RELIABLE PROTECTION OF THE LV DISTRIBUTION SYSTEM

with *PRECISION BREAKERS*

by Viv Cohen

Introduction

We live in a world that is becoming more and more acquainted with electronic or electronically controlled devices and systems. It may be prudent however, to acknowledge that, depending upon the application and the environment, certain advantages and benefits that are normally associated only with the more costly electronic solutions, can be achieved by using less sophisticated technologies.

Furthermore, the importance of good economic engineering design, whilst being a given, is regrettably not always fully appreciated or implemented. As a general rule, simple solutions usually result in the best and most economic solution. Such solutions are often found in some unexpected parts of the world.

This paper describes a method of achieving significant cost savings in low voltage electrical reticulation and distribution networks, through the judicious application of appropriate overcurrent protection components in these systems.

These overcurrent protection components have become known as *Precision Breakers*.

Protection in LV Distribution systems

Utility generated and distributed electricity is one of the cheapest, cleanest, most convenient and safest forms of energy. It is difficult however, for the average user of this energy to comprehend the power behind this energy in an uncontrolled form. Misapplication, misuse, or accident can unleash the frightening powers of uncontrolled electrical energy. Such uncontrolled release of electrical energy will invariably result in damage to both life and property through electrical shock hazard and fire hazard. Electrical fault currents fall into three main categories, including:

- Overload currents
- Short circuit currents
- Earth fault currents

The newsworthy nature related to the often spectacular or tragic results of electrical accidents in the form of fire or electrocution have resulted in a proliferation of technical articles or papers pertaining to the protection against short circuit currents and earth fault or shock hazard currents.

On the contrary, while much has been written about the components and technologies for protection against *overload current,* the specification requirements for overload current protection remain clouded in confusion and contradiction.

Overcurrent protection

One of the most extensively used and hence costly components in the low voltage network is the cable, which guides the electricity, from its point of generation to its point of application. It is for this reason that the cable is considered to be the component that requires and deserves the most attention when protection components are applied into an electrical distribution network.

The uncontrolled flow of electrical energy is generally the result of misapplication, misuse or accident and manifests itself in the form of electrical fault currents either in intended or unintended electrical circuits or paths.

The main parameter that is used by protection components to detect the fault and then protect the cable is the electrical current. Provided the current is contained within the capabilities of a particular cable, no damage to the cable or its insulation will result. In the event however, of the load current exceeding the cable rating, a potentially damaging or hazardous situation could arise. Protection components will detect overcurrents and cause the switching device associated with the protection component to open and interrupt the flow of electrical current. Overloading of electrical cables causes degradation of the insulation because of the thermal build-up at the interface between the conductor and the insulation. If this is not controlled, it can lead to a reduction of the service life of the cable, resulting eventually in a short circuit (with often spectacular results), when the insulation fails.

In electrical networks, the most common protection components used are moulded case circuit breakers and fuses. An obvious and practical requirement of the overload protection device is that it should be capable of holding at least 100% of its rated current continuously. For test purposes, National and International Standards generally require that the circuit breaker or fuse will only trip or open once it has held the conventional operating (or tripping) test current for a period of one to two hours (3 to 4 hours in the case of large fuses). The degree to which the cable would be protected can be determined by the minimum level of current that is required to trip the circuit breaker or blow the fuse, taking into account the limiting operating current level that is permitted by the relevant standard.

A recently published paper by this author [(1)] clearly demonstrated that the prospective "life expectancy" of electrical cables is critically dependant on the type of overcurrent protection device used and on the Standard to which the protection component is manufactured.

Overcurrent protection component technologies

The experience gained over the past several decades of highly effective application and usage, has shown that the preferred overcurrent protection device is the moulded case circuit breaker.

It is of interest to examine the technologies for achieving overload current sensing that have been incorporated into circuit breakers.[(2)] The overload current sensing means is usually achieved through the use of one of three different technologies which include:

- Thermal - magnetic sensing
- Magnetic - magnetic sensing (sometimes known as *PRECISION BREAKERS*)
- Solid state electronic sensing

Of these, due only to the global proliferation of manufacture of these devices, thermal - magnetic sensing is most common. This paper will however, identify both the known as well as the untapped benefits that can be realized through the use of magnetic - magnetic sensing breakers.

The expertise in the design and manufacture of magnetic - magnetic circuit breakers is restricted to only a few countries, with South Africa being the world leader in this field.

