ELECTRICAL FUSES TESTING MODULAR SOURCE USED WITH A NEW METHOD FOR PLOTTED TIME-CURENT CHARACTERISTIC WITHOUT FUSING

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Abstract: This paper contains, a short presentation, theoretical analyze and construction, of a new current (and voltage) adjustable modular source with identical ferromagnetic modules, independent primary windings, and a single common secondary. The current (and voltage) of the secondary have a large scale of range. The paper presents then some contribution for plotting time-current characteristic of reconditioned LV high breaking capacity fuses without fusing. The method presented, which can approximated an individually time-current characteristic without fusing is based on the • (I) plot of the replacement element.

The source and the method for plotting time-current characteristic without fusing can offer an independent unit for testing and selection fuses in better protection of electric devices in the overload current area.

I. INTRODUCTION

The fuses testing are doing in concordance with required conditions of norms and standards [1,2]. Some testings have a particular specificity and they are usefully both in research, production and even exploitation.

Establishing of time-current characteristic means one of the overload testing aims. In this case, it uses different current sources which are usually fixed and especially used within specialized workshops.

It is necessary adjustable and mobile modular current sources in the case of research and exploitation (reconditioning).

On the other hand, the time-current characteristics from catalogues are statistical curves and they are not valid any more in the case of fuses reconditioning.

In this paper, the authors present on the one hand a modular current/voltage source [4,5,6,7] which can be used to fuses testing and on the other hand some contributions about the plotting of time-current characteristic to high breaking capacity fuses (reconditioned fuses) without fusing [8].

II. MODULAR SOURCE

For the purpose to have currents of kA range, the normal sources are built into a transformer voltage-current supplied through an adjustable autotransformer. The sources are not normally transportable.

II.1 Construction

The modular electromagnetic source used in testing , consists of a different number of ferromagnetic modules. Each modules have its own primary winding and a common secondary, Fig.1.

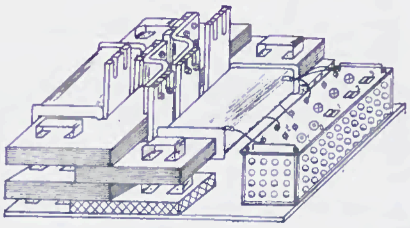

Fig.1 Three modules source

The testings of the fuses were done with the source depict in Fig.2.

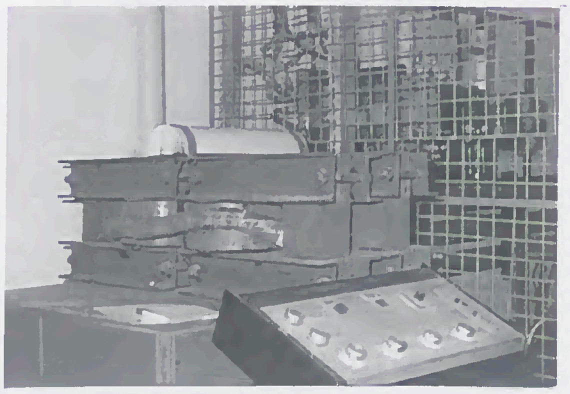

Fig.2 Tesing modular source

There are built some other sources too, with different construction of the ferromagnetic modules with high output and good cooling conditions to windings, Fig.3/A and Fig.3/B

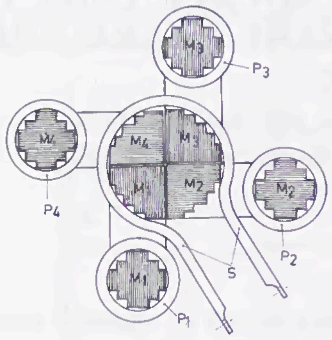

Fig.3/A Four modules source . Crossed section.

II.2 Basic elements

There follow are some considerations and analyses about operating equations of created current/voltage sources and their equivalent electrical circuits with the following assumptions:

- the losses in the magnetic core iron are considered very small, negligible;
- the cores are unsaturated, the operating takes place on linear section of magnetic core B(H) characteristic;
- it considers that the modules have identical magnetic circuits;
- the equations use the convention from receiver for primary coils and from power plant for secondary (common secondary).

