REGARDING TO THE CONTROLLED CLOSING OF THE CIRCUIT BREAKERS

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Abstract – **The controlled switching of the circuit breakers follows the minimisation of the transient stresses (overvoltages, overcurents) which appears at switching process. In the paper, after a presentation of the principles for the controlled closing and opening of the circuit breakers, its are showed the aspects regarding the controlled closing of them. The contributions it refers to the influences of: the rate of decrease of dielectric strength of the space between contacts, the target instants of contacts touching and the mechanical dispersion of the operating time to the pre-arcing time, respective of the strike voltage at closing. Its are done specifications about the target moments of mechanical touching of the contacts in function of RDDS and admissible maximum mechanical dispersion in the case of controlled closing.**

Keywords: *circuit breakers, controlled switching, controlled closing, rate of decrease of dielectric strength (RDDS), pre-arcing time.*

1. INTRODUCTION

The controlled switching of the circuit breakers follows the minimisation of the transient stresses (overvoltages, overcurents) which appears at switching process.

The controlled switching is the term used regularly to describe the using of some control electronic equipment which follows to realise the circuit-breakers opening and closing to be done into an established moment in relation with an electric signal of reference (voltage, current).

The efficient reduction of the transient's effects can be realised if the mechanical operating time is constant and if the dispersion of separation, respective closing of the circuit breakers contacts is small.

To realise the control of mechanical operating time, the synchronous switching means the usage of single-phase acting devices. Three-phase circuit breaker, which operates with unique acting mechanism, can't be used anytime for synchronised operations. The mechanical interconnections between phases is set and can't be adjusted to acts them at adequate moments, [1]. However, the standard circuit breakers, specially designed with a mechanical difference between phases, have been developed and are in exploitation.

The dispersion of operating time is influenced by the some parameters as: lower ambient temperature; charged energy in the acting mechanism; the precision of releasers and of electro-valves in function of operative voltage; the effect of mechanical hysteresis of the contacts system; the contacts erosion; the pre-arcing; the Rate of Decrease of Dielectric Strength (RDDS) of the space between contacts etc, [1]. The influence of these parameters, which can leads at big errors, can be taken in consideration by an intelligent electronic device which will realises an adaptive command of circuit breakers, [4].

2. PRINCIPLES OF THE CONTROLLED SWITCHING

The controlled closing is realised through the monitoring of the supply voltage. In Fig. 1 is shown a closing sequence corresponding to an inductive load. The closing command (curve no. 1) is given random, at a certain moment t_{com}, in comparison with the reference signal (voltage). This command is repeated (curve no. 2) by the synchronous device with a certain delay. The total delay T_{total} introduced by the controller can be written as a sum of the waiting time and the synchronizing time, [3]:

$$T_{total} = T_w + T_{syn} . \quad (1)$$

After a certain waiting time T_w which can be used by the controller for internal calculus, the expected delay for synchronisation T_{syn} is given with the relation:

$$T_{syn} = N\frac{T}{2} - T_m - \left(T_{close} - T_{prearc}\right) = N\frac{T}{2} - T_m - T_{make} . \quad (2)$$

The mechanical closing time T_{close} is the time between the moment of turn-on closing coil of the circuit breaker and the moment of mechanical touching of the contacts (curve no 3). The pre-arcing time T_{prearc} corresponds to the time between the moment of electric arc's strike (t_{make}) and moment of mechanical touching of the contacts. The making time T_{make} is the time between the turn-on of closing coil and t_{make}. The time corresponding to T_m is defined in concordance with t_{make} and the next moment of zero-crossing of monitored voltage. The time $NT/2$ corresponds to an

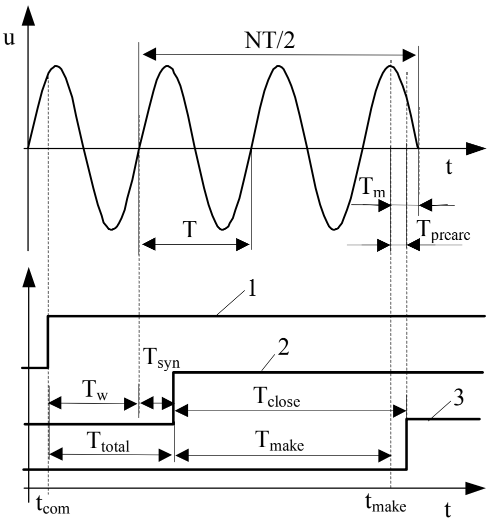

Figure 1: The closing sequence.

integer number half cycles, this size being imposed by the condition as the time T_{syn} to be positive.

The controlled opening follows as the separation of each phase of circuit breaker it realises in concordance with the phase angle of the current. In this way are controlled the arc times on each phase with the purpose to minimise the stresses of network elements.