Thermal - Magnetic circuit breakers

The performance and operating characteristics of thermal - magnetic type circuit breakers are suitable and adequate for general circuit protection. As with other circuit breaker technologies and depending on the Standard to which those circuit breakers are manufactured, together with the relevant selection and application criteria, limitations in regard to their efficacy in the protection of cables have been identified. [1] These limitations are aggravated even further by the design restrictions that result from the inherent performance limitations of the bimetal component that constitutes the main overload sensing element of these devices.

<u>Magnetic - magnetic circuit breakers</u>

The pragmatic and economic advantages relating to the use of current sensing circuit breakers as opposed to thermal sensing circuit breakers in reticulation and distribution networks, has long been recognized by utilities and other sellers of electrical energy.

In addition to the temperature independent attributes of magnetic - magnetic circuit breakers, the design and construction of these devices is eminently suited to achieving application-specific operating characteristics.

A good understanding of the application requirements of magnetic - magnetic circuit breakers has resulted in the major South African manufacturer of these devices being able to produce standard, freely available circuit breakers, whose operating characteristics are ideally suited to cable protection in reticulation and distribution networks.

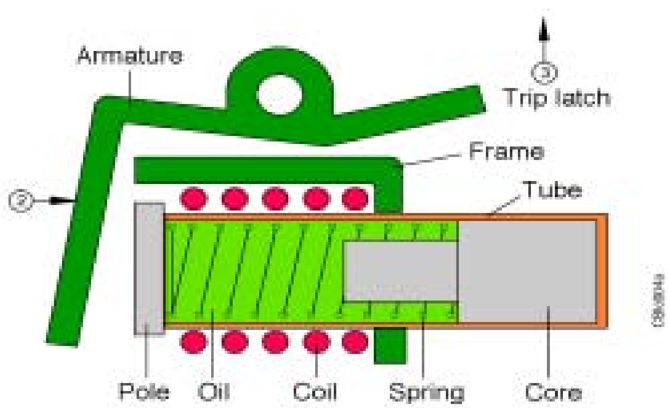
<u>PRECISION BREAKERS</u>

The technology used in the design and construction of magnetic-magnetic circuit breakers is not new, and has existed since 1934, being developed by Heinemann Electric in the USA. Over the years, these devices have been identified in various ways, including amongst others, the terms "Dual-Magnetic" and "Hydraulic-Magnetic". More recently however, in recognition of their superior capabilities of achieving highly accurate and repeatable application-specific operating characteristics, they have become known *as "Precision Breakers".*

The principle of operation of Precision Breakers is shown in the following series of diagrams, with the overload operation being shown in operating mode states 1 to 3, and the short-circuit operation shown in state 4.

Operating Mode - State 1

Precision Breakers operate on the magnetic force produced by the load current flowing through a series connected solenoid coil which is wound around a hermetically sealed tube comprising an iron core, a spring and a dampening fluid.

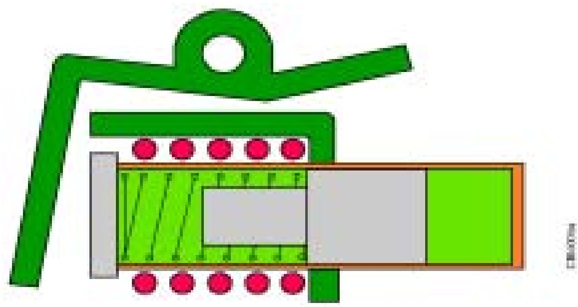


At currents below the circuit breaker rating, the magnetic flux in the solenoid is insufficient to attract the core towards the pole piece due to the spring pressure.

Where an overload occurs i.e. currents above the circuit breaker rating, the magnetic flux in the solenoid produces sufficient pull on the core to commence its movement toward the pole piece.

Operating Mode – State 2

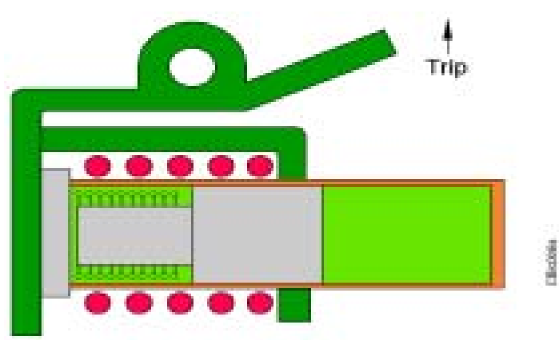
During this movement, the hydraulic fluid regulates the core's speed of travel, thereby creating a controlled time delay which is inversely proportional to the magnitude of the current. This time delay is useful in that if the overload is only of short duration i.e. start-up of motors etc., the core returns to its rest position once the overload disappears.



