MODELLING OF CIRCUIT BREAKING AT THE FUSES WORKING

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1 Introduction

The fuses are electric protection devices, assuring the limitation of the thermal effects of the short circuit currents by their interruption after given lengths of time. If the working is with limitation effect the protection is also extended at the electrodynamics effects of these currents. The fuses working is accompanied by commutation phenomena such as the electric arc transitory over voltages.

The circuit protection against the thermal and electrodynamics effects of the short circuit effects is obtained producing in these circuits transitory over voltages, able to influence the breaking fuse capacity and the isolation of the protected device.

The modelling of the circuit breaking at the fuse working requires the using of an proper model for the breaking electric arc and a program for solving transitory equations.

In this paper is studied the possibility of using a "black box" arc model in the calculus of the commutation over voltages. The authors obtained this model using a combination of Cassie and Mayr models. For the numerical modelling of the transient state is used the EMT Program.

There are presented calculus results witch put in evidence the influence of parameters variation at the transitory over voltages accompanying the fuses working.

2 Actuating of the fuses at short circuit

The heating of the fusible element crossed by an short circuit current can be considered as a adiabatic one and it is developing in time like in Fig. 1. Beginning with the initial moment of the apparition of the short circuit current, the temperature of the fusible element rapidly rises in time after a certain law so that in the moment t_1 it equalises the melting temperature. During the time between t_1 and t_2 the mass of the fusible element melts at a constant temperature θ_f. Afterwards the temperature of the liquid phase is to rise and, in t_3, to reach the vaporisation point, θ_v. The vaporisation of the fusible element is equivalent with a little explosion followed by the penetration of the vapour mixed with liquid metal particles into the arc extinguishing material which usually consists in a certain quantity of quartz sand.

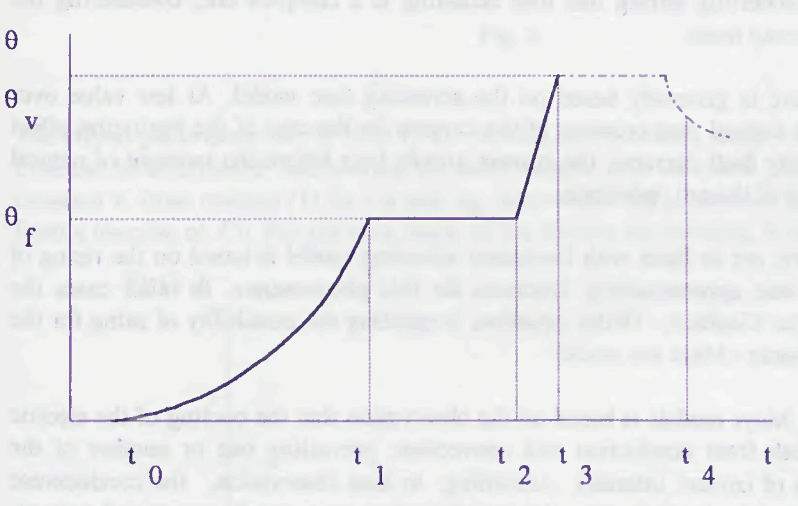


Fig. 1

The depth of the penetration depends on the dimension of the particles and, also, on the shape and the dimension of the fusible element. If the arc extinguishing material is the talc powder, then the depth of the penetration is decreased. In the moment t_3 the conductance is interrupted and the intensity of the current annulled. The transient recovery voltage caused by this interruption produces the ionisation of the fuse gap and the ignition of the electric arc, existing between t_2 and t_4.

The duration of the electric arc depends on the action of the arc extinguishing material and on the value of the transient recovery voltage, appeared as a reaction of the interrupted circuit. In the diagram from Fig.1 is emphasised the pre-arc time t_{pa} which, if it is cumulated with the t_a arc duration, leads to the actuating time of the fuse at the given current. The priming of the electric arc leads at the halting of the current intensity rising, followed by an diminution and stooped on t_a time. The limited current, corresponding to t_2, can be calculated using the relation:

$$\int_0^{t_2} j_k^2(t)dt = K, \tag{1}$$

j_k representing the current density at the fusible mass melting and K a material constant (K = 9,96.10^{16} $A^2.s/m^4$ for Cu and 6,93.10^{16} $A^2.s/m^4$ for Ag).