The sequence of opening times is given in Fig. 2. The initial opening command (curve no. 1) is random created in concordance with the phase angle of the reference signal at a moment t_{com}. This command is repeated (curve no. 2) by the synchronous device with a certain delay. As in the previous case, the total delay T_{total} introduced by the controller can be written as a sum of the waiting time and of the synchronizing time. The deliberated delay for synchronisation T_{syn} is determined in concordance with the opening time T_{open} and with the moment of contacts separation (t_{sep}):

$$T_{syn} = N\frac{T}{2} - T_{open} - T_{arc} \tag{3}$$

The moment of contacts separation, t_{sep}, is in relation with the following zero-crossing of the current when will appear the electric arc extinction. Thus, through the precise control of the moment t_{sep} (curve no. 3) it defines effectively the arc time. The mechanical opening time T_{open} is the time between the moment of turn-on opening coil of the circuit breaker and the moment of contacts separation. The time $NT/2$ corresponds to an integer number of half cycles, this size being imposed by the condition as $T_{syn}>0$.

In some applications, for example the opening of compensated lines, the wave shape of the current is strongly disturbed and an integer multiple of half cycles can't be used. In these cases, the real zero-crossing moments must be determined leaving from the wave shape monitored by the controller.

The variation of parameters, as: the operating times, the pre-strike characteristics of the circuit breakers and $NT/2$, must be taken in consideration by the

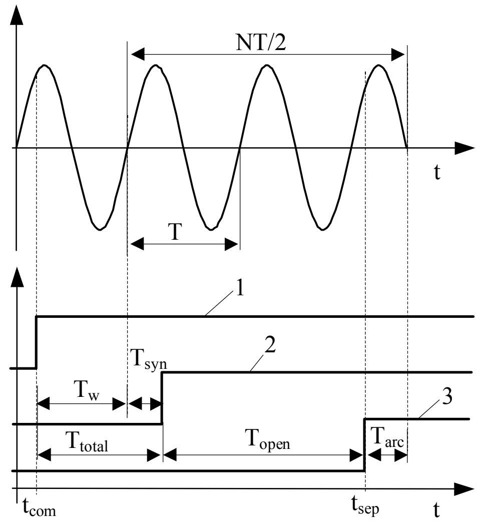

Figure 2: The opening sequence.

synchronisation device, corresponding to each application.

3. ASPECTS REGARDING THE CONTROLLED CLOSING

On closing duration, the current begin to flow through the circuit breaker before of mechanical touching of the contacts, respective from the moment in which the dielectric strength of the space between contacts become more less than instantaneous applied voltage.

One of the main parameters, which characterise the closing of circuit breakers, is the energy made by the pre-strike of the electric arc in the space between contacts. This thing influences the contact erosion and, mostly, the mechanical stresses executed to extinction chamber of the arc on the closing duration, [2]. From this point of view, the circuit breakers stresses can be modified acting against the values of pre-strike arc time and implicit against the arc energy. The evaluation of arc energy at different connection moments allows the optimisation of closing process of a circuit breaker.

In Fig. 3 are given the withstand voltage curves (supposed linears), u_{ws}, in function of time for the space between contacts. The contacts start their moving at a given moment and the effective touching of the contact pieces appears in the moment t_c. Each curve (u_{ws}-1, 2, 3) corresponds with a different moving speed of the contacts.

Considering that the strike voltage of the arc don't depends by the polarity, in Fig. 3 it presents and sinusoidal voltage curve, u_{cb}, on circuit breaker (in absolute values). The withstand voltage curves are presented for three distinct moments of contacts touching, $t_{c0} = 0, t_{c1} = 0 - \Delta T$, $t_{c2} = 0 + \Delta T$. The arc strike in the extinction chamber appears in the intersection or tangential points between the curves of withstand voltage and applied sinusoidal voltage.

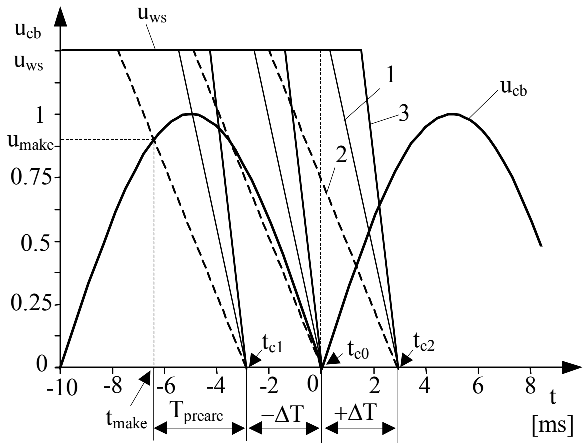

Figure 3: The voltage curve, in absolute values, on the circuit breaker and the withstand voltage curves for different decreasing slopes.

