

## **MASTER BREAKER DEVICE FOR BACK-UP PROTECTION AGAINST ELECTRIC SHOCK IN EARTHED USER UNITS WITH MAINS VOLTAGE DEPENDENT RESIDUAL CURRENT TRIGGERING AND HIGH SELECTIVITY**

A main switchgear for back-up protection against electric shock in earth-protected consumer installations with residual-current tripping dependent on line voltage and high discrimination behavior

A main switchgear for fire protection in multiple-earthed consumer installations with residual-current tripping dependent on line voltage and high discrimination behavior is known (AT 412 830), comprising a neutral conductor which is guided through. This is advantageous in the case of protective multiple earthing (TN system according to IEC 60364) because the neutral conductor is always reliably earthed in this protective system and the distribution system is arranged in such a way that the risk is acceptable that the neutral conductor assumes fault voltages of more than 50 V in the case of mains faults in the form of earth faults of the outer conductors.

Since the fault protection is also ensured by excess-current circuit breakers in the case of protective multiple earthing, the discrimination required in practice in the case of faults by the series-switched excess-current circuit breakers is given due to the nominal current decreasing towards the ends of the electric circuits.

This is not the case in earth-protected consumer installations (TT systems according to IEC 60364) in which residual-current circuit breakers are installed centrally in the current distributions. If a fault occurs at any place in the installation, then the entire current distribution, which also includes the electric circuits without fault, is duct off by the associated residual-current circuit breakers.

An additional factor is that during thunderstorms there are frequent flashovers in the installations, leading to impulse currents or mains power-follow currents against earth which lead to false tripping in residual-current circuit breakers of the conventional kind, as a result of which the entire consumer installation is switched off.

In order to achieve discriminating behavior also with respect to residual-current circuit breakers of the conventional kind, the type S was standardized. Even in the case of higher residual currents of more than five times the value of the nominal residual current it has a minimum tripping time of over 0.05 sec or over 0.04 sec over 500 A, and thus remains discriminating in

the entire residual-current range conventionally used in practice with residual-current circuit breakers of the general kind which are switched in series (see Table 1).

But even the installation of a residual-current circuit breaker of type S only allows one discriminating stage and that is too little for larger distributions, e.g. when for a number of final circuits additional protection is required by residual-current circuit breakers with a nominal residual current  $I_{\Delta N} = 30 \text{ mA}$ .

The earthing resistances are often too low even in earth-protected consumer installations, e.g. in the ohmic range, and residual currents of a few ten to a few one hundred amperes may come to flow. They are cut off within fractions of seconds by instantaneous release of miniature circuit breakers (in literature they are often abbreviated as an m.c.b.) or by fuses. Residual-current circuit breakers of the general kind and also residual-current circuit breakers of type S often additionally and unnecessarily trip in such cases and thus unnecessarily limit the availability of power supply. This can be recognized by the trip values of residual-current circuit breakers.

Table 1: Maximum overall breaktimes and minimum tripping times of residual-current circuit breakers

| Type                                                                                                                                                                                                                                        | (3)                   | Residual current |                         |                         |      |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|------------------|-------------------------|-------------------------|------|
|                                                                                                                                                                                                                                             |                       | $I_{\Delta N}$   | $2 \times I_{\Delta N}$ | $5 \times I_{\Delta N}$ | 500A |
| General (1)                                                                                                                                                                                                                                 | Maximum breaktime (s) | 0.3              | 0.15                    | 0.04                    | 0.04 |
|                                                                                                                                                                                                                                             | Minimum breaktime (s) | 0.5              | 0.2                     | 0.15                    | 0.15 |
|                                                                                                                                                                                                                                             | Minimum breaktime (s) | 0.13             | 0.06                    | 0.05                    | 0.04 |
| (1) No minimum tripping time is demanded<br>(2) Only for $I_N \geq 25 \text{ A}$ and $I_{\Delta N} > 0.03 \text{ A}$<br>(3) The terms "tripping time" and "breaktime", i.e. the total breaktime here is defined in the switchgear standards |                       |                  |                         |                         |      |

In order to reach extensive discrimination with series-connected residual-current circuit breakers of the general kind and type S with excess-current circuit breakers for higher residual currents, it is possible, as in the main switchgear for the protection against fires caused by earth fault currents that is described in patent AT 412 830, to provide a minimum tripping time of 0.2 sec

for the main switchgear in accordance with the invention for the back-up protection against electric shock.

