Zbigniew POCHANKE[1], Tadeusz DASZCZYŃSKI[1], Waldemar S. CHMIELAK[2],

Warsaw University of Technology, Institute of Electrical Power Engineering (1), Institute of Power Engineering (2)

doi:10.15199/48.2019.03.15

Experimental research on time-current characteristics of fuses – initial results

***Abstract**. The highly non-linear time-current curves characterize protection abilities of different fuses and are mainly used for selection of these devices according to the proper selectivity level. The process that lead to melting the fuse element is random due to the scattering features of fuses. The randomness of establishing the melting time is a main inconvenience for determination of time-current characteristics. There are lots of methods and laboratory setups for determination of time-current curves, but they all need lots of measurement points for proper statistical analysis, what make them expensive and time consuming. In this paper the "aggregation" method is presented. This can be an alternative method and also cheaper and less time-consuming. (**Pomiary charakterystyk czasowo-prądowych bezpieczników - koncepcja**).*

***Streszczenie.** Silnie nieliniowe charakterystyki czasowo-prądowe bezpieczników opisują ich zdolności ochronne i wykorzystywane są głównie do wyboru tych urządzeń zgodnie z odpowiednim poziomem selektywności. Proces, który prowadzi do stopienia elementu topikowego jest losowy ze względu na rozrzut cech bezpieczników. Losowość procesu doprowadzenia do przepalenia topika i ustalania czasu topnienia jest główną niedogodnością w określaniu charakterystyki czasowo-prądowej. Istnieje wiele metod i zestawów laboratoryjnych do wyznaczania krzywych czasowo-prądowych, ale wszystkie one wymagają wielu punktów pomiarowych dla odpowiedniej analizy statystycznej, co czyni je kosztownymi i czasochłonnymi. W niniejszym artykule przedstawiono metodę "agregacji". Może to być metoda alternatywna, a także tańsza i mniej czasochłonna.*

Keywords: time-current characteristics, fuse, measurement, fuse element.
Słowa kluczowe: charakterystyki czasowo-prądowe, pomiary, bezpieczniki, topik.

Introduction

Fuses, both with circuit breakers, are mainly used in electrical systems for protection against over-currents and other electrical faults. Depending on an application they can be used as a protection for cables or distribution feeders, transformers, induction motors, rectifiers etc. For the proper selection of a fuse, there have to be taken into consideration [1,4]:

- Rated voltage, current and frequency
- AC and DC service and type of a load current
- Time-current and time versus I^2t characteristics
- Rated breaking capacity
- Rated power dissipation of the fuse
- Cut-off current in AC service.
- Pre-arcing and arcing times
- Dimensions.

During normal system conditions the fuse works as a short-circuited. For over-current, depending on time, the fuse element will melt and the current will be switched off. The operation of blowing of a fuse element follows the sequence [1,4]:

- For a specified amount of heat, the fuse element melts
- Gap along the fuse element is formed during melting.
- Arc is established across each gap.
- The heat of arc further melts the ends of the element at each gap increasing it.
- The arc quenches.

The performance capabilities of fuses and be graphically represented by two types of fuse characteristic curves: time-current curves and peak let-through charts. These elements define the operating characteristics of a given fuse, and help in selecting the proper apparatus to protect equipment and electrical systems. On Fig. 1 the sample of a time-current curves for typical time-delay fuse series was presented. This characteristic describes the dependence of time which elapses for the moment when over current I_{ov} appears till the moment when fuse element melt. This highly non-linear curves characterize protection abilities of an apparatus and are used for selection proper selectivity level. It is worth to point out, that thermal processes in fuses are characterized by small time constants. According to this phenomena, direct measurements of the temperature characteristics are not possible, even by using modern methods [5].

The highest amount of the current flowing through a fuselink, the shorter is the time taken for the fuse element to reach the melting temperature. It is due to the fact, that the power available to cause temperature rise is equal to the difference between the power input. The power input is proportional to the square of the current, and the power dissipated by the fuselink. The latter quantity is dependent on the temperatures of the parts, which must be limited to the melting temperature of the element material. The power difference obviously increases with current [6].