Operating Mode – State 3

If the overload persists, the core reaches the pole piece after a time delay particular to that current and in so doing, the reluctance of the magnetic circuit drops considerably, so that the armature is attracted to the pole face with sufficient force to collapse the latch mechanism (toggle) and consequently "trip" the breaker.

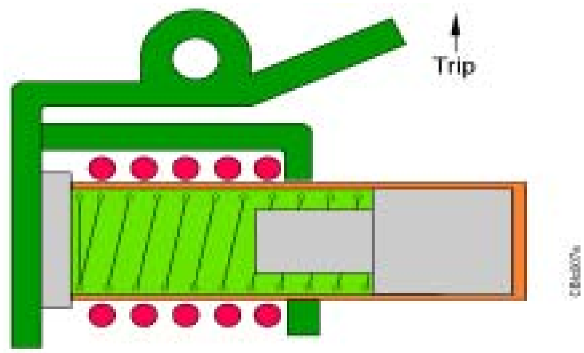
The contacts separate, current ceases to flow, and the core returns to the rest position.



Operating Mode – State 4 – Short-circuit condition

With high values of overloads or short circuit, the magnetic flux produced by the coil is sufficient to attract the armature to the pole face and trip the breaker even though the core has not moved. This is called the instantaneous trip region of the circuit breaker characteristic.

Unlike thermal circuit breakers, the hydraulic magnetic circuit breaker trip point is unaffected by ambient temperature. After tripping, the breaker may be re-closed immediately since there is no cooling down time necessary.



By the nature of the principle of operation, it is possible to obtain any variation of time/current characteristic.

Essential specification requirements

The arduous application environment found in low voltage reticulation and distribution applications, demands at the outset, certain minimum safety specification parameters to be satisfied for the protection components. This is particularly true for components such as circuit breakers, whose suitability or lack of suitability, for particular applications can easily be misinterpreted and misunderstood, mainly due to the proliferation of available specifications covering these devices.

One glaring example of this, is that some utilities have, possibly for reasons of cost, been tempted to install circuit breakers rated to IEC 60898 (7) in low voltage reticulation and distribution applications.

Such misapplication is known to exist, despite the fact that by definition, IEC 60898 circuit breakers are restricted to *“household and similar”* applications.

A fundamental difference that exists between IEC 60898 circuit breakers and circuit breakers that are manufactured in accordance with standards such as IEC 60947-2 (8) or SABS 156 (9) is that IEC 60898 permits clearance and creepage distances that are *as small as 3mm* and are applicable to *all critical live parts*.

The current edition of IEC 60898 does not include any impulse test voltage withstand requirements. Furthermore, as one consequence of the extremely small clearance and creepage distances permitted in IEC 60898, the draft technical revision of IEC 60898 (10) included only a limited impulse withstand voltage requirement of 4kV for installations rated up to 440V.

Extensive research in recent times re-affirms the rated impulse withstand requirements that are included in IEC 60364-4-443. [11] This latter standard states that for equipment used at the origin of an installation, overvoltage category IV is required. For 230/400V systems, the required impulse withstand voltage for overvoltage category IV is 6kV.

Only standards like IEC 60947-2, together with it's well advanced amendments, and it's derivatives, including the draft revision of South African Standard SABS 156, incorporate such mandatory impulse voltage test and marking requirements.

For all low voltage reticulation and distribution applications, in the interests of fundamental safety, and more particularly, in those regions of the world that are subject to high atmospheric lightning flash densities, only circuit breakers that have certified and marked ***" U_{imp} – 6kV "*** should be considered.

It is also essential that for these applications, documentation (preferably from an independent authority) is provided, confirming that the circuit breakers have been tested and certified at power frequency test and power frequency recovery voltages that are permitted according to the upper tolerance limits of the delivered voltage.

In increasing parts of the world, (including South Africa), and in accordance with IEC 60038, the upper tolerance limit of the delivered power frequency voltage is U_n +10%.

Electrical Protection of highway power supplies and street furniture.