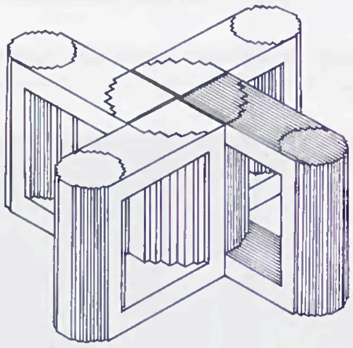

Fig.3/BFour modules source.View without windings

The principle electrical circuit of current source with two ferromagnetic modules is shown in Fig.4.

It can write the next equation systems, using the single-phase transformer model:

$$u_1 = R_1\, i_1 + L_{d\,1}\frac{di_1}{dt} + N_1\frac{d\Phi_{01}}{dt} \qquad (1)$$

$$u_2 = R_2\, i_2 + L_{d\,2}\frac{di_2}{dt} + N_2\frac{d\Phi_{02}}{dt} \qquad (2)$$

$$-e_3 = N_3\left(\frac{d\Phi_{01}}{dt} \pm \frac{d\Phi_{02}}{dt}\right) \qquad (3)$$

When in secondary there is a load (R,L,C) it gets the equation systems:

$$u_1 = R_1 i_1 + L_{d13}\frac{d\,i_1}{d\,t} + N_1\frac{d\,\Phi_{01}}{d\,t} \qquad (4)$$

$$u_2 = R_2 i_2 + L_{d23}\frac{d\,i_2}{d\,t} + N_2\frac{d\,\Phi_{02}}{d\,t} \qquad (5)$$

$$-u_3 = R_3 i_3 + (L_{d31} + L_{d32})\frac{di_3}{dt} + N_3\left(\frac{d\,\Phi_{01}}{d\,t} \pm \frac{d\,\Phi_{02}}{d\,t}\right) \qquad (6)$$

where:

u_1, u_2 - two primaries voltage supplies;
R_1, R_2 – primary coils resistance;
N_1, N_2, N_3 – wire numbers of primary and secondary;
Φ_{01}, Φ_{02} - core magnetization fluxes;
i_1, i_2 – primary coils currents;
e_3 – electromotive force to secondary terminals.

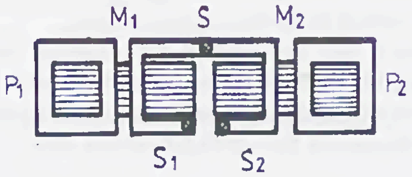

Fig.4 Electrical principle circuit of current source

Principle electrical circuit of modular source with one-turn wire single secondary is shown in Fig.5.

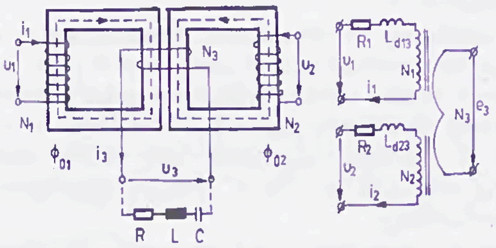

Fig.5 One turn wire common secondary

It considered, for clarity, $N_3 = 1$ to given build (Fig.5) and it can notice this situation is equivalent with two transformers which P_1 and P_2 primaries are supplied by the same source or different voltage sources and secondaries (single wire) are in series. When $N_3 \neq 1$ it can notice wire by wire alternating series of primaries. For a three modules assemble, from Fig.6, it can write the equation systems with phase values.

In this case, the equation system becomes (7…15):

$$\underline{U_{pl}} = R_p \underline{I_{pl}} + jX_{dls}\underline{I_{pl}} - \underline{E_{mpl}} \qquad (7)$$

$$\underline{U_{p2}} = R_p \underline{I_{p2}} + jX_{d2s} \underline{I_{p2}} - \underline{E_{mp2}} \qquad (8)$$

$$\underline{-U_{p3}} = R_p \underline{I_{p3}} + jX_{d3s} \underline{I_{p3}} - \underline{E_{mp3}} \qquad (9)$$

$$-\underline{U_s} = R_s \underline{I_s} + j(X_{ds1} + X_{ds2} + X_{ds3})\underline{I_s} - \underline{E_{ms}}$$

