Artur HEJDUK
Henryk SIBILSKI
Andrzej DZIERŻYŃSKI
Janusz KURASZKIEWICZ
Krzysztof KRASUSKI
Rafał GRZEGORZEWSKI

NEW ULTRA-FAST EARTING SWITCH FOR MV SWITCHGEAR

ABSTRACT *The appearance of the short circuit current inside of MV switchgear is the most serious fault associated with generation of high temperature and pressure as well as emission of gazes produced by the electric arc and melted elements inside of the switchgear. The ultra-fast earthing switch (UFES) developed by the authors will be able to reduce the above mentioned effects due to direct grounding of the three phases current caring bars. The operation time of the UFES should be as short as possible to reduce the arc energy dissipated inside of the switchgear. Therefore, a prototype of the UFES was built in the Electrotechnical Institute laboratory and was experimentally validated. The UFES developed in the Electrotechnical Institute for 24 kV with the required operating time of about 2 ms can be used several times with no need to replace any of its parts. It is ecological, environmentally friendly and is safe for the staff working nearby. In the UFES, the most important elements used are the ultra-fast actuator and the vacuum chamber as a switching element, therefore the UFES can operate many times without necessity to replace any of its parts. This is the greatest advantage of this solution. The earthing switches produced presently have the operating time of about 2 ms, but the contacts are actuated by means of exploding materials, therefore after operation the switch has to be replaced with a new one.*

Keywords: *MV switchgear, ultra-fast earthing switch, Thompson coils*
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Artur HEJDUK, M.Sc.[1)], Henryk SIBILSKI, Ph.D., D.Sc.[1)], Prof., Andrzej DZIERŻYŃSKI, Ph.D.[1)], Janusz KURASZKIEWICZ, M.Sc.[1)], Krzysztof KRASUSKI, Ph.D.[1)], Rafał GRZEGORZEWSKI, M.Sc.[2)]
[1)] e-mail: [a.hejduk; h.sibilski; a.dzierzynski; j.kuraszkiewicz; k.krasuski]@iel.waw.pl
[2)] e-mail: grzegorzewski@energotechnika.com
[1)] Electrotechnical Institute, M. Pożaryskiego 28, 04-703 Warsaw, Poland
[2)] ENERGOTECHNIKA, Chełmżyńska 29, 04-247 Warszawa, Poland

1. INTRODUCTION

In the case of a fault current in the switchgear, the circuit breaker has to interrupt the short circuit current, and to protect the equipment installed inside and in the neighbourhood and the personnel working there. However, the operating time of the circuit breaker (CB) is too long (some tenth of millisecond) and is not able to reduce the expansion of arc current inside the switchgear and to reduce the resulting damages [1]. During the CB operating time the arc inside the switchgear, which is followed by the expansion of poisonous gases (created with the decomposition of the materials used inside) are a serious threat to the people working in the vicinity of the switchgear, and for the environment. As it is known, the switchgears are often installed in residential buildings, in streets, sometimes even close to the recreation centres.

2. THE ULTRA-FAST EARTCHING SWITCH FOR MULTIPLE OPERATIONS

The new type of the UFES is original. Its model was developed and tested in the Electrotechnical Institute [2]. The operating time (from the time of tripping to contacts closure) is about 2 ms. After making operation, the short-circuit current inside the switchgear is extinguished and is bypassed by the UFES. During such a short time damages inside the switchgear are negligible, and after review can still be used. Circuit breaker finally interrupts the short circuit current. After that UFES can externally be opened by electromagnet actuator.

The UFES developed in the Electrotechnical Institute is ecological, environmentally friendly and safe in use and does not pose a threat to the services. Important is that it can be used several time without the necessity to exchange any part and after operation is still able to be used again. The ultra-fast earthing switches produced at present [2] have to be replaced with new ones after operation. The cost of them is rather high.