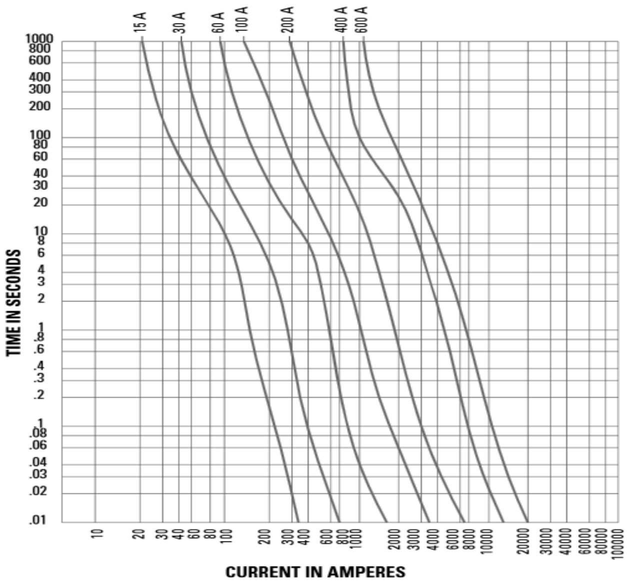

Fig. 1. Sample of a time-current curves for typical time-delay fuse series [2]

The process that lead to melting the fuse element is random due to the scattering features of fuses. Manufacturers often include this information by providing bandwidth, in which the real acting times of specified type of a fuse can be located. The randomness of establishing the melting time is a main inconvenience for determination of time-current characteristics.

The „aggregation" method

In the proposed method it is assumed, that the subject of research is a type of fuses determined in terms of design, technology and rated current.

For determining the time-current characteristic $t_0(I)$ it is necessary for a sufficiently large number of points give a function of distributor of the probability distribution $P(t_i<\eta;I_i)$ of melting the fuse element at current I_i and time less than η. The time-current characteristic of a fuse and its statistical description of uncertainty for assumed confidence level 0,95 was shown on Fig. 2.

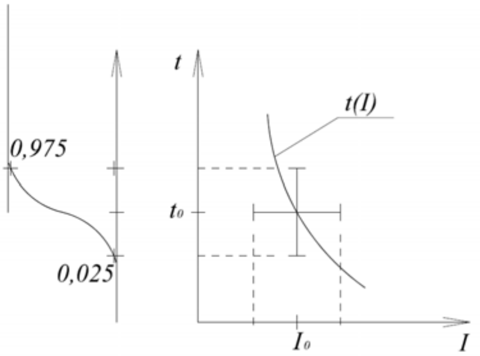

Fig. 2. The time-current characteristic of a fuse and its statistical description of uncertainty for assumed confidence level 0,95

The natural method for obtainment the distribution $P(t_i<\eta;I_i)$ is the series method, where the time measurements are carried out in many tests taken for successive set values of current. More realistic and connected to standardization, where the requirements are set for the trip current at three characteristic times: 10 s, 1 s, 0,01 s, is the "up and down" method for each characteristic time. Both methods need, to be statistically reliable, at least 100 tests. There are lots of methods and laboratory setups that meet this demands [3,6]. Those methods are very expensive and time consuming.

Significant savings in test costs, while maintaining statistical correctness of determining the characteristic and its distribution, can be achieved by combining time measurement results for current values distributed in the full range of characteristic into one set. For a proper statistical analysis of results it is possible to get the mathematical expression of characteristic and objectively determined band of uncertainty of the time of operation of fuse.

In proposed approach it is assumed that the subject of research is a specified type of fuses, described by its construction, technology and the rated current. The time-current characteristic $t_0(I)$ is assumed to be rated but unknown during the measurements. In relation to the definition of time-current characteristic, it is the mean values of times from the distribution $P(t_i<\eta;I_i)$. During the experiment the series of m tests of operation of a fuse will be performed. As a result, a set of test current values $\{I_k\}$ and times to melt down the fuse element $\{t_k\}$ are obtained. It is assumed also that these values are measured correctly.

The subject of the search is the nominal operation estimated characteristic of the $t_n(I)$, which is obtained as a result of the analysis of the results of a few series of measurements. This characteristic is random: in a repeated series of measurements a slightly different relationship $t_n(I)$ is obtained. This is due to the fact, that the results depend on the scatter of times of operation of a fuses in given series. So the aim of analysis is not only the estimate $t_n(I)$ of the characteristic $t_0(I)$, but also determining its uncertainty as intervals of time lower and upper values $[\Delta t_{ndi}(I), \Delta t_{ngi}(I)]$ or as boundary lower and upper characteristics (1).

