# ANALYTICAL IDENTIFICATION OF THE FUSES PROTECTION CHARACTERISTICS

PhD, Prof. Eng. **Virgil MAIER**, PhD, Student Eng. **Victoria-Florica POLEC,**
PhD, Prof. Eng. **Sorin-Gheorghe PAVEL,** PhD, Assist. Eng. **Horia-Gheorghe BELEIU**

Technical University of Cluj-Napoca, Electrical Engineering Faculty,
Department of Electrical Power Systems and Management, Cluj-Napoca, Romania.

**REZUMAT. Principalul obiectiv al prezentei cercetări îl reprezintă identificarea de funcții analitice pentru caracteristicile de protecție ale SF, care să poată fi utilizate direct, în redarea rapidă a caracteristicilor şi în analiza selectivității, precum şi în cadrul unor programe pe calculator, pentru analiza asistată a condițiilor de selectivitate.**

**Cuvinte cheie:** caracteristicile timp-curent a siguranțelor fuzibile, identificarea analitică a funcțiilor

**ABSTRACT. The main objective of this study is the analytical identification of the fuses protection characteristics, which can be used directly, in the fast rendering of the characteristics and in selectivity analysis, as well as in the context of computer programs, for the assisted analysis of the selectivity conditions.**

**Keywords:** fuses time-current characteristics, functions analytical identification

## 1. INTRODUCTION

Ensuring the receivers and electrical networks protection is one of the most important technical issues for the proper and safety operation of the electrical networks. Regulations in the fuses field, as the most common protection device against the short circuit over currents and even the overload in low voltage (LV) and medium voltage (MV), determine the fuses types compared to deliveries, rated current range for socket and fuses elements and also for their protection characteristics [1].

The fuses time-current characteristics is regulated by international standards, in graphical form, indicating a range from the time-current plan, in which they situate the pre-arc time in relation with the surge presumed [6]. Producers of the fuses give the time-current characteristics in graphical form also, bringing together the ensemble of the curves in plan in a diagram corresponding to a particular type of fuse [7].

Accordingly, the only way to analyze the protection selectivity, both between the fuses and also between fuses and other protection devices, remain the protection characteristics represented on the same graphic, for the devices of which selectivity aims to. The time intervals between time-current characteristics of two series protection devices must meet the values and positions indicated in [3], and the possible intersection point to be outside the range defined by the maximum short circuit presumed current.

## 2. TECHNICAL CHARACTERISTICS OF FUSES

### 2.1. Fuses types

From the protected elements point of view, so the intended use, the following types of LV fuses are manufactured: of general use, for the electrical motors protection, transformers, power lines, semiconductor devices, photovoltaic modules and mining installations. Leaving aside the particular applications, it highlights [1], [2] the following LV fuses types:

- **gG,** of general use (G), performing the protection for the overcurrents full range (g), and where is considered included the fuses type designed for lines and cables protection (gL);
- **gTr,** for power transformers protection (Tr), on the overcurrents full range (g), spotted even by transformers apparent power, which protection are designed for;
- **aM,** for receivers short-circuit protection, which supplies electrical motors (M), providing protection on an overcurrents limited area (a), namely short-circuit currents range. In such circuits, if the receiver overload protection is required (according to norm I7) is necessary to provide a device for overload protection, which can be a thermal relay combined with a contactor, the latter acting as execution element.

According to a time-current characteristics classification prior to defining the types above, it can be said that the first two types, gG and gTr, have fast type characteristics, and the aM fuses have slow type ones [3].

## 2.2. Rated current range

The fuses types above mentioned, made in the thread form construction, with an average breaking strength or with knives, taken with high breaking capacity (MPR), are differentiated both by the socket rated current and fuse element as well. Because for the paper objective is important to refer the fuse element rated current $I_{Fn}$, their normalized range for the aM, LV fuses, it is shown in Table 1 [7].