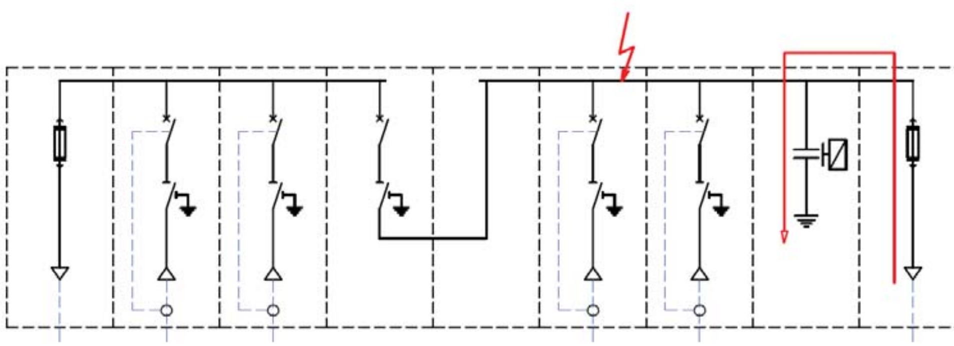


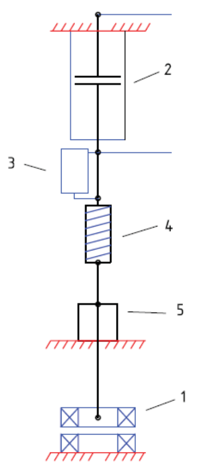
Fig. 1. UFES protects MV switchgears with lower short circuit withstand

3. BLOCK DIAGRAM OF THE MODEL ULTRA-FAST EARTHING SWITCH

The UFES includes a vacuum chamber mounted in the housing, wherein the movable contact is connected via contact spring with the actuator. The movable contact of the vacuum chamber is driven by the ultra-fast drive mechanism based on electromagnet Thompson coils. The two coils are connected in series in opposite direction. During discharge of a capacitor the impulse current flows across both coils (see Fig. 2a). The impulse current produces required axial forces to repel the armature.

Action of the UFES is as follows. When the rate of rise of the short circuit current inside of the switchgear exceeds the admissible value, an electronic control system generates impulse to discharge a previously charged capacitor across the repulsion coils with a high current. As a result, it creates a significant driving force that acts on the movable contact of the vacuum chamber and causes a very fast contact closure, bypassing the arc in the switchgear. The vacuum chamber contacts, just before the end of movement, are rapidly decelerated so the contact closure velocity does not exceed the assigned value. The reduction of contact velocity protects the contacts of the vacuum chamber from deformations and bouncing. Finally, the electrical arc in MV switchgear is bypassed through the UFES.

a)



b)

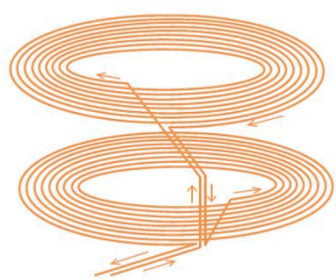


Fig 2. a) The schematic diagram of the high voltage UFES with vacuum chamber and with ultra-fast actuator, b) Connections of the two coils of the actuator [3];
1 – coils, 2 – vacuum chamber, 3 – mechanical brake, 4 – contact spring, 5 – blockade at the open and closed position

TABELA 1
Proposed parameters of the new UFES

Rated voltage	24 kV
Rated making current	65 kA
Mechanical life	100 times
Rated operations of short-circuit breaking current interruption	50 times
Rated power frequency withstand voltage (1 min.)	60 kV
Rated lighting withstand voltage 1.2/50 μs	110 kV

The electromagnetic actuator with the electronic control system is located in the lower part of the UFES.

4. CALCULATION AND MODELING OF THE ACTUATOR FOR UFES

With application of the FEM computer program the magnetic field distribution between electromagnet coils has been investigated. Both coils of twelve turns were wound with copper wire 6 x 1.5 mm and insulation of 1 mm between turns. The discharge current was supplied from a capacitor. Figures 3a, b, c, d show, that with the increase in time and distance between coils the magnetic field distribution also changes, and moves more to the centre of the coils and reduces its intensity.

The extreme acceleration results in high stresses that can deform the armature before repelling it away. Upon the discharge of the capacitor bank, the current pulse reaches its peak after 2 ms, that is in much shorter time than the contacts of the vacuum chamber can be closed. This effect plays an important role in the selection of the energy source, i.e., its capacitance, inductance and resistance of the circuit (Fig. 3).

For calculations, a model shown in Figure 4 was assumed as below.