$$N_p \underline{I_{p1}} + N_s \underline{I_s} = N_p \underline{I_{0p1}} \; ; \qquad (11)$$

$$N_p \underline{I_{p2}} + N_s \underline{I_s} = N_p \underline{I_{0p2}} \; ; \qquad (12)$$

$$N_p \underline{I_{p3}} + N_s \underline{I_s} = N_s \underline{I_{0s}} \qquad (13)$$

$$\underline{U_s} = \underline{Z_c I_s} \; ; \qquad (14)$$

$$\underline{U_{p3}} = \underline{Z_R}\, \underline{I_{p3}} \qquad (15)$$

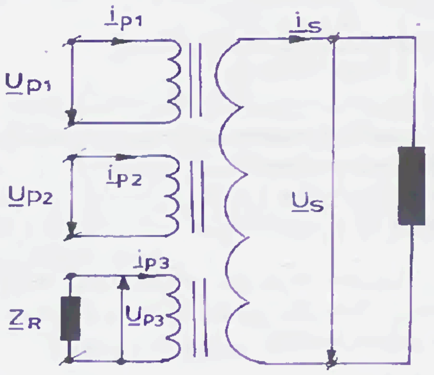

Fig.6 Electrical circuit of three modules source

To get the secondary current expression, for simplification, it considers the following:
- it refers the primary coil data to common secondary (noted ");
- it considers the magnetization currents almost zero:

$$\underline{I''_{pi}} + \underline{I_s} \approx 0 \text{, with i=1...3;} \qquad (16)$$

- the modules position is symmetrically to get the same dispersions.

After equation systems processing it gets the expression:

$$\underline{I_S} = \frac{\underline{U''_{p1}} + \underline{U''_{p2}}}{3\underline{Z''_p} + \underline{Z''_R} + \underline{Z_c} + \underline{Z_S}} \qquad (17)$$

where: $\underline{U''_{p1}} = \frac{N_2}{N_1}\underline{U_{p1}}$; $\underline{U''_{p2}} = \frac{N_2}{N_1}\underline{U_{p2}}$;

$\underline{Z''_p} = R_p + jX_{dp}$, X_{dp} – the stray reactance primary-secondary for one magnetic module;

$\underline{Z''_R} = \underline{Z_R}\left(\frac{N_2}{N_1}\right)^2$ - refered adjustment impedance;

$\underline{Z_c} = R_c + jX_c$ - load impedance (can be a fuse);

$\underline{Z_s} = R_s + 3jX_{ds}$, X_{ds} - stray reactance secondary-primary for one magnetic module.

From above expression, with done assumptions, it results that secondary current values will depend on following:
- primary voltage supplies;
- adjustment impedance value, $\underline{Z_R}$; with this impedance we can adjust the cos • factor;
- wires ratio between primary and secondary;
- dispersion inductance values;
- load values;
- magnetic material quality.

When it use these sources it can choose one or a combination of them depending on means.

Generalizing the (17) expression for n modules from among m have connected to primary terminals the adjustment impedance $\underline{Z''_{Rk}} \geq 0$ (where k=1…n) and n-m modules are supplied with $\underline{U''_{pi}}$ voltages (with i=1…n-m) it gets the expression (18):

$$\underline{I_S} = \frac{\sum_{1}^{n-m} \underline{U''_{pi}}}{\sum_{1}^{n} \underline{Z''_{pj}} + \sum_{1}^{m} \underline{Z''_{Rk}} + \underline{Z_c} + \underline{Z_S}} \qquad (18)$$

(with $\underline{Z_S} = R_S + njX_{dS}$)

III TIME-CURRENT PLOTTING METHOD

III.1 Basic elements

Time-current characteristics shown in catalogues and standards are curves of statistical mean values experimentally established, in the individual cases the deviations could be up to +10% from mean values, an unacceptable error, especially to the protection of installations with power semiconductors.

So, it is necessary to work out a method to establish the individually time-current characteristic of high breaking capacity fuses.