The term "back-up protection" is given a similar meaning as has been used for a long time in excess current protection. It means there a back-up fuse (mostly a fusible cutout) which protects a series-connected excess-current circuit breaker (mostly a miniature circuit breaker) when the short-circuit current is so high that it would destroy it. In back-up protection, the back-up fuse cuts off the short-circuit current before it can cause any damage, i.e. the series-connected circuit breaker would fail. In back-up protection against electric shock, a main switchgear is additionally installed in the TT system in a similar way which upon failure of the residual-current circuit breaker assumes the cut-off of the occurring fault current with acceptance risk for fault protection. A discrimination behavior of the main switchgears with the series-connected residual-current circuit breakers as well as the miniature circuit breakers to be protected is especially important because in fault-free operation it is the residual-current circuit breakers or the miniature circuit breakers and not the main switchgear that should cut off the defective party of the installation in the case of insulation faults. Notice must be taken in connection with miniature circuit breakers that the cut-off within 0.1 sec is demanded in the standards for testing instantaneous tripping. If ageing phenomena are considered after a prolonged period of installation, a minimum tripping time of 0.2 sec must be demanded for the line-side main switchgear in order to ensure the required discrimination. As a result, one thus simultaneously achieves a higher discrimination against series-connected fuses which are used only rarely nowadays however for the protection of final circuits.

As already explained, this also ensures full discrimination with the series-connected residual-current circuit breakers of all types. It is obvious that the reliability of the various protective devices becomes pre-eminently important in the protection against electric shock.

Since residual-current circuit breakers are electromechanical switchgears that are subject to high requirements concerning their tripping sensitivity, one must expect failures. They also occur in practice as has been seen by extensive checks in earth-protected consumer installations as described in literature. In actual fact, the currently marketed residual-current circuit breakers have failure rates  $\lambda$  of up to 1,000 fit, i.e. failure rates  $F$  in the percentage range, irrespective of whether they work with residual-current tripping independent or dependent upon line voltage, which failure rates are too high.

In this case, the main switchgear in accordance with the invention substantially increases the reliability of protection against electric shock. When installed at the entrance to distribution, it is

highly discriminating with series-connected residual-current circuit breakers of general design or type S. In the case of insulation faults in the protected consumer installation, one of the series-connected residual-current circuit breakers will cut off. If one of these switches fails however, there is a high risk of accident in the entire installation because high fault voltages occur in the entire consumer installation in an insulation fault in one of the electric circuits which are now unprotected as a result of the defective residual-current circuit breaker. If a main switchgear in accordance with the invention is installed centrally in the installation, this risk is eliminated by its cut-out. Since the main switchgear in accordance with the invention uses the principle of a residual-current circuit breaker of high tripping reliability according to EP 495 771 A2 and preferably its electronic modules are arranged in a separate functional chamber which allows a low operating temperature for the same as described in AT patent application A 928/2004, its failure rates  $\lambda$  are in the same magnitude as for miniature circuit breakers, which means that the series connection of the main switchgear with residual-current circuit breakers of general design or type S is not only highly discriminating, but also exceptionally reliable and thus allows for an acceptable accident risk for the protection against electric shock in earth-protected consumer installations.

It is thus necessary to determine the breaktimes of the main switchgear in accordance with the invention in such a way that from an electropathological standpoint they mean an acceptable risk for a hazardous electric shock. Longer times will naturally be agreed upon conventionally for back-up protection than for the usual fault protection.