The contact movement can be divided into following phases:

1) armature mass m_0 acceleration by impulse force F_3, presses the spring k_1;
2) pushing the moving contact mass m_1 by the actuator mass m_0 and force F_1 of spring k_1;
3) free movement of the moving contact mass m_1 until the extremity of spring k_2 touches brake mass m_2;
4) breaking the velocity of the moving contact mass m_1 due to action of spring k_2;
5) continuous actuator movement until latching in the closed position;
6) contact closing with minimum bouncing.

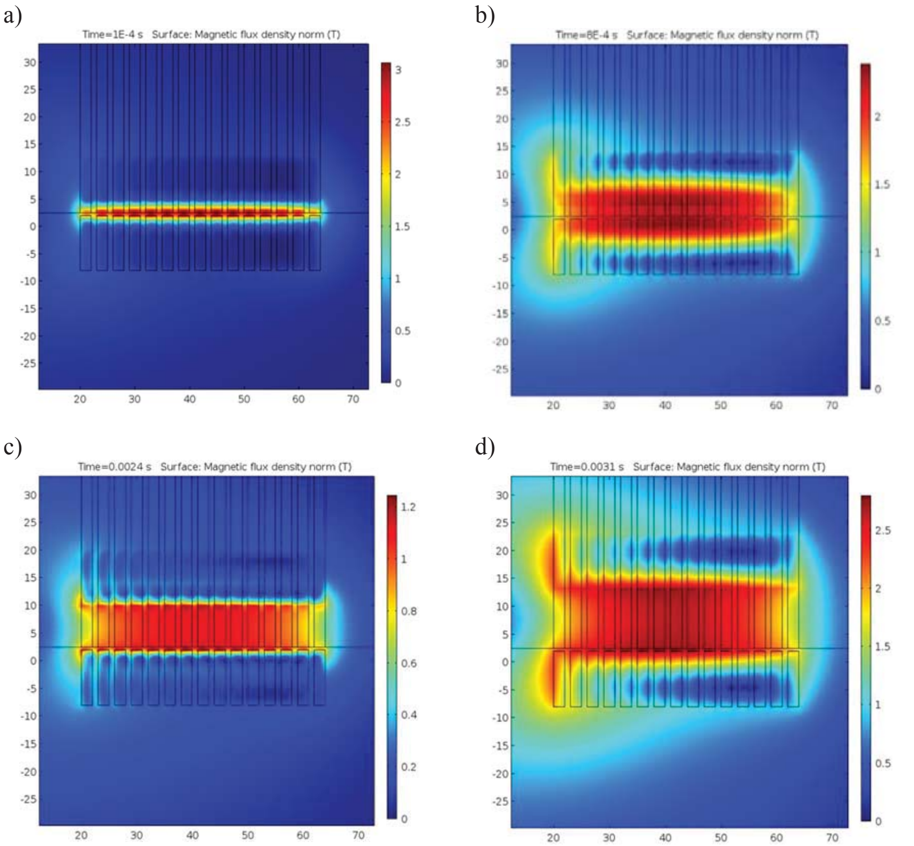


Fig. 3. Magnetic flux density distribution between actuator coils
after a) 0.1 ms b) 0.8 ms c) 2.4 ms d) 3.1 ms

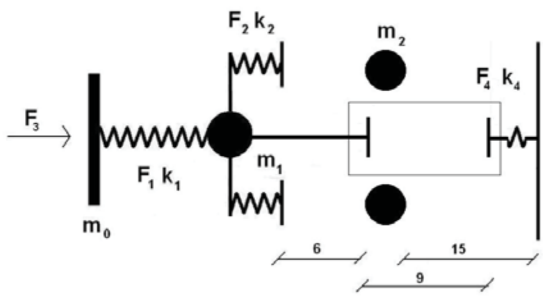


Fig. 4. Model diagram of the actuator

m_0 – mass of actuator, m_1 – mass of the contact, F_1 k_1 – force of the contacts spring, m_2 – mass of the braking system, F_2 k_2 – elasticity of the breaking system, F_4 k_4 – elasticity of the stationary contact, F_3 – actuator force

Mathematical analysis of the actuator movement is presented below.