The replacement elements used at tests proceed from those reconditioned to the Distribution Branch within the S.C. "Electrica" S.A. belonging to the National Company of Electricity – "CONEL", Ia• i – Romania,, for own installatons use. The experimental determinations of the temperature values were performed using resistance of the element variation method[8,9].

As a result, it could measured the temperature values at different currents and it obtained the curve from Fig.7.

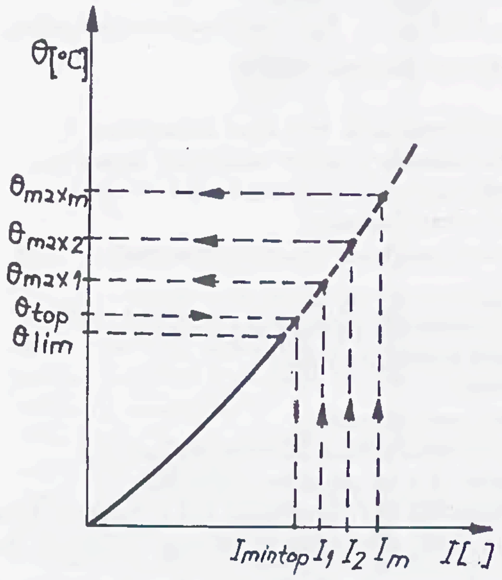

Fig7 Extrapolated • (I) characteristic

The limit temperature what can be attained without fusing, was considered θ_{lim}=0,9 θ_{top} .The θ(I) curve can be approximated with an arc of parabole:

$$\theta(I)=K_{med}I^2 \tag{19}$$

where K_{med} is a constant (mean value) infered from experimental data.

A better approximation for θ(I) curve is obtained with the expresion [10]:

$$\theta(I)= A\ \mathrm{sh}\ [a \left(\frac{I}{I_n}\right)] \tag{20}$$

where **A** and **a** are constants what can be calculated from experimental data.

The θ(I) curve, from extrapolation, using one of expressions before, can be known over θ_{lim} . For value of currents $I_1,I_2,...,I_m$ from area (minimum melting current - breaking capacity) using curve from Fig.7, it can establish the maximum heatings.

Then, it plots the heating curve θ(t) for values of currents $I_1,I_2,...,I_m$ Fig.8. In the area θ_{lim} - θ_{top}, the heating curve can be approximated with an exponential curve. The maximum heatings θ_{max1}, $\theta_{max2}...\theta_{max\ m}$, infer from diagram before, Fig.7.

In the crossing points of heating curves θ(t) with the line θ= θlim (points A, B...) it plots the tangents to those curves, getting the time constants $T_1, T_2 . . T_m$, these

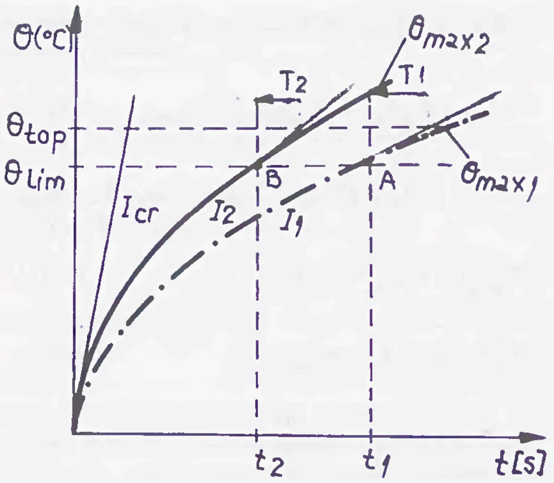

Fig.8 The heating curve θ(t)

constants can be obtained analytically with the relation:

$$T_i = \frac{t_i}{\ln\left(\frac{\theta_{max\,i}}{\theta_{top}-\theta_{lim}}\right)} \quad , \ i = 1, ... ,m \tag{21}$$

There is a critical current value, I_{cr} [3], which the heating evolution is the line:

$$\theta(t) = \mathbf{c}\ t \tag{22}$$

where **c** is a constant what can be calculated using the fuse parameters. Over that current value I_{cr} the prearcing time has the expression [2]:

$$t_{pa} = \frac{S^2K}{I^2} \tag{23}$$

where **K** is a material constant and **S** is the cross section of fuse link.