*Table 1*

Nominal values series of the LV fuse elements rated currents $I_{Fn}$, aM type

| Ratio | Fuse element rated current $I_{Fn}$, A | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2** | **4** | **6** | **8** | **10** | **12** | **16** | **20** | **25** | **32** | **40** | **50** | **63** | **80** | **100** |
| $q_F$ | 2 | 1,5 | 1,33 | 1,25 | 1,2 | 1,33 | 1,25 | 1,25 | 1,28 | 1,25 | 1,25 | 1,26 | 1,27 | 1,25 | |
| $q_{Fmed}$ | 1,494 | | | | | 1,259 | | | | | | | | | |
| | 1,732 | | 1,264 | | | | | | | | | | | | |

*Table 1 (cont.)*

| Ratio | Fuse element rated current $I_{Fn}$, A | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **100** | **125** | **160** | **200** | **250** | **315** | **400** | **500** | **630** | **800** | **1000** | **1250** |
| $q_F$ | 1,25 | 1,28 | 1,25 | 1,25 | 1,26 | 1,27 | 1,25 | 1,26 | 1,27 | 1,25 | 1,25 | |
| $q_{Fmed}$ | 1,258 | | | | | | | | | | | |

In table is also present the reports values $q_F$, between two successive fuses rated currents, determined by the relationship:

$$q_{F(k)} = I_{Fn(k+1)} / I_{Fn(k)}, \qquad (1)$$

where $I_{Fn(k)}$ represents the fuse element rated current, on $k$ position, in the nominal values series, and $I_{Fn(k+1)}$ are the same but on next position, ($k$+1). This way, the report defined by (1) it is the geometric progression ratio, represented by the nominal values series, with discrete and average values, on certain periods or decades, specified in the table above.

Because for the two decades values, with a consistent representation, such as those for the meeting multitudes:

$$I_{Fn} \in \{10 \div 100\} \cup \{100 \div 1.000\}\, A \qquad (2)$$

are defined ten values on a decade, the more exactly ratio for such a geometric series is given by relationship:

$$q_F = \sqrt[10]{10} = 1{,}258925, \qquad (3)$$

value that is found, with a technical admissible error (table 1), on an extended nominal values range, such is the one defined with $I_{Fn} \geq 6\ A$.

Therefore, an important range of the rated current $I_{Fn}$,, it can be write the recurrence relation between the fuse elements rated currents, such:

$$I_{Fn(k+1)} = q_F \cdot I_{Fn(k)}, \qquad (4)$$

where the indices, $k$ and ($k$ +1), have the same meanings as defined above.

## 2.3. Time-current characteristics

The overcurrent which claims the fuses, at a time, noted with $I_F$, normalized called presumed short-circuit current. The time interval between the occurrence moment of an overcurrent, circuit which includes a fuse and the melting parts of the lower section of its fuse element represents the pre-arc time.

The fuse time-current characteristic renders the relationship between the pre-arc time, denoted with $t_d$, and the presumed short-circuit current $I_F$, of general function form:

$$t_d = f(I_F), \qquad (5)$$

being represented in double logarithmic scale, because of the extended range of values (on 5-6 decades), of the two quantities involved. Figure 1 shows the time-current characteristics family, for aM fuses type, according [7]; these characteristics will be further analyzed and identified.

Even if the fuse with rated current $I_{Fn} < 2\ A$ is dropped, there are up to 25 characteristics which must be identified. In attempt to reduce the number of time-current characteristics, it was proceeded to generalize the characteristics abscissa, by reporting the presumed short-circuit current $I_F$ to the fuse element rated current $I_{Fn}$, for each characteristic.