Since safety requirements are generally covered by mandatory regulations, many electrical wiring codes do not always include specific provisions for the protection of highway power supplies and street furniture. One particular example that does include such specific provisions is the British IEE Wiring Regulations – Sixteenth Edition – BS 7671:1992. [4]

Although IEC 60364 [5] does not apply to public street lighting installations, the IEE Wiring Regulations are based on and derived from the fundamental safety rules of International Standard IEC 60364. A draft proposal for a technical revision of the South African Wiring Code [6] will introduce similar requirements.

In addition to the normal requirements pertaining to the overcurrent protection of cables, the IEE Wiring Regulations includes a requirement for protection against indirect contact shock hazard.

Protection against indirect contact is achieved by co-ordinating the characteristics of the protective device with the relevant circuit impedance and earthing arrangements, so that during an earth fault, the voltages between simultaneously accessible exposed conductive parts are of such a magnitude as not to cause danger.

For a phase to earth fault in earthed electrical distribution systems, commonly known as TN systems, this requirement is met where the following condition is fulfilled.

$$Z_s <= U_o / I_a$$

Where Z_s = earth fault loop impedance.
I_a = current causing automatic operation of protective device in a time <= 5 seconds.
U_o = nominal voltage to earth (230V).

A practical demonstration of the successful implementation of this approach was described in a recent paper [12] that included a description of a case study in Botswana [3], to determine the maximum practical cable length on the basis of three different controlling parameters viz:

- Maximum cable length based on available earth fault current.
- Maximum cable length as a function of maximum allowable voltage drop.
- Maximum cable length as a function of circuit breaker current rating.

That study used the following parameters which were based on cable data taken from BS 7671:1992 together with the IEE guidelines in regard to typical values for source impedance.

Maximum source earth fault loop impedance:	$Z_e = 0{,}5$ ohms.
Phase conductor:	10sq.mm. copper.
Earth conductor:	25sq.mm. bare copper earth wire.
Cable working temperature (light load)	50^oC

Since it was anticipated that voltage drop would be a deciding criterion, the cable selection of 10sq. mm. was chosen on the basis of being considered to be about the largest size cable that could be reasonably terminated in a pole access housing. The bare copper earth wire selection of 25sq. mm. was chosen as being the smallest size allowable for direct burial.

For the portion of the study that was based on the available earth fault current, it was first determined [4] that using the above phase and earth conductors, the average impedance at a working temperature of 50^oC, would be 2,82 milliohms per metre (Z_c).

The maximum value of the earth loop impedance at the point of fault can then be expressed as:

$$Z_s = Z_e + Z_c$$

(giving $Z_s = 0{,}5 + 2.82 * 10^{-3} * l_c$ for the above parameters.)

and since Z_s can also be expressed as $Z_s = U_o / I_f$

the cable length can be derived from the relationship $l_c = 10^3 / Z_c * (U_o/I_f - Z_e)$

where

l_c	=	cable length	(metres)
Z_c	=	cable impedance per metre	(ohms)
U_o	=	Nominal supply voltage	(230V)
Z_e	=	source impedance	(ohms)
I_f	=	Fault current required for 5 second disconnection	

The parameter I_f , which is the fault current required to result in circuit disconnection within 5 seconds, becomes the key factor in determining the maximum cable length l_c .

The value I_f can be further expanded into $I_f = x * I_{bkr}$

Where

I_{bkr} = circuit breaker ampere rating
x = multiple of breaker rating resulting in 5 second operation

From the above relationships, the maximum cable length as a function of the circuit breaker operating characteristic can be seen for circuit breakers rated at 10A, 15A and 20A in Figure 1.

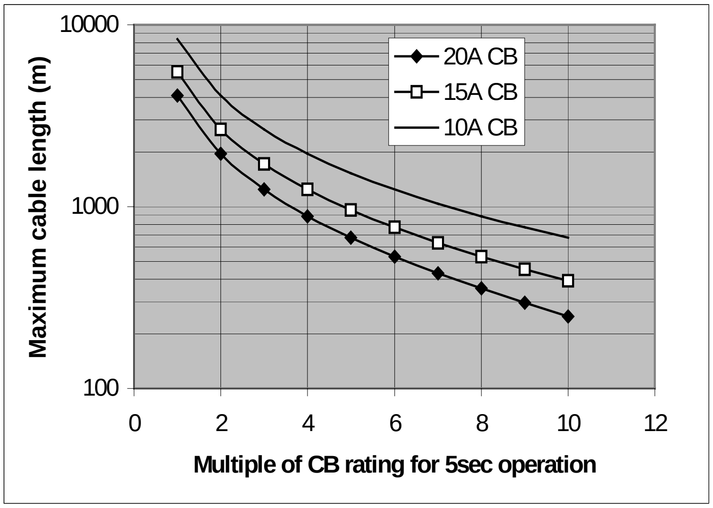


Figure 1

Examination of Figure 1 clearly shows that for any given circuit breaker rating, the limiting circuit length is critically dependent on the level of overload current together with the operating time of the circuit breaker. Since shock hazard protection in the event of indirect contact requires the circuit breaker to trip within a time period of 5 seconds, the limiting cable length will be reduced as the 5 second operating level of the circuit breaker increases.