The last stages of a fuse actuating are the ionisation of the fuse gap and ignition of the electric arc, followed by its extinction and the interruption. of the circuit.

The ignited arc among liquid metal drops resulted from the melting of the fusible mass leads at their vaporisation, the sand from arc zone being submitted to a sinter synthesis process, resulting a corps with resistivity strongly depending on temperature. The conduction is established through this corps, its resistivity rising along with the diminution of the temperature, finally being obtained the circuit interruption.

The amplitude of the transient recovery voltage depends on the value of the limited current on the pre-arcing time and on the values of the interrupted circuit inductance. The diminution of the transient recovery voltage accompanying the actuating of a fuse can be obtained by rising the limitation effect (diminution of the intensity values) and by the delay of the burning duration of the electric arc.

The first possibility is materialised by the perforation of the fusible elements, which must be made from metals with a small Meyer constant, Ag for instance. The rising of the arc duration is obtained making the fusible bands or threads with variable section.

3 Modelling of the electric arc

The problem of the primed electric arc modelling during one fuse actuating is a complex one, considering the special burning conditions inside the replacing mass.

In AC the extinguishing of the electric arc is generally based on the actuating fuse model. At low value over currents the extinguishing produces at the natural zero crossing of the current. In the case of the limitation effect actuating, which intervenes at high intensity fault currents, the current annuls long before the moment of natural zero crossing due to the very rapidly rising of the arc resistance.

In many cases, the modelling of the electric arc in fuses with limitation actuating model is based on the rising of arc resistance and consists in using of some approximating functions for this phenomenon. In other cases the modelling of the electric arc is based on the Elenbaas - Heller equation, suggesting the possibility of using for the communication processes in fuses of an Cassie - Mayr arc model.

A combined model, originated in Cassie - Mayr models is based on the observation that the cooling of the electric arc is a complex one and takes place both from conduction and convection; prevailing one or another of the mentioned ways depending on the values of current intensity. According to that observation, the conductance G(t) of the electric arc results from the introduction into the calculus using some synchronisation functions, of the conductance calculated using Cassie and Mayr equations:

$$G(t) = C(t)G_C(t) + M(t)G_M(t), \tag{2}$$

where C(t), M(t) are the synchronisation functions, and $G_C(t)$, $G_M(t)$ - Cassie and Mayr conductances. For example, having an sinusoidal current, in [1] the synchronisation functions are considered like :

$$C(t) = \sin^2(\omega t + \varphi_C + \psi), \quad M(t) = \cos^2(\omega t + \varphi_M + \psi), \tag{3}$$

where:

$$\varphi_C = \mathrm{arcctg}(\omega T_a), \quad \varphi_M = \mathrm{arcctg}(2\omega T_a), \tag{4}$$

the parameters of the model being U_0, P_0, T_a and ψ [1].

4 Simulation of actuating of the fuses, using the EMT Program

4. 1 Single-phase fault current

There is simulating the commutation of an single-phase fault current in a AC low voltage circuit, due of the actuating with current limitation of a fuse.