Contact spring characteristic:

$$F_1 = \begin{cases} F_{10p}\varepsilon_1 + k_{1p}(h_{10} - h_1) & for\ h_1 < h_{10} \\ k_{1m}(h_{10} - h_1) & for\ h_1 \geq h_{10} \end{cases} \quad \text{where} \quad \varepsilon_1 = \frac{tan^{-1}\left(\frac{h_{10} - h_1}{\delta_1}\right)}{\frac{\pi}{2}} \tag{1}$$

Brake spring characteristic:

$$F_2 = \begin{cases} 0 & \text{for } x_2 \geq x_1 \\ k_2(x_2 - x_1) & \text{for } x_2 < x_1 \end{cases} \tag{2}$$

The following ordinary differential equations describe the actuator movement:

$$\frac{dx_0}{dt} = V_0 \tag{3}$$

$$\frac{dV_0}{dt} = \frac{-F_1}{m_0} \tag{4}$$

$$\frac{dx_1}{dt} = V_1 \tag{5}$$

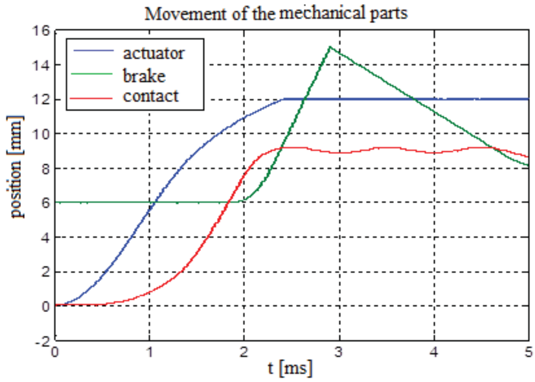
$$\frac{dV_1}{dt} = \frac{F_1 - F_2 - F_4}{m_1} \tag{6}$$

$$\frac{dx_2}{dt} = V_2 \tag{7}$$

$$\frac{dV_2}{dt} = \frac{F_2}{m_0} \tag{8}$$

and the zero initial conditions and supplemental conditions:

actuator latching condition: for $x0 \geq 12$ mm $V_0 = 0$
end of brake mass movement condition: for $x2 \geq 15$ mm $V_2 = -0{,}9\ V_2$



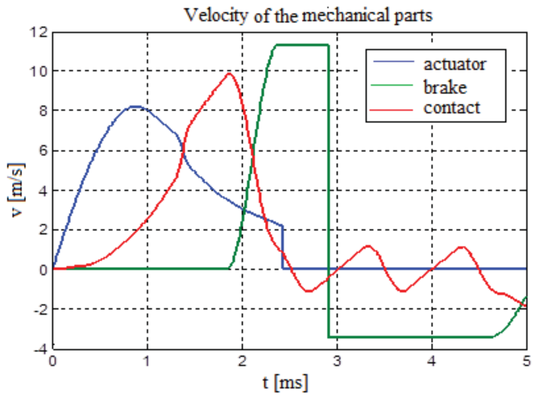


Fig. 5. Calculated results of UFES mechanism operation: blue line - the actuator movement

During making operation (Fig. 5) the movement of the actuator (blue line) is rapidly braked just before the contact closing. The brake (green line) reduces the contact velocity to eliminate the contact deformation and bouncing. The red line indicates the contact movement.

5. SUMMARY

The idea of the UFES developed at the Electrical Institute was presented. The apparatus can bypass the short-circuit current several times without any part replacement and maintenance. The UFES designed enables to extinguish the electric arc due to short-circuit inside of the high voltage switchgear and in this way protect it against destruction. The circuit breaker receives the time necessary to interrupt the short-circuit.

In the next paper, the second part of investigations (measurements and test results) will be presented.

LITERATURE

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NOWY ULTRA SZYBKI UZIEMNIK PRĄDU DLA ROZDZIELNIC SN

Artur HEJDUK, Henryk SIBILSKI, Andrzej DZIERŻYŃSKI,
Janusz KURASZKIEWICZ Krzysztof KRASUSKI,
Rafał GRZEGORZEWSKI

STRESZCZENIE *W artykule przedstawiono rozwiązanie ultra-szybkiego uziemnika prądu zwarciowego ograniczającego skutki zwarcia i palącego się łuku w rozdzielnicy poprzez uziemienie trzech faz szyn zbiorczych. Uziemnik zaprojektowano na napięcie 24 kV, jego czas działania wynosi około 2 ms. Zaletą nowo opracowanej konstrukcji jest możliwość wielokrotnego działania bez konieczności wymiany po zadziałaniu jak w przypadku uziemnika pirotechnicznego.*

Słowa kluczowe: *rozdzielnica SN, ultra-szybki uziemnik prądu, cewki Thomsona*