(1)
$$\begin{aligned} t_{dn}(I) &= t_n(I) - \Delta t_{nd}(I) \\ t_{gn}(I) &= t_n(I) + \Delta t_{gd}(I) \end{aligned}$$

Those boundaries are used to find the probability 1-α shown in (2).

(2)
$$P\left[t_{dn}(I) \le t_0(I) \le t_{gn}(I)\right] = 1 - \alpha$$

The main way to make possible to aggregate the time measurements for different values of current to estimate nominal characteristic $t_0(I)$ is approximation of this deterministic characteristic by simple function (3).

(3)
$$t_0(J) = A_0 (I - I_N)^{\alpha_0} = A_0 J^{\alpha_0}$$

where: I_N – rated current of a fuse; A_0, α_0 – nominal parameters of a fuse.

In (3) the shifted current value is introduced (4) and used in equation, in which nominal operating time value strive for infinity when current has a nominal value (for $\alpha_0 < 0$).

(4)
$$J = I - I_N$$

Another assumption is made, that random randomly implemented time of operation of a fuse is proportional to nominal (depend on current) operating time t_0, which is expressed in (5).

(5)
$$t = t_0 e^{\varepsilon}$$

where: ε – random variable with zero mean value and with normal distribution with standard deviation

(6)
$$\sigma \text{ - } \varepsilon : N[0, \varepsilon].$$

The correctness of this assumption is hypothetical, but it gives the natural connection of absolute values of time scatter with its deterministic part.

Analysis of measurement results of operating time of fuses

With respect to (3) the main aim of measurements of operation of fuses with nominal current I_N is to determine estimates A_n and α_n of coefficients A_0 and α_0 and determination of statistical features of ε based on tests for times 10 – 0,01 s.

The result are sets of current values $\{I_i\}$ for i=1,…,m and then $\{J_i\}$ and time values for melting the fuse element $\{t_i\}$ gather in vectors J and t.

Analysis aimed at determining coefficients A_n and α_n is based on approximation operating times (with respect to (3)) by function (7).

(7)
$$\begin{aligned} t_i &\cong A_n J_n^{\alpha_n} \\ i &= 1, \ldots, m \end{aligned}$$

The logarithm of function (7) will be then (8).

(8)
$$\ln t_i \cong \ln A_n + \alpha_n \ln J_i$$

The coefficients A_n and α_n can be found using least squares method (9).

(9)
$$\vec{b} = \left(\overrightarrow{X^T}\vec{X}\right)^{-1} \overrightarrow{X^T}\vec{y}$$

where

$$\vec{b} = \begin{bmatrix} \ln A_n \\ \alpha_n \end{bmatrix}; \quad \vec{X} = \begin{bmatrix} 1 & \ln(J_i) \\ \ldots & \ldots \\ 1 & \ln(J_n) \end{bmatrix}; \quad \vec{y} = \begin{bmatrix} \ln(t_i) \\ \ldots \\ \ln(t_m) \end{bmatrix}$$

The A_n is an estimate of A_0 and α_n is an estimate of α_0. For expressions 6 ÷ 8 the estimated nominal characteristic $t_n(I)$ can be expressed by (10).

(10) $$t_n(I) = \exp(b(1)) \cdot (I - I_N)^{b(2)}$$

Test measurements

The tests were performed at reduced voltage. At full voltage, the arc time would be much longer. First test measurements were carried out on 6,3 A medium voltage fuses. The pre-arcing time was measured. The results are shown in Table 1.

Table 1. Test measurements of 6,3 A MV fuses

No	Equivalent RMS value of a current in A	pre-arcing time in s
1	31,73	0,20
2	23,43	1,06
3	19,13	180,00
4	23,86	0,74
5	22,35	2,01
6	22,13	1,55
7	20,50	90,00
8	55,10	0,04
9	98,48	0,01

The time-current characteristic for 6,3 A MV fuses is shown on Fig. 3.