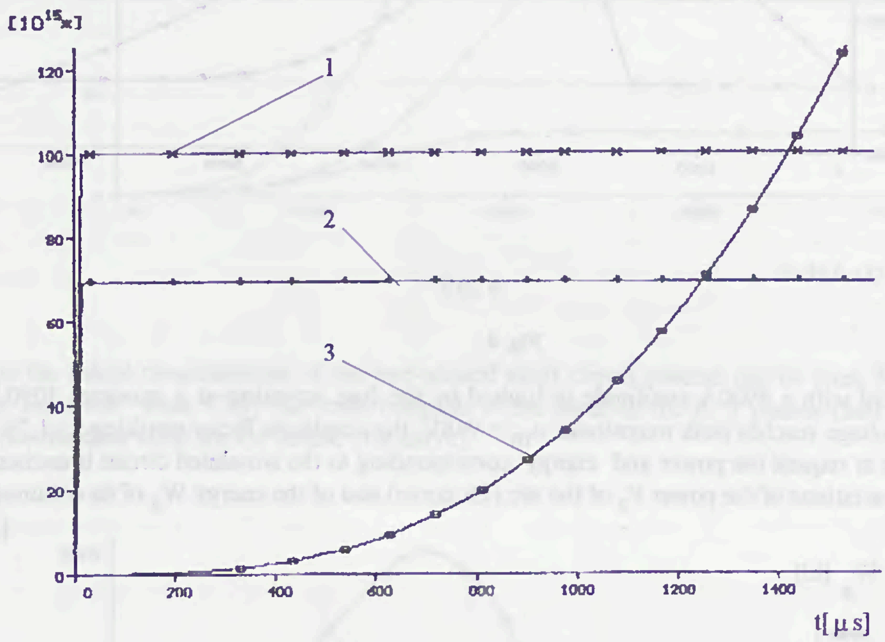


Fig. 2

The circuit parameters are: U= 539V, $R = 0{,}02\Omega$, L= 0,25mH, $\cos\varphi = 0{,}25$. As it can be seen in Fig.2 the pre-arc time can be determined intersecting the Joule integral (the 3rd curve) with the right lines 1,2 corresponding to the constant K from relation (1) for Cu and Ag. Afterwards the simulation is restricted only at the case of an fuse with fusible element of Cu. For the next stage, of the electric arc burning, is used the combined Cassie - Mayr model.

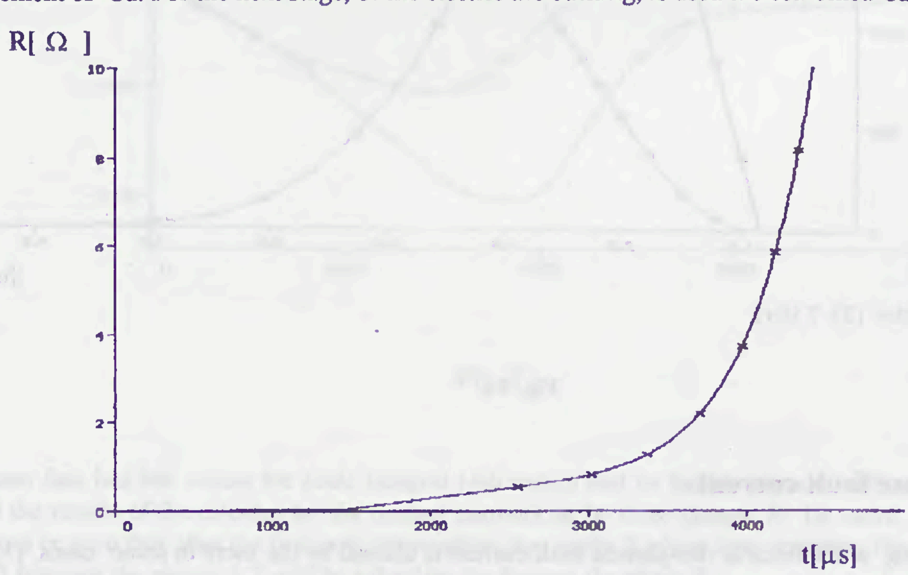
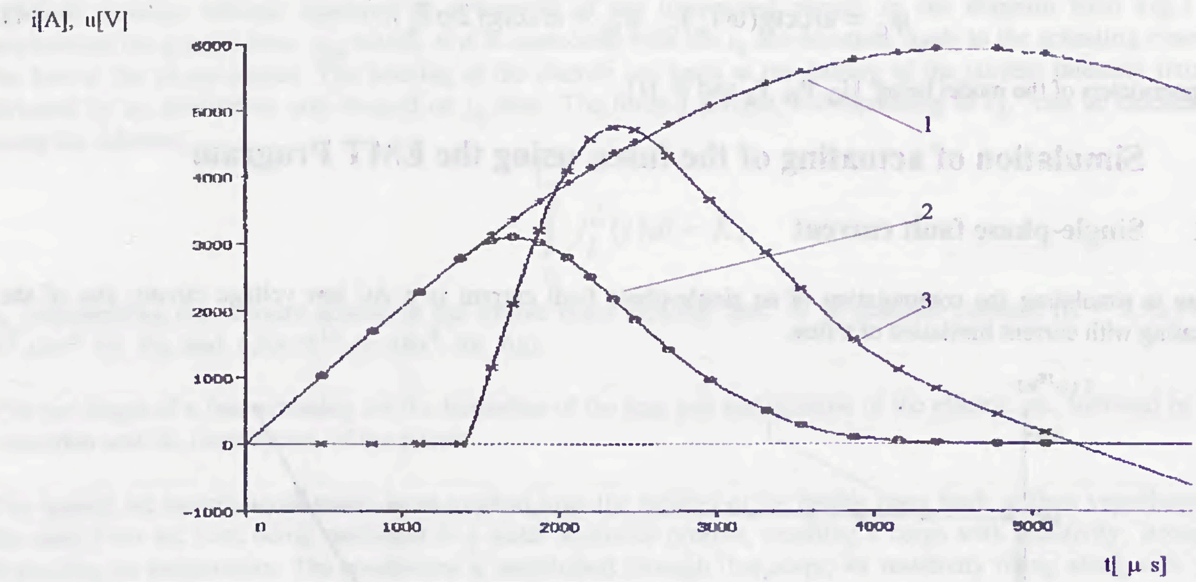


