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TECHNICAL AND ECONOMICAL ANALYSIS FOR THE LOW VOLTAGE ELECTRICAL NETWORK ORGANIZING METHODS

BY

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Abstract. The low voltage (LV) electrical network organizing involves both the establishing of the distribution steps number and the distribution points number, the last one being finally defined as Distribution Panels (DP). For establishing of the DP number, the last decade had offered some technical and technical-economical methods fundaments. The comparison between the results offered by the three previously studied methods, completed with an economical approach, represents the main aim of this paper. Among them, the determination of the optimal economical number of receivers per DP is emphasized through the use of the principal economical cost of the electrical components as the analytical base. The minimization of the demand currents total moment does use an objective function that is direct proportional with the power losses and the network conductors material.

Key words: distribution panel/point; demand currents moment; actualized total costs; implicit selectivity.

1. Introduction

One of the most important aspects in the low voltage (LV) electrical network distribution, still not enough outlined in the technical literature, is the

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optimal structural determination. This involves the final determination over the network type and the end-users and consumers grouping on the distribution panel (DP). Owing the advantages and the spreading (Maier & Pavel, 2002), it can be considered that the LV distribution network is a radial one, the advantageous version which has been taken into consideration being the "two steps" one. Over the last mentioned structure, three technical methods have been applied (Maier *et al.*, 2006) with useful results in designing. Thus, from the general distribution panel (GDP), the secondary DPs are directly connected. These aspects being known, the next step is the determination of the number of DPs and the number of receivers on each DP.

2. Theoretical Basis

2.1. Analytical Grouping Methods for Electrical Receivers

Some of the recognized analytical methods (Mateaş, 2010) which offer specific information regarding the number of DP are

a) DP economic optimum number;
b) minimization of the demand currents for the total moment;
c) the implicit selectivity condition.

a) *DP economic optimum number*

The determination of the economic optimum number of the distribution points has been substituted by Maier *et al.* (2006) by estimating and economic optimum number of equivalent receivers on a DP. The proposed relationship for the economic optimum number of electrical receivers is

$$N_{oe} = \frac{N}{n_D} = n_N^{1/3}\left(\frac{4aA_D}{k_r a_r}\right)^{2/3}, \tag{1}$$

N being the receivers total number; n_D – the DP economic optimum number; $v_N = N/A_s$ – the receivers medium number on the bay surface unit; a – the updating rate; A_D – constant component of DP cost; k_r – the coefficient of the radial network configuration (Mateaş, 2010); a_r – specific expenses for an electrical output with I_N as rated current, given by the relation

$$a_r = aa + 3b\,'t a_i^2\, r\, I_N J_N, \tag{2}$$

where: J_N is the calculus density for the I_N current at DP outputs, α – the constant component of the specific cost for the electrical line, k, with a s_k section; ρ – the resistivity of the conductor material; β' – the specific cost of the energy losses; τ – maximal lowes duration (Kajalov, 1986); I_{med}/I_N – the utilization medium coefficient of the electrical receivers connected at the end of the k radial line.

According to relationship (1), a nomogram has been elaborated (Mateaş, 2010), which represents both qualitatively and quantitatively the dependences expressed by the mentioned relationship. Having N_{oe} already determined, the DP economic optimum number is decided by the relation

$$n_D = \left[\frac{N}{N_{oe}} \right], \tag{3}$$

where the brackets mean the "integer part"; as it was mentioned before, the DP economic optimum number choice is facilitated by identifying a range for N_{oe}.

The relation (1) has been obtained in accordance with the results established by Maier *et al*. (2006), by minimizing the update total costs for the ensemble conductors – DP, that confers a special importance to the results. At the same time, by transforming the relation (1) according to the results obtained by one of the authors (Mateaş, 2010), a relative constancy of the calculus results has been emphasized *versus* the costs evolution. The only objection to the relation (1) is that the analytical basis for its deduction appears (Maier, *et al*., 2006), but not the demonstration.

b) *Minimization of the demand currents total moment*

Owing its proportionality with the power losses and with the used conductors volume (Maier & Pavel, 2001; Mateaş, 2010), the demand currents moment (DCM) represents the most important and synthetic indicator of the electrical networks. The DCM deep significances impose this one as a veritable working instrument in the end-users electric power organizing. The method for the DP optimum number determination by minimizing the total DCM is presented by Maier *et al*. (2006) for a two steps radial distribution network.

