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Experimental analysis of assessing of the tripping effectiveness of miniature circuit breakers in an electrical installation fed from a synchronous generator set

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ABSTRACT

Due to the supply reliability concerns or to supply remote loads in some distribution networks, the synchronous generators are used as auxiliary power sources. In Poland the generators are usually connected to the network of TN (earthed neutral point) structures. Both TN-C and TN-S or their mixed arrangements TN-C-S are used. Overcurrent protection in these circuits, according to Polish and international standards and the recommendation of SEP (Association of Polish Electrical Engineers), should also act as anti-shock protection. The protection is considered to be effective (for 400 V electrical installations) if the overcurrent protection trip takes less than 0.4 s (maximum allowable time of touching voltage occurrence). The investigation performed by authors, showed that the producers of the generators usually use B or C characteristic circuit breakers and for large generator sets (greater than 100 kVA) they recommend load split to the value of one fifth of the generator maximum power. Additionally, the most frequently excitation forcing equipment is mounted to keep short circuit current three times greater than nominal current of the generator. To assess the effectiveness of the anti-shock protection measures in circuits fed from auxiliary generator and for current lower than 32 A, the set up including a self-exiting 5.5 kVA and 400 V generator, overcurrent protection and load was built in laboratory. The set up uses miniature circuit breakers and enables short circuits in different instants, compared to the initial phase angle of the generator voltage.

Results: of the performed short circuits showed, that for the self-excited generators (majority of small generator sets with stator current lower than 32 A) the overcurrent protection cannot act as anti-shock protection, when breakers allowing full utilisation of the generator power. The alternative is to limit generator load or to introduce excitation forcing increasing device price. The proposed solution for these generators given by authors is to modify anti-shock protection system in such way, that the tripping occurs always in the time below 0.4 s. Modifications include not only introduction of the measurements of currents, but also the measurements of the generator voltage. The short circuit is indicated not only by current increase, but also by voltage drop during short circuit.

Experimental: device utilizing both measurements was build and tested for different initial short-circuit instants, with respect to the synchronous generator phase voltages. In every case, the switch-off time of the short circuit was not longer than 0.4 s, what means that the protection against the risk of electric shock was effective. The settings of the device are fully adjustable, what means that levels of the measured quantities indicating trip as well as the reaction time are adjustable.

1. Introduction

Protection measures against electric shock in low-voltage TN-connected supply systems are described in many publications [1–12]. Installations employing generating sets for backup power must meet the requirements regarding electric shock prevention in the same way as grid-powered installations [2,3,5,7,9–12]. Protection against electric shock via automatic power supply switch-off imposes a permissible time (for switching off) in the case of insula-

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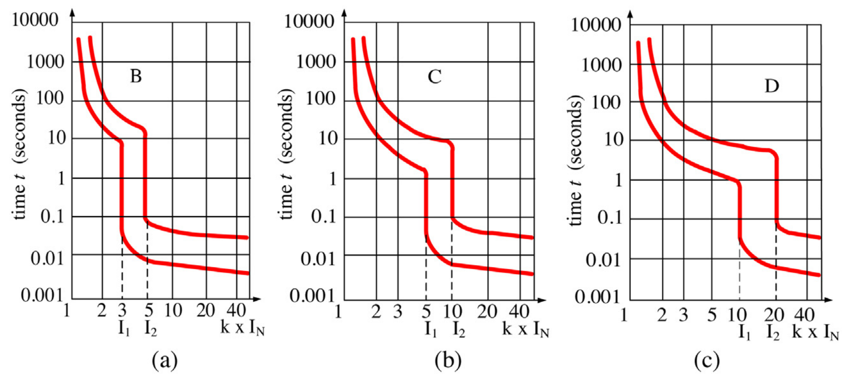

Fig. 1. Time–current curves of miniature circuit breakers a) type B, b) type C, c) type D.

tion fault. In the case of short-circuit in TN systems at the 230/400 V level, for overcurrent protection and working currents ≤32 A and for residual current devices (RCDs), the maximum switch-off time is set to 0.4 s [5]. In TN systems with a separate earthing conductor (PE), protection against electric shock is most often realized through residual current devices (RCDs) and fuses or miniature circuit breakers (MCBs) [8–18]; when a separate PE conductor is not available, the protection is based only on overcurrent devices. TN systems ensure a negligibly small risk of electric shock if the short-circuit impedance of the PE conductor Z_{PE} or PEN conductor Z_{PEN} (PEN is a conductor that combines the functions of both a PE conductor and an N conductor) is small enough and the touch voltage U_t (as the drop voltage on the impedance of the Z_{PE} or Z_{PEN} conductors) does not exceed the permissible value $U_t = 50$ V [1,5]:

$$Z_{PE} = Z_{PEN} \leq \frac{U_t}{I_k} \tag{1}$$

where I_k is the current flowing via the PE or PEN conductor.