Fig. 3

The time evolution of the arc resistance, Fig. 3, is in concordance with literature [2], [4] and is attest the correctness of the used arc model.

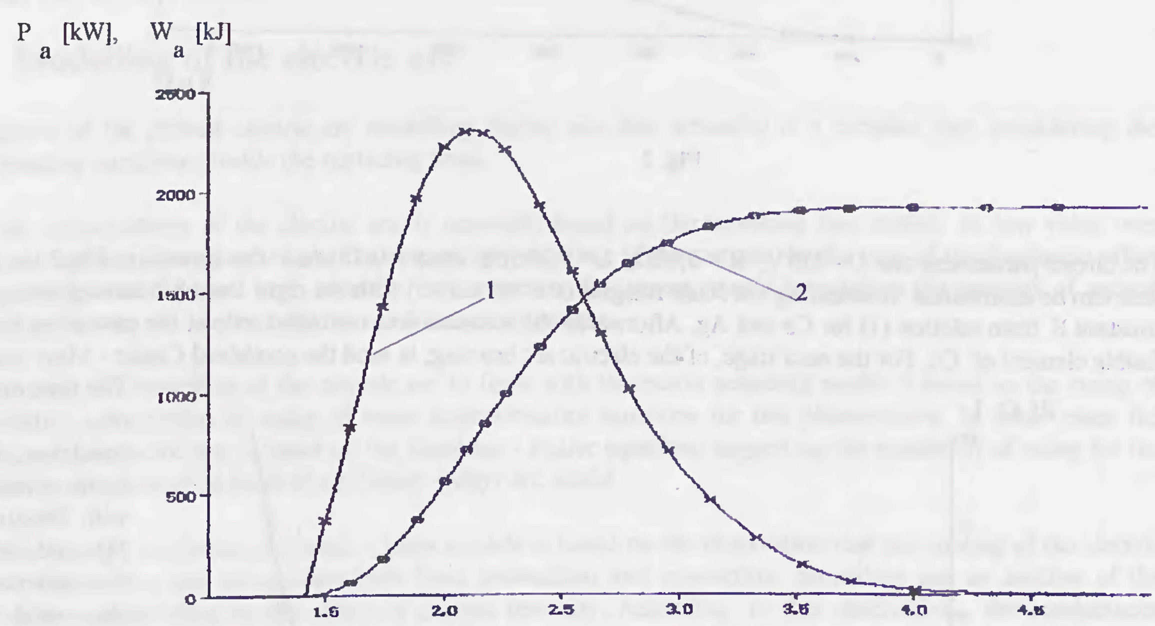
The simulation results are graphically presented in Fig. 4 by the curves representing: 1-the presumed short circuit current, 2-the limited short circuit current, 3-electric arc voltage.



Factor: (3): 5.0E+0

Fig. 4

The presumed current with a 5900A amplitude is limited by the fuse actuating at a maximal 3090A value. The transient recovery voltage reaches peak magnitude $u_m = 948V$, the amplitude factor resulting $\gamma = 1{,}76$.
EMT Program gives at request the power and energy corresponding to the simulated circuit branches. In **Fig. 5** is presented the time variations of the power P_a of the arc (1st curve) and of the energy W_a of its column(2nd curve).