It consists that, in the case of touching moment t_{c0}, the curve u_{ws}-1 is tangential at the voltage curve of the circuit breaker, in the zero-crossing moment of it, fact that does as the burning arc duration to be zero. The curve u_{ws}-1, defines the minimum decreasing slope of the withstand voltage for which the closing of the circuit at zero-crossing of the voltage is possible. The curve u_{ws}-3 corresponds to a bigger decreasing slope, then in the precedent case and the curve u_{ws}-2 corresponds to a smaller slope.

It observes that, in function of curves slope u_{ws} and of the mechanical touching points t_c are cases in which the electric arc appear, the burning duration of it being different and cases in which it not appears.

Corresponding to Fig. 3 the burning duration of electric arc at closing it obtains with the relation:

$$T_{prearc} = t_c - t_{make} = \frac{\left|U_m \sin \omega t_{make}\right|}{S}, \qquad (4)$$

where U_m is the voltage amplitude u_{cb} and $S = \frac{du_{ws}}{dt}$ the decreasing slope of withstand voltage.

If it considers $S = \gamma \cdot S_0$, where $S_0 = \left.\frac{du_{cb}}{dt}\right|_{t=0} = \omega U_m$ is the nominal slope of the linear Rate of Decrease of Dielectric Strength-RDDS and γ normalised value of the RDDS then:

$$T_{prearc} = \frac{\left|U_m \sin \omega t_{make}\right|}{\gamma \omega U_m}. \qquad (5)$$

The maximum burning duration of the electric arc at the closing of circuit breaker is given by the relation (for 50 Hz):

$$T_{prearc-\max} = \frac{1}{\gamma\omega} = \frac{3{,}18}{\gamma}, \text{ [ms]}. \qquad (6)$$

In Fig. 4 and Fig. 5 are presented the evolutions of burning time of the electric arc at closing, T_{prearc}, respective the strike voltage, u_{make}, in function of the moment of contacts touching, considering as parameter γ, in the range [0.6, 5].

It consists the increasing of burning time of the electric arc at the same time with the decreasing of RDDS for a target moment of the contacts touching, Fig. 4. To obtains a $T_{prearc} = 0$ is necessary as $\gamma \geq 1$ and the target moment to be the same with the zero-crossing of the voltage u_{cb}. It can obtains $u_{make} = 0$ when $\gamma \geq 1$ and the target moment is zero, Fig. 5.

In Fig. 6 and Fig. 7 are presented the dependencies of the burning time of the electric arc, T_{prearc}, respective the strike voltage, u_{make}, in function of the normalised value of RDDS, γ.

The maximum burning time of the arc increases at the same time with the decreasing of rate of decrease of dielectric strength, Fig. 6. In the situation in which it chooses the target moments –1 ms, respective +1 ms, it consists that it prefers the second situation (+1 ms) because T_{prearc} as well as u_{make} are smaller than in the first situation, Fig. 6, 7.

It consists that, for the controlled closing is necessary as $\gamma \geq 1$, case in which it obtains the situation $T_{prearc} = 0$, $u_{make} = 0$ considering the moment of

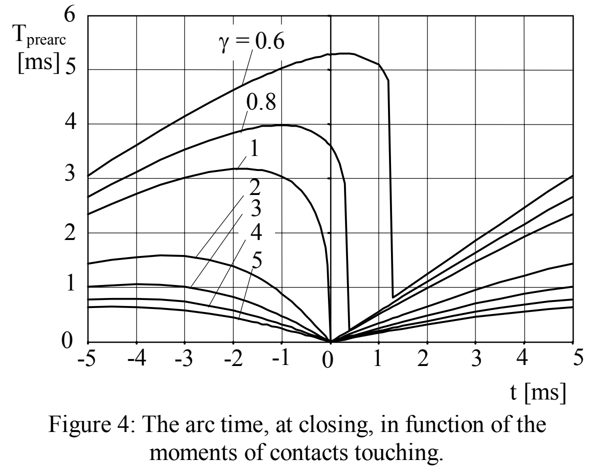

Figure 4: The arc time, at closing, in function of the moments of contacts touching.

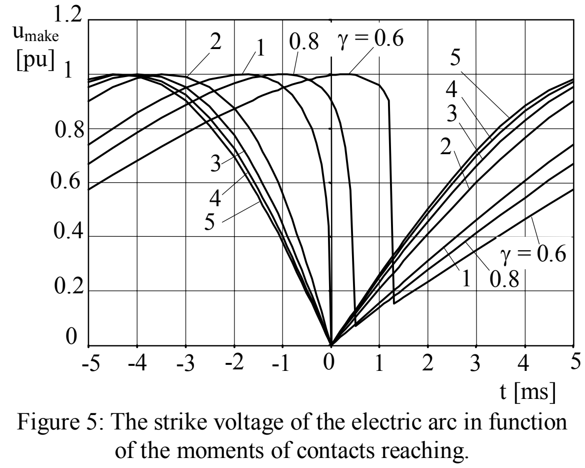

Figure 5: The strike voltage of the electric arc in function of the moments of contacts reaching.