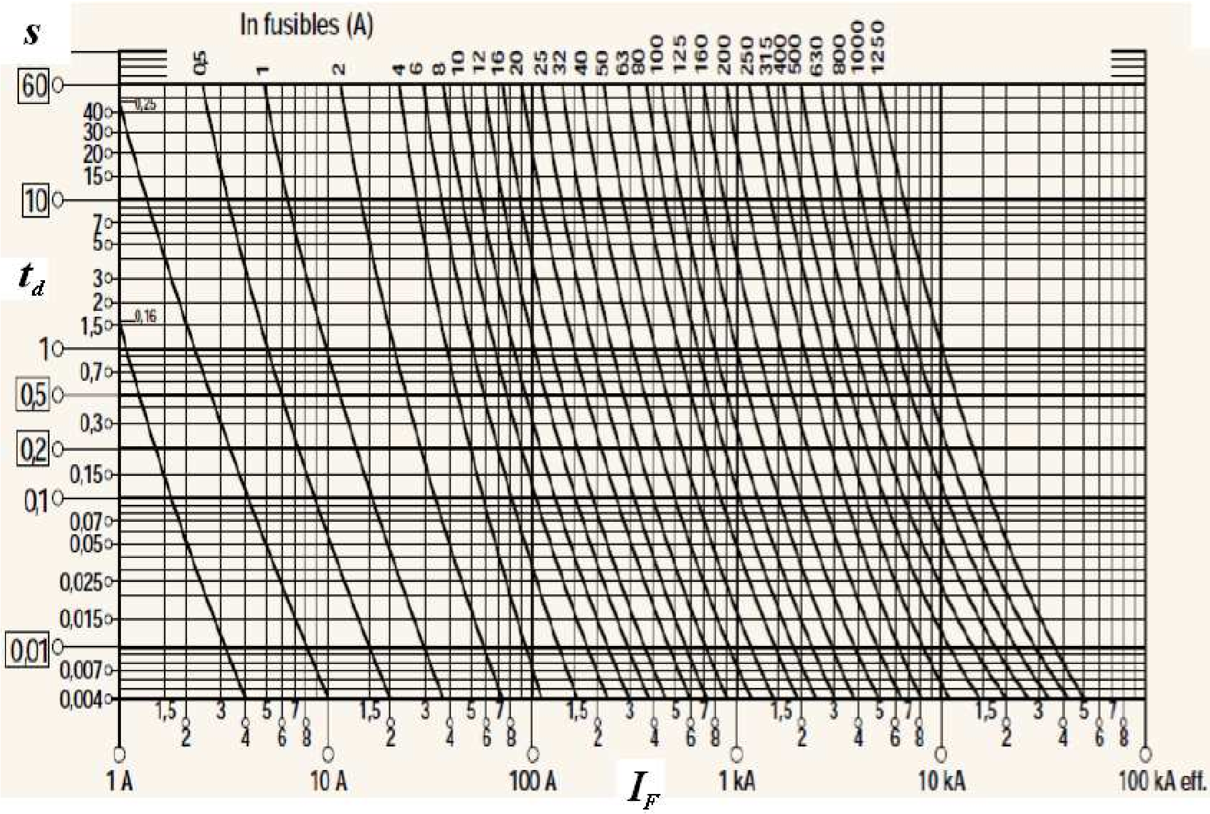



**Fig. 1.** Fuses time-current characteristics, aM type, for fuse elemenst rated currents range $I_{Fn} \in \{1 \div 1250\} A$ .

In this way, there were obtained protection characteristics, having the following form:

$$t_d = f(I_F / I_{Fn}), \quad (6)$$

so the ordinates preserves the pre-arc time $t_d$, of the initial time-current characteristics, expressed in absolute values as well. However, for the exposure simplicity, the characteristics expressed like in relationship (6) will be referred to by the relative protection or time-relative current characteristics.

Through closer characteristics mediation, on a wide range of the short-circuit relative currents ($I_F/I_{Fn}$) and limit recorded deviations from the average values, a group of time-relative current characteristics was reached, according table 2, the seven represented characteristics, numbered at the bottom of the head table, to can be further referred.

However, for a better characteristics differentiation and groups performed additional justification, was proceeded to their graphical representation, in Figure 2.

The figure legend allows the characteristics identification through the order numbers attributed in the table 2 header. Is noted that there is a tendency that a particular characteristic, for example the one marked with 1, to presents the same pre-arc time $t_d$=40 *s* at the higher relative currents than the one marked with 2, maintaining on top of it until an intersection point, when the first one passes below.Practically, this phenomenon has prevented the association of several individual characteristics within the same average characteristic.