Factor: (2): 7.5E+2

Fig. 5

4.2 Three-phase fault current

Testing of the actuating of the fuses at tree-phased fault current is clamed by the users in some cases, [3] and the simulation of this state leads to interesting results.

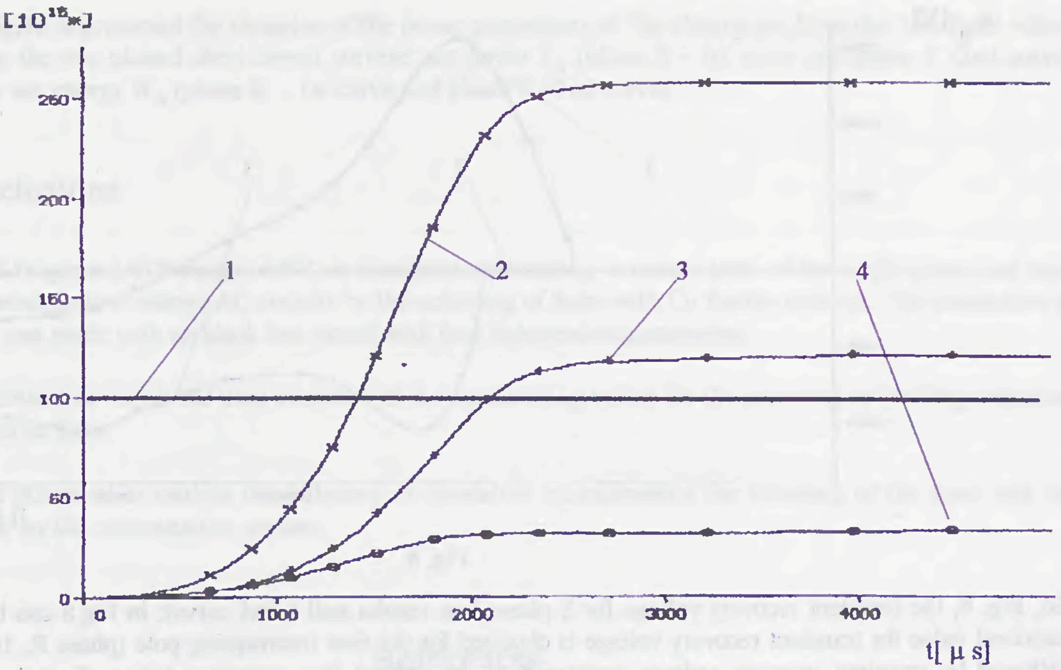


Fig. 6

Depending on the initial circumstances of the tree-phased short circuit process can be seen, Fig. 6, that only two from all three fuses will work. Only the Joule integrals of the fuses on the R, T phases (2nd and 3rd curves) are intersecting the constant value for Cu fusible (1st curve).