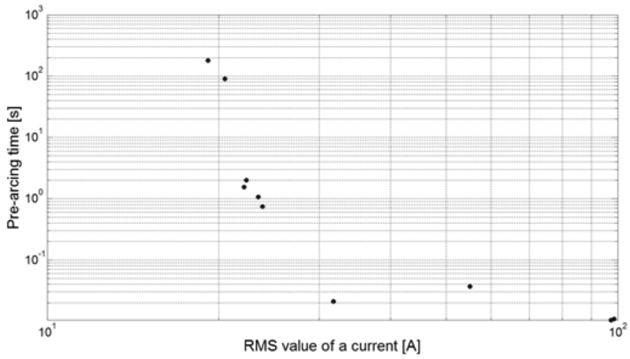

Fig. 3. Time-current characteristic for 6,3 A MV fuses

Next test measurements were carried out on 63 A MV fuses. The pre-arcing time was measured. The results are shown in Table 2.

Table 2. Test measurements of 63 A MV fuses

No	Equivalent RMS value of a current [A]	pre-arcing time [s]
1	308,71	1,976
2	240,59	7,222
3	240,00	11,003
4	963,15	0,033
5	959,83	0,033
6	554,69	0,175
7	481,02	0,324
8	616,00	0,136
9	831,34	0,037
10	743,88	0,060
11	984,26	0,027
12	1610,70	0,005

The time-current characteristic for 63 A MV fuses is shown on Fig. 4.

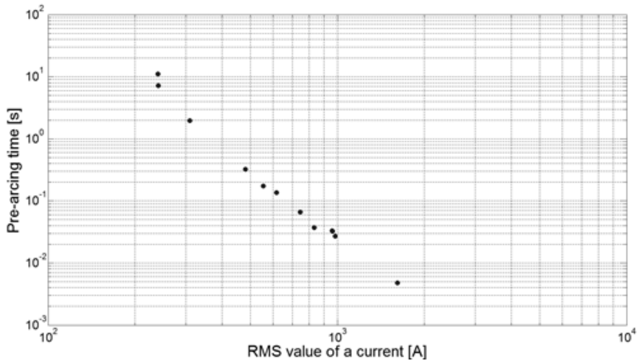

Fig. 4. Time-current characteristic for 63 A MV fuses

Conclusions

In this paper Authors showed new approach for determination time-current characteristics for fuses. The 'aggregation' method was presented with possible analysis of the measurement results. Next step will be to do test measurements on real fuses and prepare the analysis of errors of the method.

The main conclusions are:

- Test measurements showed, that proposed approach approximated good the time-current characteristics,
- Proposed method of analysis allows for such planning of experiment for optimization of cost and accuracy of obtaining the time-current characteristics,
- Improving the method requires increasing the size of the trial series in order to better characterizing the scattering the operation of fuses,
- It would be helpful - not only to improve the method, but also to improve the technology of fuses - to create a mathematical model process of melting process of the fuse element with random factors

***Authors**: dr hab. inż. Zbigniew Pochanke, Politechnika Warszawska, Instytut Elektroenergetyki, ul. Koszykowa 75, 00-662 Warszawa, E-mail:zbigniew.pochanke@ee.pw.edu.pl; dr inż. Waldemar Chmielak, Instytut Energetyki, ul. Mory 8 , 01-330 Warszawa, E-mail:waldemar.chmielak@ien.com.pl; dr inż. Tadeusz Daszczyński, Politechnika Warszawska, Instytut Elektroenergetyki, ul. Koszykowa 75, 00-662 Warszawa, E-mail:Tadeusz.daszczynski@ee.pw.edu.pl.*

REFERENCES

[1] D. Li, L. Qi, "Energy Based fuse Modelling and Simulation", Electric Ship Technologies Symposium (ESTS), 22-24 April 2013
[2] Technical Application Guide, Fuse Characteristics Curves And Charts, Littelfuse
[3] C. Jiong, W. Jimei, "Using a Parallel Resonance Circuit to Measure Time-Current Characteristics of High Voltage Current-Limiting Fuses", 8th International Conference on Electric Fuses and their Applications, 10-12 Sept. 2007
[4] W. Tian, C. Lei, Y. Zhang, D. Li, R. Fu, R. Winter, "Data Analysis and Optimal Specification of Fuse Model for Fault Study in Power Systems", Power and Energy Society General Meeting (PESGM), 17-21 July 2016
[5] Wesołowski M., Niedbała R., Kucharski D., "Thermovision techniques precision of temperature measurements", Przegląd Elektrotechniczny, volume 85, Issue 12, pages 208 - 211, ISSN 0033-2097
[6] A. Wright, P. G. Newberry, "Electric Fuses", IEE Power & Energy Series, vol. 49, 3rd edn, London, 2001