*Table 2*

**Time-relative current characteristics group and defining the average characteristics, $t_d=f(I_F/I_{Fn})_{med}$**

| **$t_d$, s** | **$I_{Fn}$, A** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **4** | **6, 12, 63** | **8, 20, 50, 80, 125, 160, 200** | **10, 100, 250, 315** | **16, 25, 32, 40** | **400, 1250** | **500, 630, 800, 1000** |
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| **60** | 5,7 | 4,90 | 4,51 | 4,54 | 4,47 | 4,24 | 4,14 |
| **30** | 5,93 | 5,24 | 4,82 | 4,93 | 4,87 | 4,49 | 4,44 |
| **10** | 6,75 | 5,96 | 5,61 | 5,83 | 5,43 | 5,26 | 5,18 |
| **3** | 8,18 | 7,10 | 6,73 | 6,86 | 6,54 | 6,49 | 6,31 |
| **1** | 9,65 | 8,49 | 8,09 | 8,27 | 7,74 | 7,96 | 7,67 |
| **0,4** | 11,3 | 10,09 | 9,62 | 9,84 | 9,15 | 9,63 | 9,37 |
| **0,2** | 12,5 | 11,30 | 10,97 | 11,23 | 10,45 | 11,25 | 10,99 |
| **0,1** | 14,3 | 13,43 | 12,81 | 13,23 | 12,38 | 13,30 | 13,26 |
| **0,04** | 17,2 | 16,60 | 16,09 | 16,51 | 15,38 | 16,95 | 17,68 |
| **0,02** | 19,7 | 19,13 | 18,82 | 20,04 | 17,88 | 21,05 | 21,57 |
| **0,01** | 23,5 | 23,73 | 23,67 | 24,48 | 22,35 | 28,40 | 29,60 |
| **0,007** | 25 | 26,23 | 26,43 | 27,79 | 24,88 | 32,60 | 34,63 |
| **0,004** | 28 | 29,83 | 30,29 | 31,72 | 28,60 | 39,55 | 42,72 |