Notice must be taken that in earth-protected consumer installations, fault voltages can occur in case of fault which can lie close to the mains voltage against earth, i.e. approximately 200 V.

Fig. 1 shows the time/current zones for acceptable and unacceptable risk of a hazardous shock Z1 (AC) and Z2 (AC) for alternating current with 50 Hz on a human being, as correspond to the latest level of knowledge in electropathology. Protective ranges 1 and 2 have been entered for touch currents and current paths from hand to hand (hand to foot) to both hands-torso (a person sits on the ground and holds a defective electric appliance with both hands). The limit is formed by the transitional area c-c'. In the case of touch voltage of 200 V it is found that a breaktime of the main switchgear of not more than 0.5 sec is still acceptable as a risk for a hazardous electric shock, with the boundary line c' for back-up protection in a TT system being determined conventionally as valid. If in the case of a dead short circuit to exposed conductive part there is a touch voltage of only 50 V, the breaktime can be limited with 1 second, although 50 V AC are permitted in international norms for an unlimited period of time. The total breaktime of the main switchgear of not more than 0.5 seconds must therefore be allocated to the touch voltage of 200

V and thus to dead short circuit to exposed conductive part in protective earthing under unfavorable conditions. If one demands this total breaktime  $t_g$  for a fault current  $I_F = 10 \times I_{\Delta N}$  (with  $I_{\Delta N}$  being the nominal fault current of the main switchgear), one obtains a calculation of the highest permissible earthing resistance  $R_A$  of the earth-protected consumer installation (TT system) of

$$R_A \leq \frac{230 \text{ V}}{10 \times I_{\Delta N}}$$

The following applies for the determination of the characteristics of the total breaktime  $t_g$  depending on the fault current:

As a result of the mechanical breaktime which remains virtually constant at fault currents over  $10 \times I_{\Delta N}$ , the characteristic only changes very little, even when the fault current has a few hundred amperes and can further be determined conventionally with not more than 0.5 sec. The total breaktime  $t_g$  goes to indefinite between  $0.5 \times I_{\Delta N}$  and  $1.0 \times I_{\Delta N}$ . If one determines the breaktime characteristic with the two points  $I_{\Delta N}$ , 5 sec and  $10 \times I_{\Delta N}$ , 0.5 sec with the intermediate value  $2 \times I_{\Delta N}$ , 1 sec, a breaktime characteristic according to Table 2 follows therefrom.

Table 2: Maximum total breaktime  $t_g$  and minimal tripping time  $t_a$  of the switchgear for back-up protection in accordance with the invention.

| Residual current                        | $I_{\Delta N}$ | $2 \times I_{\Delta N}$ | $10 \times I_{\Delta N}$ | 100 A | 500 A |
|-----------------------------------------|----------------|-------------------------|--------------------------|-------|-------|
| Total breaktime (max)<br>$t_g$ (s)      | 5              | 1                       | 0.5                      | 0.5   | 0.5   |
| Tripping time (min) $t_a$ (s)           | 0.2            | 0.2                     | 0.2                      | 0.2   | 0.2   |
| $I_{\Delta N}$ Nominal residual current |                |                         |                          |       |       |

The minimum tripping time is in the entire release area  $t_a = 0.2$  sec according to the statements made above.

The letter F is proposed for labeling the tripping characteristic of the main switchgear according to Table 2.

The earthing resistance  $R_A$  may not be more than  $230 \Omega$  for a main switchgear in accordance with the invention with  $I_{\Delta N} = 0.1$  A, and not more than  $77 \Omega$  at  $I_{\Delta N} = 0.3$  A. The values usually lie

under  $10\ \Omega$  in practice and thus cut-off usually occurs in less than 0.5 seconds by back-up protection in the case of insulation faults in earth-protected consumer installations when the series-connected residual-current circuit breakers fail, i.e. within a time frame which is smaller than the heart period of a human. This substantially reduces the risk of a hazardous electric shock.