III.2 Methodology

Knowing these elements and material constants, it proposes the next methodology to establish the individually time-current characteristic without fusing:

- for some values of currents $I_1,I_2,...,I_m$ from area $I_{min\ top}$-Ir, it establishes the maximum heatings $\theta_{max1},\theta_{max2}...\theta_{maxm}$ using a curve like that shown in Fig.7;
- it establishes the times t_1, t_2, ... ,t_m, resulted from crossing of heating curves θ(t) with limit temperature line $\theta = \theta_{lim}$, Fig.8;
- plotting the tangents in the crossing points established before, it gets time constants T_1, T_2 . . T_m or using the relation (21);
- it calculates the prearcing time t_{p1}= t_1 +T_1, t_{p2}= t_2 +T_2, ... ,t_{pm} = t_m +T_m. If currents are over the critical value I_{cr} the prearcing times calculate with relation (23);
- the time-current characteristic t(I), meaning the breaking time variation of one fuse depending on

overcurrent, can express in two alternatives: melting characteristic t_{pa} (I) and interrupting characteristic τ(I).

Because the arcing time of electric arc is about 5 ms, in the overcurrent area the characteristics t_{pa}(I) and τ(I) actually overlap, Fig.9.

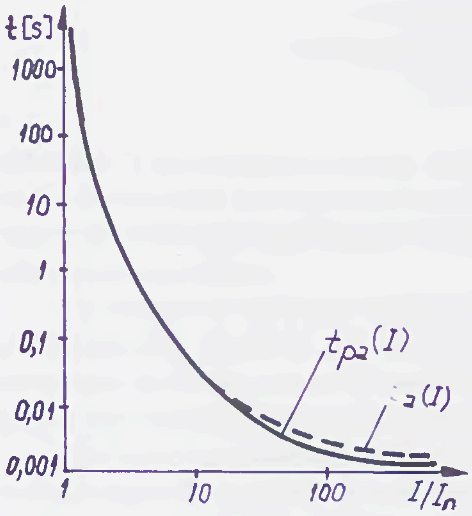

Fig.9 Time-current characteristic

The figure Fig.10 contains a comparison among the time-current characteristics for high breaking capacity fuses of Romanian production (plot1) [1], German production (plot 2) [12] and replacement element with fixed joining in the fuse link with prescribed melting temperature (plot3).

IV CONCLUSIONS

From all experimental data we can notice the following conclusions:

- the time-current characteristic, t(I) of high breaking capacity fuses is plotted without fusing;
- knowing the time-current characteristic, t(I) of high breking capacity fuses, permits a correct ensurance and anticipated checking of electric installations protection;
- the selectivity between fuses in series may be checked and can be settled for certain;
- the quality of installations protection increases;
- it is possibly a better protection for electric devices in the area of overload currents, using replacement elements with fixed joining in the fuse-link with prescribed melting temperature.

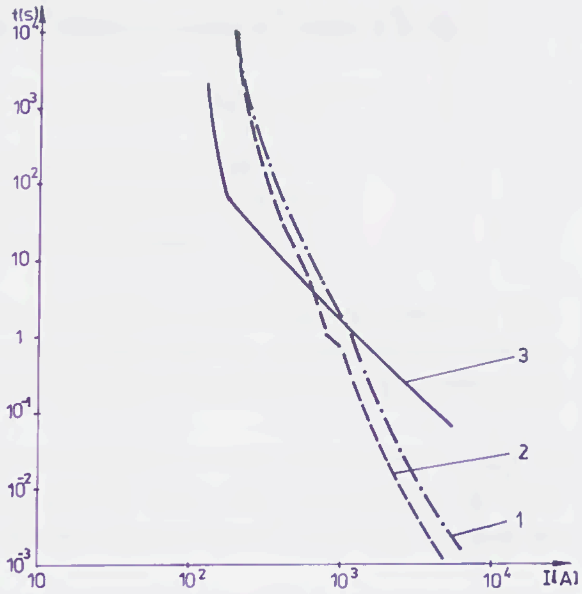

Fig.10 Comparison among the time-current characteristics of different production

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