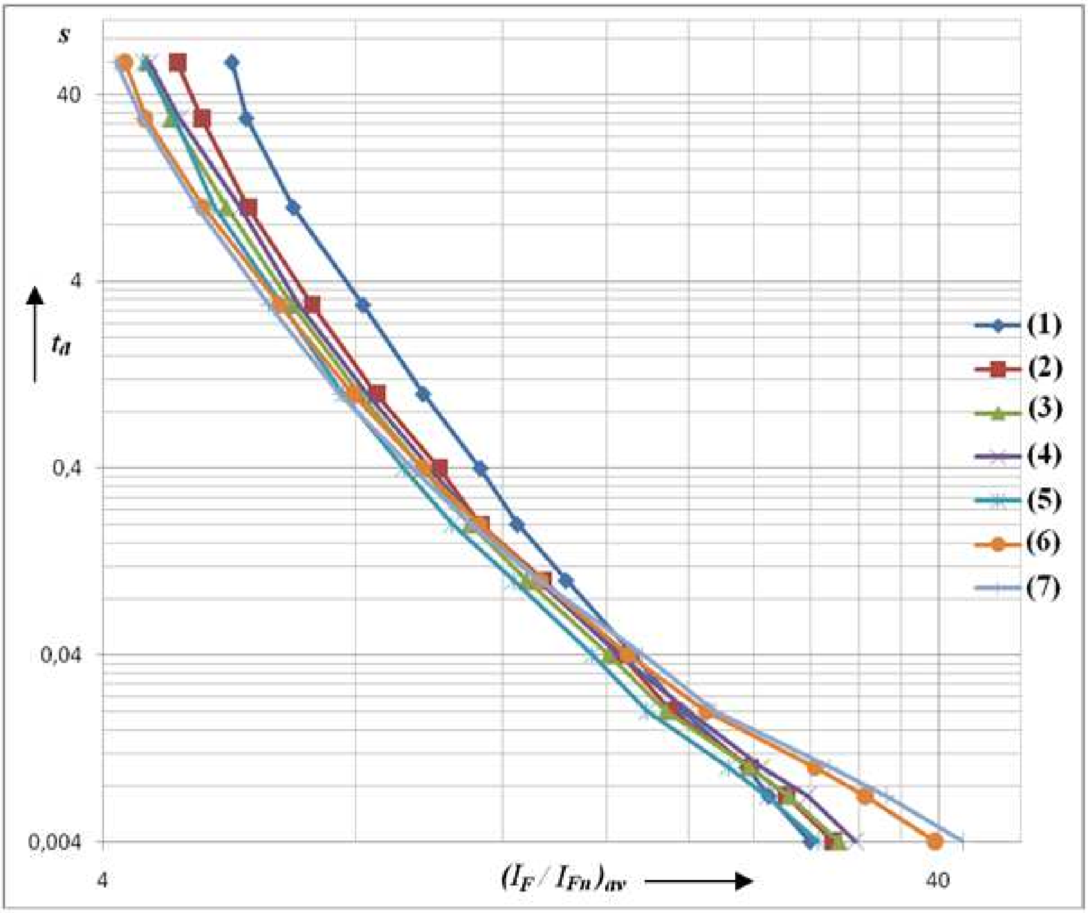



**Fig. 2.** Graphical representation of the time-relative current average characteristics, for the fuses group, aM type, highlighted in Table 2

## 3. OPTIMAL IDENTIFICATION PROGRAM

### 3.1. LabVIEW program

The large number of available elementary functions, as well as the combinations of points that can be taken into account in order to determine their parameters, lead to the need of developing a computation program, which will realize the identification of the requested dependence by scanning all possible variants.

The idea of an overall program, to identify a minimum error function and express it by a single function across the entire variation range of the independent variable, concretized in LabVIEW, appreciated for its offered facilities in the engineering research domain . The developing of some applications for the optimal identification is useful both in the domains in which they interfere, but also for the verification and development of the facilities which are provided by this original program.

From the mathematical point of view, it would be desirable that the expressions of the identified functions to be as simple as possible, the character of the function to remain unchanged, meaning to maintain the monotony intervals of the initial function and the deviations of the identified function to be within the domain of an admitted error.

Another condition taken into account is to have a single function across the domain of definition, so identifications as Spline functions type are not considered. There are also situations where, for a certain experimentally function, more than one optimal function are returned and which are between the range of the admitted error. In such cases, taking into account the necessities imposed by the practical applications in which this function interfere, the user can opt for different analytical expressions, that corresponds to the specific needs of the considered application.

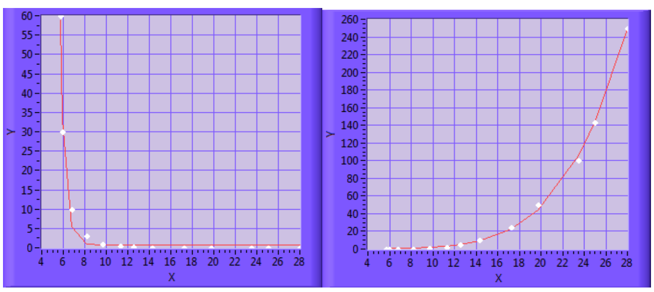
### 3.1. Analytical identification of the fuses time/current operating characteristics

Table 2 shows the pairs of coordinates $(t_d, (I_F / I_{Fn})_{med})$, as determined from the graph, for thirteen points comprising as better as possible the domain of interest. By entering this coordinates in the identification program and running it for all implemented functions, were identified and showed two of the best determinations, for each function, under the aspects of errors and manageability, concentrated in Table 3, where "$z = t_d^{-1}$".