The main switchgear in accordance with the invention is therefore a residual-current circuit breaker for the back-up protection against electric shock in earth-protected consumer installations with switched neutral conductor and a summation current transformer whose secondary winding is connected with an electronic storage and/or amplifier circuit which is non-dependent on the mains voltage and which actuates an electromechanical relay or a thyristor when the residual current exceeds a predetermined value. As a result, a latching mechanism is unlatched in a manner functionally dependent on the line voltage by an open-circuit shunt release and thus the opening of the outer conductor contacts and the neutral conductor contact is effected. In accordance with the invention, the electronic storage and/or amplifier circuit is dimensioned in such a way that irrespective of the level of the fault current the tripping time of the switchgear is always higher than 0.2 sec and the total breaktime is always smaller than 0.5 sec from  $10 \times I_{\Delta N}$ .

Fig. 2 shows the main switchgear in accordance with the invention, comprising the housing (1) which houses the contact apparatus for the outer conductor (2) and the neutral conductor (4), the latching mechanism (3), the conducting paths for the outer conductors L1, L2 and L3 and the neutral conductor N, the summation current transformer (5), an electronic storage and/or amplifier circuit (6) functionally independent on line voltage, an electromechanical relay or a thyristor (7) and an open-circuit shunt release (8). Both the conducting paths of the outer conductors L1, L2 and L3 as well as the current path of the neutral conductor N are interrupted during the cut-off of the main switchgear by the outer conductor contacts (2) and the neutral conductor contact (4).

Fig. 3 shows an example of the protective characteristics of the main switchgear in accordance with the invention with a nominal residual current  $I_{\Delta N1} = 0.3\text{ A}$  in series with a residual-current circuit breaker of type S with a nominal residual current  $I_{\Delta N2} = 0.1\text{ A}$  and a miniature circuit breaker, nominal current  $I_N = 16\text{ A}$ , characteristic B, with instantaneous tripping set between  $3 \times I_N$  and  $5 \times I_N$ .

Upon exceeding the operating limit of the instantaneous release of the miniature circuit breaker at approximately 60 A, the miniature circuit breaker cuts off with a total breaktime of

approximately  $t_g = 0.02$  sec. Its total breaktime lies beneath this number with the thermal releases in the second and minute range and beneath approximately 20 A it stays activated, as designated. When residual currents against earth are in the ampere range when there are no dead short circuits exposed to conductive parts for example and can be hazardous to cause fires, the miniature circuit breaker will be ineffective. Generally, the residual-current circuit breakers of general type or type S will cut out. Fig. 3 shows the cut-out characteristic of a residual-current circuit breaker of type S which cuts out according to Table 1 with  $I_{\Delta N2} = 0.1$  A at  $t_g = 0.5$  sec and whose total breaktime  $t_g$  at higher residual currents lie close to 0.2 sec for  $2 \times I_{\Delta N2} = 0.2$  A and 0.1 sec for  $5 \times I_{\Delta N2} = 0.5$  A, i.e. beneath 0.15 sec as demanded for  $5 \times I_{\Delta N2}$ . Its minimum tripping times  $t_{a2}$  are according to Table 1 0.13 sec for  $I_{\Delta N2}$  and 0.04 sec at 500 A. It is therefore selective at residual currents over approximately 80 A with series-connected miniature circuit breaker.

The main switchgear cuts out with  $I_{\Delta N1} = 0.3$  A at 5 sec, with  $2 \times I_{\Delta N1} = 0.6$  A under 1 sec and with  $10 \times I_{\Delta N1}$  or 100 A and 500 A under 0.5 sec. Its minimum tripping time  $t_{a1}$  is 0.2 sec in the entire range. It is therefore selective in the entire tripping range with the series-connected residual-current circuit breaker of type S and also with the miniature circuit breaker.