The following relationship has been obtained for the total DCM, in the aggregate of the two steps radial network:

$$M_t(I_c) = M_{t0} \left[\frac{n_2 + n_1 \gamma_a}{(1+\gamma_a) n_1 n_2 \cos \varphi_n} + \frac{k_c^{'}}{\cos \varphi_c} \right], \tag{4}$$

M_{t0} representing the constant part of the expression which may be calculated with relation

$$M_{t0} = \frac{n P_n (L_1 + L_2)\sqrt{3 D A_n}}{4 U_{ln}}, \tag{5}$$

while the other variables are: L_1 , L_2 – the length, respectively the width of the area where the consumer receivers are placed; n – number of identical receivers, uniformly distributed in plan, with the known technical characteristics (P_n , DA_n, η_n , cos φ_n); k_c , cos φ_c – consumption characteristics: demand coefficient and demand power factor, respectively; n_1 , n_2 – divisions numbers of the area, on the length or/and the width; $\gamma_a = L_2/L_1$ – area aspect ratio corresponding to the feeding network; $k_c^{'}$ – the corrected demand coefficient for $n_{rD} = n/(n_1 n_2)$ receivers, the product from the denominator being just the total number of the divisions n_D, *i.e.* of DP

$$n_D = n_1 n_2; \tag{6}$$

U_{ln} – the rated line voltage for the three-phase receivers.

The expression of the corrected demand coefficient is

$$k_c^{'} = k_c + \frac{1 - k_c}{k_a}, \tag{7}$$

where k_c is the demand coefficient of the receivers category and k_a – the influence coefficient of the receivers number (Kajalov, 1986), determined for n_{rD} receivers grouped on the same DP.

Modifying the divisions number only on the length or only on the width, as well as the total number of divisions and calculating the $M_t(I_c)$ function values according to (4), some characteristics presented in Fig. 1 were determined, which emphasizes the minimum points.

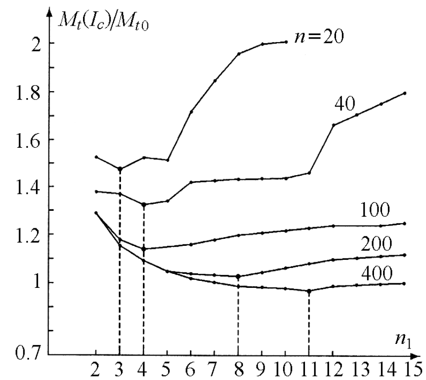

Fig. 1 – Influence of the receivers number, *n*, on the minimum objective function values, based on the length dividing of the consumer area disposal ($\gamma_a = 0.5$).

c) *The implicit selectivity condition*

This original method, proposed by Mateaş (2010), has as initial hypothesis the use of fuses (SF) for the short-circuit protection for both the receivers circuits and the columns circuits. The receivers and the receivers circuits protections are dimensioned and adjusted in accordance with the fusible rated current on a receiver circuit being I_{nfr}.

The main condition on which this method is based is

$$\left(n_{rD}-1\right)\left(k_c+\frac{1-k_c}{k_a}\right)\leq\frac{\cos j_c}{\sqrt{DA_n}}\left(\frac{\sqrt{3}q_f^2 I_{nfr}U_{ln}}{P_n}-\frac{l}{h_n c\cos j_n}\right), \tag{8}$$

where: q_r is the geometrical progression ratio, represented by the values series for the fuses nominal currents; c – safety starting coefficient; λ – relative starting current for the equivalent receiver, all the other symbols being presented early.

Its solutions have to be numerically identified, because no analytical expression is known for the correction factor, k_a , but only its chart *versus* the end-user number of receivers. Computing firstly the left member which has a general character and secondly the right one, that contains the specific data of the equivalent receiver and comparing their values, n_{rD} is determined. The variation of n_{rD} *vs.* the receivers rated powers, deduced according to (8), is presented in Fig. 2.

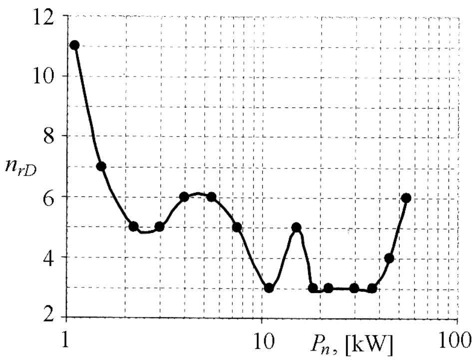

Fig. 2 – The receivers minimum number on a DP *vs.* the receivers rated power.

2.2. Optimum DP Number on the ATC Basis

The Actualized Total Costs (ATC) calculus for the distribution network is performed using the following relation:

$$Z_{Ld}=\sum_{k=1}^{n_{Ld}}\left[a\left(a_k+b_k s_k\right)+3b'ta_i^2 r\frac{I_{Nk}^2}{S_k}\right]l_k, \tag{9}$$

while for the feeding network ATC calculus is used the relation

$$Z_{Lf} = \sum_{k=1}^{n_{Lf}} \left[a\left(a_k + b_k s_k\right) + 3b' t a_i^2 r \frac{I_{Nk}^2}{S_k} \right] l_k , \tag{10}$$

where S_k and l_k are the section, respectively the length for the k radial network ramification; n_L – lines number; $\alpha + \beta S_k$ – total specific cost for the k ramification with the l_k length and S_k section; a – the updating rate, without the maintenance costs (a = 1/years number); ρ – line conductor material resistivity; β' – specific cost for the energy losses, [Eur/kWh lost]; τ – maximum power losses period (t_{PM} , cos φ_{nat}); $\alpha_i = I_{medk}/I_{Nk}$ – medium usage coefficient for the electrical end-users connected at the end of radial line k; it is also called ***loading coefficient*** and is approximately equal to k_{cmed} (medium demand factor).