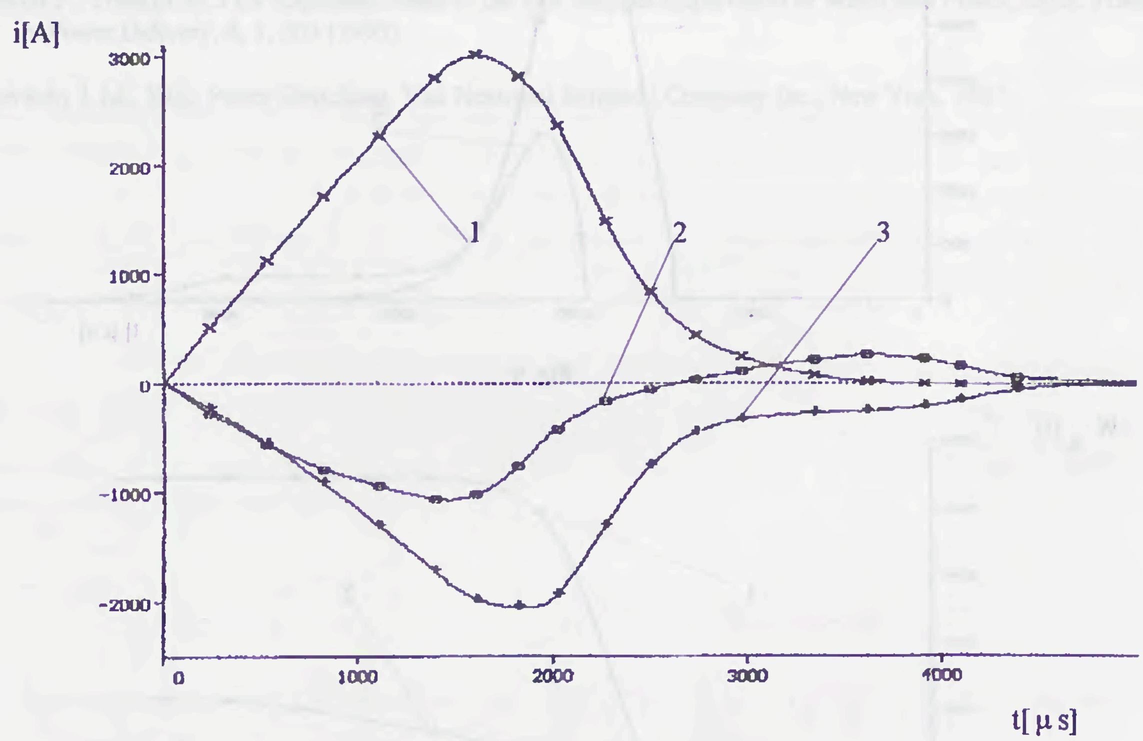


Fig. 7

The S phase fuse has low values for Joule integral (4th curve) and its fusible element will not melt. In Fig. 7 are presented the results of the calculus for the limited currents on he three phases: R- 1st curve, S- 2nd curve, T- 3rd curve. It can be seen that after the first pole interruption due to the R phase fuse actuating the double-phased short circuit left between the phases S,T will be solved by the fuse on the phase T.

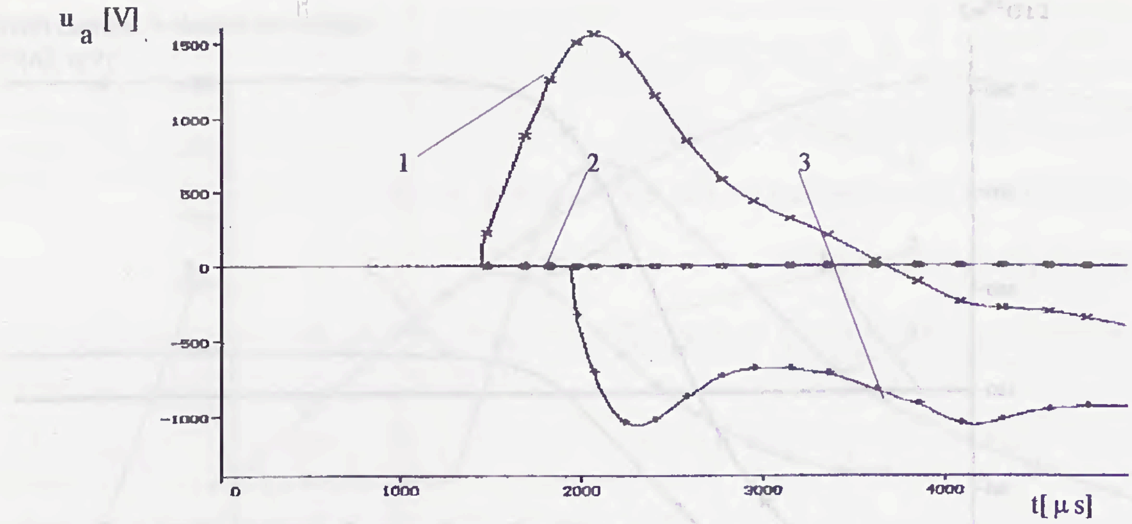


Fig. 8

So, Fig. 8, the transient recovery voltage for S phase fuse results null (2nd curve); in Fig.8 can be seen that the maximal value for transient recovery voltage is obtained for the first interrupting pole (phase R, 1st curve), being followed by transient recovery voltage registered at the second fuse actuating (phase T, 3rd curve). For the amplitude factors are resulting the following values: $\gamma_1 = 2{,}87$ and $\gamma_3 = 1{,}97$.

