no fault. There are various factors which can cause an EL circuit breaker to trip in this manner, for example, transients due to switching or lightning, capacitive currents due to long cables, or radio interference capacitors. If the nuisance is repetitive, steps must be taken to find and correct the cause, but the causes of isolated nuisance tripping incidents are difficult to diagnose and can usually only be endured.

It is interesting to note that many of the limitations of EL circuit breakers (as listed in Appendix C of SABS 767) have been addressed by some manufacturers.

The effect of these developments is that modern EL circuit breakers available in South Africa are:

- not affected by interruption of the neutral conductor;
- not affected by the loss of one phase in a three-phase system;
- not affected by DC fault components.

Developing areas

The rapidly changing socio-economic environment in South Africa has highlighted the need for the electrification of millions of homes in coming decades.

The severe limitations of monetary resource in achieving this end indicate a need for relaxation of certain standards in recognition of the deregulatory trend.

The climate of deregulation could spread to electrical installations, particularly where some users may be totally unfamiliar with either the advantages or hazards of electricity.

It is only a proven protection device such as the earth leakage circuit breaker that will facilitate such deregulation whilst at the same time providing the necessary protection against the hazards of electric shock and possible electrocution and fire that may result from deregulation.

Conclusion

Earth Leakage circuit breakers have presented the world with what has proven to be one of the most powerful tools in providing safe electricity to the masses.

In recognition, however, not only of human fallibility, but also possible maloperation resulting from misuse, environmental contamination or damage, it is essential that these devices be tested regularly.

The ‘Test button’ which is incorporated in all earth leakage circuit breakers is an effective way of conducting such a test. Users should be trained and encouraged to use this integral test facility on a regular basis to ensure the ongoing safe usage of electricity.

Further, if an earth leakage persistently trips, the reason should be determined as this is an indication of an abnormal and potentially dangerous situation.

NOSA recommends that the sensitivity of the earth leakage device be checked at regular intervals by means of a sensitivity device, that simulates a controlled earth fault, to ensure that it trips between 1 5 mA and 30 mA. These tests should be done on at least one socket on the grid protected by the earth leakage device.

Acknowledgement is made to the National Occupational Safety Association, Box 26434, Arcadia 0007 (Tel: 012-21-7736), which publishes NOSA data 2.22.01 : ‘Earth Leakage Circuit Breakers Use and Check’.

References

1. Technical article prepared for NOSA by Viv Cohen; Technical Manager, Circuit Breaker Industries

2. A guide to the application of moulded case circuit breakers for low voltage electrical installations by CBI and graphic material from CBI.

3. SABS Standard - SABS 767 - ‘Earth Leakage Protection Units Part 1 and 2

4. SABS 0142 ‘Code of Practice for the Wiring of Premises (Clause 4.5.4 (d) - Earth leakage protection in circuits supplying socket outlets)’.

5. MOSAct (6 of 1 983) Electrical Machinery Regs. 9 & 10.

6. The NOSA MBO 5 Star Safety & Health Management Systems.

7. NOSA data 2.23.01 ‘Electricity - Protection for Safety’.