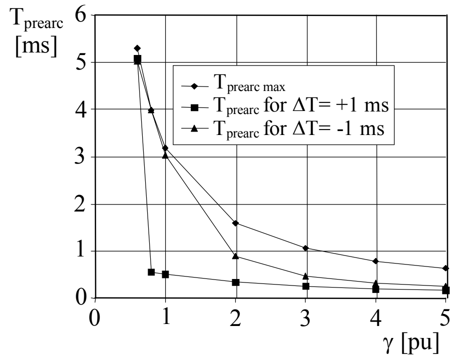

Figure 6: The arc time, at closing, in function of the normalised value of RDDS.

the contacts touching at the voltage zero-crossing u_{cb}. Because of the mechanical dispersion of the operation time is preferred to choose a target point of the contacts touching moved to right in concordance with the moment of voltage zero-crossing u_{cb}. For example, a mechanical dispersion of ± 1 ms (maximum dispersion accepted for controlled closing) in concordance with the zero moment, leads to an arc time of 0.5 ms (for +1 ms) and 3.04 ms (for –1 ms), respective at a voltage u_{make} of 0.156 (for +1 ms) and 0.954 (for –1 ms), it considers $\gamma = 1$. If the target moment is + 1 ms then, considering the same mechanical dispersion of ± 1 ms, it obtains an arc time of 0.99 ms (for +2 ms) and 0 ms (for 0 ms), respective at a voltage u_{make} of 0.312 (for +2 ms) and 0 (for 0 ms). In the case of moving to left of the target moment, at –1 ms then results an arc time of 3.18 ms and a voltage u_{make} of 0.998 (for –2 ms). Results that for the all three target moments – 1, 0, +1 ms, the moment +1 ms has the variation ranges of T_{prearc} and u_{make} the most favourable from the point of view of controlled switching.

The values of rate of decrease of dielectric strength of a extinction chamber takes values in the range 35 … 100 kV/ms, [3], values that allows to obtains some $\gamma \geq 1$. In the situation in which the withstand voltage characteristics, u_{ws}, have a slope smaller than 1, the controlled closing can be good through the obtaining of some minimum values for the arc time, respective for the arc strike voltage. Thus, for $\gamma = 0.8$, respective $\gamma = 0.6$ the target moments must be established in the right of the moments +0.4 ms for the first case, respective +1.3 ms for the second case, when T_{preacr} and u_{make} have minimum values, Fig. 4, Fig. 5. For the maximum mechanical dispersion at the controlled closing of ± 1 ms, the target moments that must be established by the synchronisation device, in the above cases, are +1.4 ms, respective 2.3 ms.

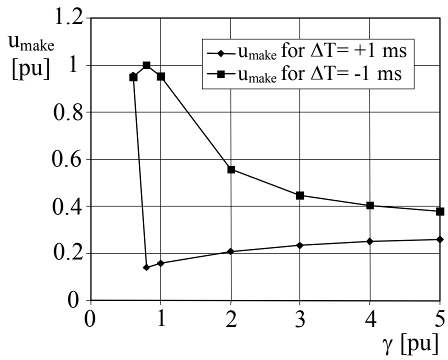

Figure 7: The strike voltage, at closing, in function of the normalised value of RDDS.

4. CONCLUSIONS

The controlled closing is realised through the monitoring of the supply voltage and the controlled opening is realised, in general, through the monitoring of the current which cross the equipment.

An important parameter, which characterises the closing of circuit breakers is the energy made by the pre-strike of the electric arc in the space between contacts. Thus, the circuit breakers stresses can be modified through the values of pre-strike arc time and implicit of the arc energy.

For the controlled closing is necessary as $\gamma \geq 1$, case in which it obtains the situation $T_{prearc} = 0$, $u_{make} = 0$ considering the moment of the contacts touching at the voltage zero-crossing u_{cb}. Because of the mechanical dispersion of the operation time is preferred to choose a target point of the contacts touching moved to right in concordance with the moment of voltage zero-crossing u_{cb}.

Even in the situation in which $\gamma < 1$, the controlled closing can be advantageous at the obtaining of some minimum values for the arc time, respective for the strike voltage of the arc.

An electronic device for controlled closing, through the monitoring of circuit breaker voltage, will establish the target moment of the contacts touching taking in consideration the dispersion of the equipment operation time and the slope of RDDS corresponding to the space between contacts.

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