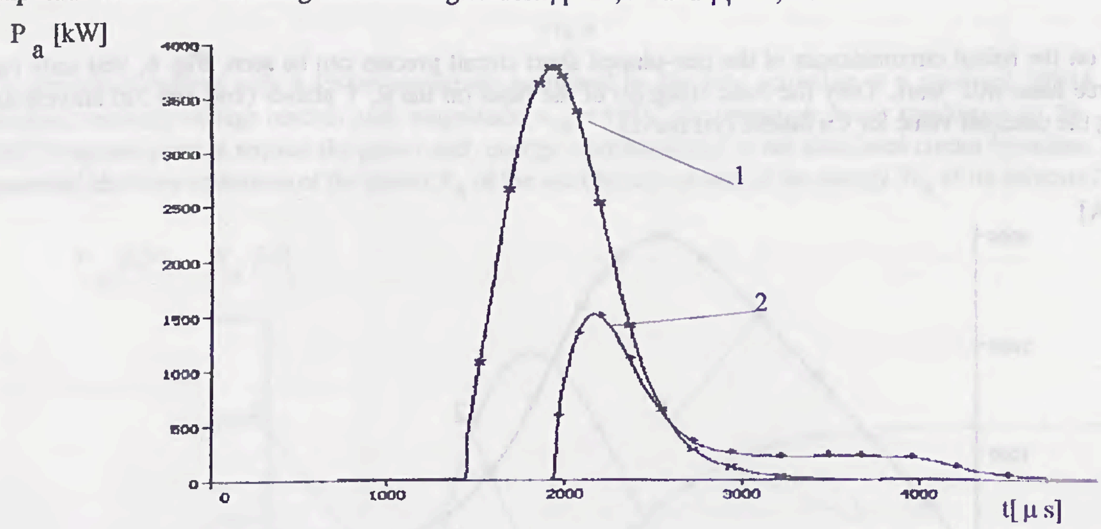


Fig. 9

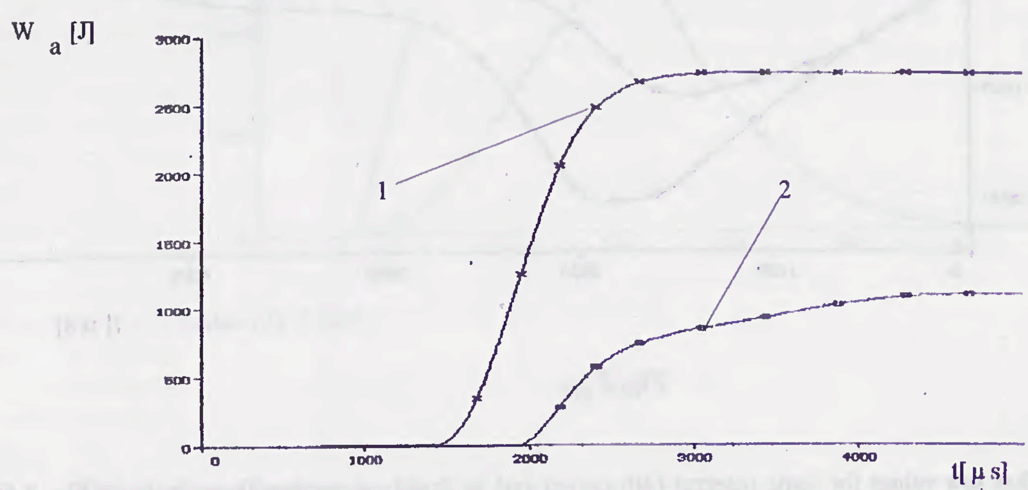


Fig. 10

In Fig.9 and Fig.10 is presented the variation of the power parameters of the electric arc from the two fuses which are interrupting the tree-phased short circuit current: arc power P_a (phase R - 1st curve and phase T -2nd curve) respectively the arc energy W_a (phase R - 1st curve and phase T - 2nd curve).

5 Conclusions

Using the EMT Program (ATP version 1992) is simulated the limiting transient state of the single-phase and tree-phase fault currents in low voltage AC circuits by the actuating of fuses with Cu fusible element. The simulation of the electric arc was made with an black box model with four independent parameters.

There are presented like curves the time evolution of the conditioning values for the actuating in limiting transient state of the electric fuses.

The simulation allows us to analyse the influence of the values characterising the actuating of the fuses and the protected device on the commutation process.

References

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