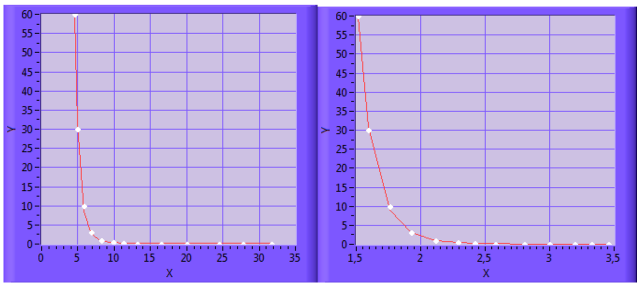
*Table 3*

**The Optimal Identified Functions**

| **Optimal identified approximation function** $t_d = f(I_F / I_{Fn})_{med}$ | **RMSD, %** |
|---|---|
| "$I_{Fn} = 4$" $t_d(I_F/I_{Fn})_{med} = 7{,}1867 \cdot 10^{-14} \cdot [\sin(I_F/I_{Fn})_{med}]^{-14{,}8627} + 0{,}7292$ | 6,165 % |
| $z(I_F/I_{Fn})_{med} = 1{,}3065 \cdot 10^{4} \cdot [\sin(I_F/I_{Fn})_{med}]^{5{,}2438} + 0{,}6264$ | 1,587% |
| "$I_{Fn} \in \{6;12;63\}$" $t_d(I_F/I_{Fn})_{med} = 2{,}0812 \cdot 10^{-9} \cdot [\sin(I_F/I_{Fn})_{med}]^{-9{,}7848} + 0{,}3051$ | 2,013 % |
| "$z = \ln(I_F/I_{Fn})_{med}$" $t_d(z) = 5{,}2442 \cdot 10^{-14} \cdot [\sin z]^{-16{,}0918} + 0{,}21$ | 1,396 % |
| "$I_{Fn} \in \{8;20;50;80;125;160;200\}$" $t_d(I_F/I_{Fn})_{med} = 2{,}4189 \cdot 10^{-9} \cdot [\sin(I_F/I_{Fn})_{med}]^{-9{,}4044} + 0{,}3908$ | 3,267 % |
| $z(I_F/I_{Fn})_{med} = 3{,}6660 \cdot 10^{3} \cdot [\sin(I_F/I_{Fn})_{med}]^{3{,}9453} + 0{,}2765$ | 2,058 % |
| "$I_{Fn} \in \{10;100;250;315\}$" $t_d(I_F/I_{Fn})_{med} = 1{,}3549 \cdot 10^{-7} \cdot [\sin(I_F/I_{Fn})_{med}]^{-7{,}8447} + 0{,}222$ | 2,091% |
| "$z = \ln(I_F/I_{Fn})_{med}$" $t_d(z) = 1{,}2577 \cdot 10^{-18} \cdot [\sin z]^{-12{,}461} + 0{,}0745$ | 1,403% |
| "$I_{Fn} \in \{16;25;32;40\}$" $t_d(I_F/I_{Fn})_{med} = 1{,}8061 \cdot 10^{-8} \cdot [\sin(I_F/I_{Fn})_{med}]^{-8{,}5923} + 0{,}1074$ | 1,941% |
| $z(I_F/I_{Fn})_{med} = 4{,}4451 \cdot 10^{3} \cdot [\sin(I_F/I_{Fn})_{med}]^{3{,}921} - 0{,}0518$ | 1,709% |
| "$I_{Fn} \in \{400;1250\}$" $t_d(I_F/I_{Fn})_{med} = 8{,}5922 \cdot 10^{-11} \cdot [\sin(I_F/I_{Fn})_{med}]^{-10{,}46} - 0{,}0518$ | 4,870 % |
| $z(I_F/I_{Fn})_{med} = 9{,}785 \cdot 10^{2} \cdot [\sin(I_F/I_{Fn})_{med}]^{3{,}0434} - 0{,}42$ | 1,801% |
| "$I_{Fn} \in \{500;630;8000;1000\}$" $t_d(I_F/I_{Fn})_{med} = 2{,}954 \cdot 10^{-9} \cdot [\sin(I_F/I_{Fn})_{med}]^{-9{,}0232} - 0{,}3855$ | 3,041% |
| $z(I_F/I_{Fn})_{med} = 7{,}4693 \cdot 10^{2} \cdot [\sin(I_F/I_{Fn})_{med}]^{2{,}8417} - 0{,}6494$ | 1,803% |



a1 a2



b1 b2

**Fig. 6.** Graphical representations of the identified functions and the initial points: a1/a2 – optimal functions for "$I_{Fn} = 4$"; b1/b2 optimal functions for "$I_{Fn} = 10;100;250;315$".

## 4. CONCLUSIONS

Analytical identification of the fuses time-current characteristics is the general problem part of the examination and assuring protection selectivity.