It can be seen that in the entire residual current range there is full selectivity between the main switchgear in accordance with the invention and the series-connected residual-current circuit breaker and the miniature circuit breaker, i.e. the miniature circuit breaker and or the residual-current circuit breaker of type S switch first and the main switchgear in accordance with the invention remains on. Only when the residual-current circuit breaker of type S (or any other series-connected residual-current circuit breaker) fails and only in the case of residual currents beneath the operating limit of the rapid release of the miniature circuit breaker will the main switchgear in accordance with the invention cut out the consumer installation and thus prevent the application of high and dangerous residual voltages.

The advantages of the solution in accordance with the invention is shown by way of example in the installation diagram of Fig. 4 with an earth-protected consumer installation with two sub-distributions. One sub-distribution uses a residual-current circuit breaker (2) of type S for fault protection, e.g. nominal current 40 A, nominal residual current  $I_{\Delta N} = 0.1$  A because selectivity with the final circuits for socket-outlets is demanded in which residual-current/miniature circuit breakers (4), nominal residual current  $I_{\Delta N0} = 0.03$  A for additional protection, are used. A part of these final circuits of said sub-distributions supplies the lighting circuits whose final circuits are protected only against overload with miniature circuit breakers (5). The second sub-distribution

for electric heating appliances for example is protected by a residual-current circuit breaker (3) of general design, e.g. with a nominal residual  $c_{uppevt} \Delta N1 = 0.1$  A, nominal current 40 A.

Without the main switchgear (1), the hazardous fault voltage would be present in the entire consumer installation in the case of failure of the residual-current circuit breakers (2) or (3) and an insulation fault in the final circuits which are only protected by miniature circuit breakers (5), without there being any cut-outs. The main switchgear in accordance with the invention, for the design of which the identifier [F] could be proposed in the standards, will then have the nominal residual current  $I_{\Delta N} = 0.3$  A, nominal current  $I_N = 63$  A. It will cut out in residual currents occurring in practice in earth-protected consumer installations in less than 0.5 sec when the residual-current circuits breakers (2) or (3) fail.

CLAIMS:

1. A main switchgear for back-up protection against electric shock in earth-protected consumer installations, comprising a housing (1), terminals for mains cables, a contact apparatus with associated latching mechanism (3) for the interruption of outer conductors L1, L2 and L3 (2) and a neutral conductor N (4), an open-circuit shunt release (8), a summation current transformer (5), an electronic storage and/or amplifier circuit (6) and an electromechanical relay or a thyristor (7), with the electronic storage and/or amplifier circuit (6) being connected with a secondary winding of the summation current transformer (5) and, once a residual current exceeds a predetermined value, actuating the open-circuit shunt release (8) via the electromechanical relay or the thyristor (7) dependent on line voltage, which open-circuit shut release unlatches the latching mechanism (3) and thus causes the opening of the contact apparatus, characterized in that the electronic storage and/or amplifier circuit (6) is dimensioned in such a way that irrespective of the level of the residual current the tripping time of the main switchgear is always higher than 0.2 sec and the total breaktime is always lower than 0.5 sec for residual currents over ten times the value of the nominal residual current.
2. A main switchgear according to claim 1, characterized in that the electronic storage and/or amplifier circuit (6) is functionally independent of line voltage.
3. A main switchgear according to claim 1 or 2, characterized in that the housing (1) comprises a first functional chamber and a second functional chamber which is thermally separated from the same.
4. A main switchgear according to claim 3, characterized in that at least the contact apparatus, the latching mechanism (3), the open-circuit shunt release (8) and the summation current transformer (5) are arranged in the first functional chamber.
5. A main switchgear according to claim 3 or 4, characterized in that at least the electronic storage and/or amplifier circuit (6) and the electromechanical relay or the thyristor (7) are arranged in the second functional chamber.