The operating characteristics of standard magnetic - magnetic circuit breakers manufactured in South Africa are such that repeatable values of low level instantaneous tripping currents can easily be achieved. This can be used to advantage in achieving the 5 second operating requirement at 3 times rated current as shown in Table 5. The availability of circuit breakers having instantaneous tripping levels even lower than (3 * In) will result in further performance enhancement, especially in cases where fault resistance is encountered.

<u>Protection of Low Voltage Distribution circuits</u>

Electrical distribution utilities have recognized that a careful balance needs to be reached between ensuring the satisfaction of their customers (the users of electricity), and the protection of their distribution cables. From the users point of view, a continuing availability of a supply of electricity on demand is paramount. The utility needs to optimize their distribution network in order to meet the user demands, whilst keeping costs to a minimum and ensuring that the chosen fault protection will result in the maximum possible life of the installation.

Arising from the many decades of installation experience gained in South Africa, many electrical distribution utilities have recognized the importance of using *current* sensing overcurrent protection devices as opposed to thermal sensing devices. The reason for this is that users of electricity are generally charged on the basis of *kilowatts* used. Since the quality of the supply of electricity is always regulated, at least in regard to the *voltage* that is delivered.

It is sometimes claimed that thermal sensing overcurrent devices can provide superior protection, simply because their operation depends on the heating of a bimetal element. This assumption however, ignores the inherent inaccuracies that are fundamental to such devices.

On the other hand, current sensing circuit-breakers always hold 100% rated current independent of environmental factors such as ambient temperature and altitude i.e. no de-rating or up-rating.
Furthermore, these devices will always trip at a value not exceeding 130% of rated current, independent of ambient temperature

The precise operating characteristics of magnetic-magnetic circuit breakers together with the cost savings that can result from the increased circuit lengths that have been shown to be possible, make precision breakers ideal for the protection of both distribution and reticulation circuits.

Using Figure 1 as a guide, this indicates that the use of circuit breakers having time-current operating characteristics that are less accurate and less sensitive than those of Precision Breakers, would reduce the permissible feeder lengths.

It should be noted that solutions which provide protection against indirect contact, require that at least minimum levels of fault current as indicated need to be developed. Even though indirect contact protection is provided, such solutions cannot be considered as a replacement for 30mA sensitive earth leakage circuit breakers, which will provide both additional protection, as well as shock hazard protection in the event of direct contact.

Conclusions

The challenges that are often initiated by economic constraints have once again demonstrated that it is possible to maximize the latent benefits of existing technologies without having to resort to costly and largely untried solutions. Many decades of practical installation experience indicates that Precision type magnetic-magnetic circuit breakers, which are widely used and freely available in Southern Africa, are eminently suited to low voltage reticulation protection applications. In addition to meeting the arduous environmental requirements of such applications, cost savings have been achieved together with improved protection through significant increases in achievable line lengths.

References

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(3) *John Wilkinson - A.R. Edwards and Associates - Gaborone, Botswana*.

(4) *Requirements for Electrical Installations - BS 7671:1992*

(5) *Electrical Installations of Buildings - IEC 60364:1992*

(6) *Code of practice for the wiring of premises - SABS 0142:1993*

(7) *Circuit breakers for overcurrent protection for household and similar installations – IEC 60898:1995*

(8) *Low voltage switchgear and controlgear – Part 2 – Circuit breakers – IEC 60947-2:1995*

(9) *Moulded case circuit breakers - SABS 156*

(10) *Draft amendment 1 to IEC 60898:1995 – IEC document 23E/407/CDV*

(11) *Protection against overvoltages of atmospheric origin or due to switching - IEC 60364-4-443*

(12) *Overcurrent Protection in Long Lines*
- Viv Cohen and John Wilkinson – published in “Energize” – November/December 1999.