Through reporting the presumed short-circuit currents to fuse rated current it succeed to reduce the characteristics number, which could be analytical determined, with acceptable errors values.

The software program for the analytical identification of the tabular form functions, permitted selecting those functions with the lowest mean square deviation on the independent variable entire range. Interesting is the fact that the optimal function was a power of sinus function. This suggest that a physical model that highlights the time-current characteristic analytical, should be based on such a function.

## BIBLIOGRAPHY


[1] **Bessei, H.** Fuse Manual, Power fuses, Manual for users of low-voltage and high-voltage fuses. Lappersdorf: Kerchensteiner Verlag, 2011.

[2] **Lucache, D. D.** Instalații electrice de joasă tensiune, Baze teoretice şi elemente de proiectare. Iaşi: Editura PIM, 2009.

[3] **Maier, V., Pavel, S. G. şi Beleiu, H.G.** Ghid pentru proiectarea instalațiilor electrice la consumator. Cluj-Napoca: Editura UTPRESS, 2013.

[4] **Polec, Victoria, Maier, V. and Carafa, L.** Analytical identification of the graphic or tabular functions using a Lab VIEW Programme. In: Acta Electrotehnica, Special Issue, Vol. 52, Number 5, 2011, pp. 356-361, Cluj-Napoca.

[5] *** Îndreptar de proiectare a protecției prin relee şi siguranțe fuzibile în PT şi în rețeaua de joasă tensiune, 1 RE–Ip 45–90. Bucureşti: ICEMENERG, 1993.

[6] STAS 4173/1-98 Siguranțe fuzibile de joasă tensiune, cu mare putere de rupere, pentru scopuri industriale şi analoage.

[7] *** Cahier Technique, Systems de coupure et de protection, SOCOMEC, 2011.

## About the authors

Prof. Eng. **Virgil MAIER**, PhD.,
Technical University of Cluj-Napoca, Electrical Engineering Faculty, Department of Electrical Power Systems and Management, G. Barițiu 26-28, 400027 Cluj-Napoca, Romania.
email: virgil.maier@enm.utcluj.ro

Graduated the Technical University of Cluj-Napoca, Electrical Engineering Faculty. Since 1970 he works in the Technical University of Cluj-Napoca, Electrical Engineering Faculty, Department of Electrical Power Systems. The research topics: electrical installations and lighting, power quality, simulation and modeling of electrical power systems.

Eng. **Victoria Florica POLEC**, PhD. Student,
Technical University of Cluj-Napoca, Electrical Engineering Faculty, Department of Electrical Power Systems and Management, G. Barițiu 26-28, 400027 Cluj-Napoca, Romania.
email: victoria.polec@enm.utcluj.ro

Graduated the Technical University of Cluj-Napoca, Electrical Engineering Faculty, Department of Electrical Power Systems and Management. After finishing the university he started PhD studies at Department of Electrical Power Systems and Management.

Prof. Eng. **Sorin Gheorghe PAVEL**, PhD.,
Technical University of Cluj-Napoca, Electrical Engineering Faculty, Department of Electrical Power Systems and Management, G. Barițiu 26-28, 400027 Cluj-Napoca, Romania.
email: sorin.pavel@enm.utcluj.ro

Graduated the Technical University of Cluj-Napoca, Electrical Engineering Faculty. After finishing the university he worked in the Institute of Computing Technique Cluj-Napoca as designer. Since 2001 he works in the Technical University of Cluj-Napoca, Electrical Engineering Faculty, Department of Electrical Power Systems and Management. The research topics: electrical installations and lighting, power quality, simulation and modeling of electrical power systems.

Assis. Eng. **Horia Gheorghe BELEIU,** PhD,
Technical University of Cluj-Napoca, Electrical Engineering Faculty, Department of Electrical Power Systems and Management, G. Barițiu 26-28, 400027 Cluj-Napoca, Romania.
email: horia.beleiu@enm.utcluj.ro

Graduated the Technical University of Cluj-Napoca, Electrical Engineering Faculty, Department of Electrical Power Systems and Management. After finishing the university he started PhD studies in Power Quality. Now he works at Technical University of Cluj-Napoca as Assistant to Department of Electrical Power Systems and Management.