In the case of fuse-based overcurrent protection, Joule's integral (which is the sum of a pre-arc thermal integral calculated from $t = 0$ to $t = t_p$ and the arc thermal integral calculated from $t = t_p$ to $t = t_0$) is the crucial factor determining the tripping of the fuse under fault conditions [13]:

$$I^2t = \int_0^{t_P} i_k^2 dt + \int_{t_P}^{t_O} i_k^2 dt \tag{2}$$

where t_O is the operating time, t_p is the pre-arcing time (the thermal pre-arcing integral usually acting on the narrowing of a fuse link), and $(t_O - t_p = t_a)$ is the arcing time.

From expression (2), the thermal equivalent current I_{th} is frequently calculated [13,14] as follows:

$$I_{th} = \sqrt{\frac{I^2t}{t_w}} \tag{3}$$

where t_w is the duration of the thermal equivalent current.

For a fuse, the Joule integral (2) is given in the catalogues by individual producers [15]. The response time of a fuse is determined by its time–current characteristics [15]. This time is dependent on equivalent short-circuit current I_{th} (3). The tripping condition of an MCB in the shorted circuit assumes that the RMS value of the short-circuit current does not reach values smaller than that of the assumed equivalent tripping current of the short-circuit release. It is very difficult to assess the tripping effectiveness of an MCB in electrical installations fed from low-power synchronous generator sets, up to several kVA, while considering the breaker's time–current characteristics owing to relatively low values of short-circuit currents and high contents of transients in short-circuit currents. In these electrical installations, the only reliable method to assess the tripping effectiveness of MCBs is the experimental one. The practical choice of the nominal current for the circuit breaker is most commonly derived from the single-phase I_{N1ph} or three-phase I_{N3ph} rated current of the synchronous generator and the character of the load (most commonly R, RL or motor). Depending on the load characteristics, circuit breakers are chosen based on B, C or D time–current characteristics (see Fig. 1). Table 1 presents the tripping times of miniature circuit breakers of B, C or D time–current characteristics in relation to the k-ratio of the short-circuit current $I_k = kI_N$ (where I_N is the rated current) [16–18].

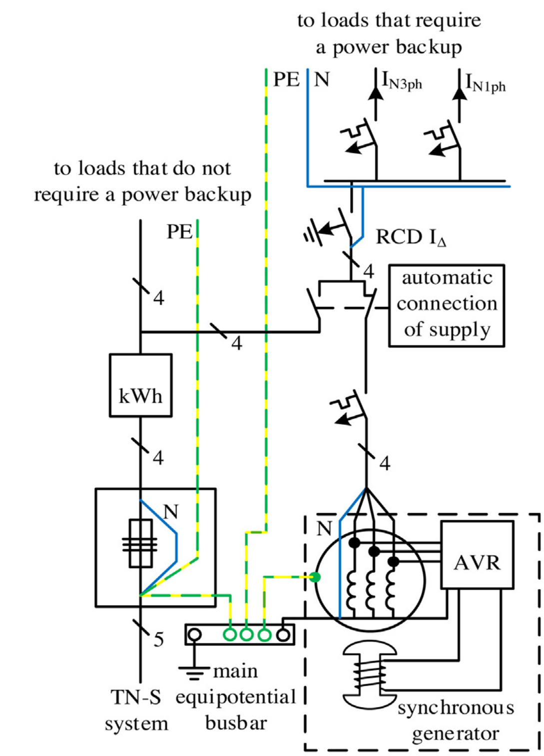

Fig. 2. An example of a power protection variant in TN-S system and synchronous generating set working as a backup power supply.

Tripping times of miniature circuit breakers in relation to B, C or D characteristics are current dependent, thus to achieve fast enough switching off times the value of short circuit current has to have large values for a certain time. Minimal values of the currents required to achieve a breaker with a known characteristic to trip in time below 0.1 s are stated in the IEC standards [17,18]. For a tripping time 0.4 s, the thermal equivalent current can be estimated from characteristics (Fig. 1) or determined during the experiment.

In a low-voltage electrical installation, the stability of the power source (of the electrical power system) is, by definition, the essence