The total investments costs for n_D DPs are

$$Z_D = \sum_{j=1}^{n_D} \left[A_{Dj} + n_{pj} \left(B_{TDj} + C_{TDj} I_{Nj} \right) \right], \tag{11}$$

where: n_p is the outgoing number from a DP; I_N – nominal outgoings current; B_{TD} , C_{TD} – constants that allow the variable components calculus for an installed DP; A_D – constant component costs for one installed DP.

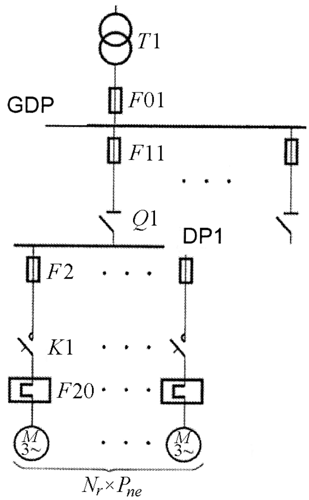

Fig. 3 – General structural circuit variant.

The total costs are

$$Z_T = Z_{Ld} + Z_D + Z_{Lf} . \tag{12}$$

The structural analysed variants, following the general distribution scheme, are presented in Fig. 3.

3. Comparative Analysis Methods and Economical Implementation

3.1. Initial Hypothesis

This paper is based on the following initial assumptions:

a) the equivalent receivers area has a rectangular shape, with the length $L_1 = 30$ m and the width $L_2 = 20$ m, resulting an aspect ratio of $\gamma = L_2/L_1 =$ $= 0.67$;

b) the equivalent receivers number belongs to the $n \in \{40, 100\}$ domain and the nominal power range has been chosen $P_n \in \{1.5; 5.5; 15\}$ kW;

c) the specific nominal characteristics, like the efficiency, power factor and the relative starting current, are established according to the rated inputs of the asynchronous motors;

d) equivalents receivers consumption characteristics are $k_c = 0.13$ and $\cos j_c = 0.5$;

e) the medium current density for the mentioned three receivers is $J_{\text{med}} \in \{2.4; 5.4; 3.9\}$ A/mm^2;

f) the DPs are considered to be positioned in such a way that the medium length for the radial networks is minimum, so the relative coordinate for the DP is $m = n = 0.5$, resulting the value $k_r = 1.015$ for the radial network configuration coefficient;

g) the loading coefficient is $a_i \cong k_{\text{cmed}} = 0.4$ for the $n = 40$ case and $a_i \cong k_{\text{cmed}} = 0.22$ for the $n = 100$ case;

h) the maximum power losses period ($\cos j_{\text{nat}}$, t_{PM}) is of 3,400 h;

i) the receivers density on the surface unit is $n_N = n/(L_1L_2) \in \{0.067;$ $0.167; 0.200\}$ m^{-2}, corresponding to those three equivalent receivers numbers, respectively.

The equipping considered for the receiver circuits, independently of their powers, can be also remarked in Fig. 3: thermal relay and contactor for the receivers protection against the accidental overloads (ex. *F*20 with *K*1) and fuse for the circuits protection against the short-circuit currents (ex. *F*2). The columns equipping configuration taken into consideration is also presented in Fig. 3, that is protection against short-circuit with fuses at the upstream end (ex. *F*11) and decoupling with separator at the downstream end, also to the entrance in the fed DP.

The final implementation realized in EDSA has been possible after that the receivers and columns circuits have been dimensioned in all analysed cases.

3.2. Comparative Results. Functionality Interpretations

The consistent application of all three considered methods, taking in consideration the initial hypothesis above mentioned, lead to the set of results presented in Table 1.

Because "the DP Economic Optimum Number N_{oe}" and "the implicit selectivity condition" methods lead to preliminary results concerning the optimum receivers number per DP, it was considered useful to include this value in the same table. The method importance is increased by using the relative economical ratios, which confers a relative stability *versus* the costs evolution; "the minimization of the demand currents total moment" method, for the two steps radial distribution network was codified using MTCC acronym.

Table 1

Receptors Number, n_{rD}, for one DP, According to Those Three Considered Methods

Method	The power and the number of the equivalent receptor								
	1.1 kW			5.5 kW			15 kW		
	40	100	120	40	100	120	40	100	120
N_{oe}	23	37	39	21	31	34	12	18	21
MTCC	10	25	30	10	25	30	10	25	30
Implicit selection	11			6			5		

The graphical representation from Fig. 4 implements the $n_{rD}(P_n)$ dependency types for the most representative cases, having the method as a parameter, when n = 40 and n = 100 equivalent receptors are involved. The case n = 120 has been intentionally omitted due to its similarity to the n = 100 one.

The DP number is determined knowing the total receivers number, n, and the receivers/DP number. The first two methods lead to the optimum DP number from the methods point of view, the implicit selectivity methods leading to the maximum number of DP that can be used also for meeting the short-circuit selectivity condition.

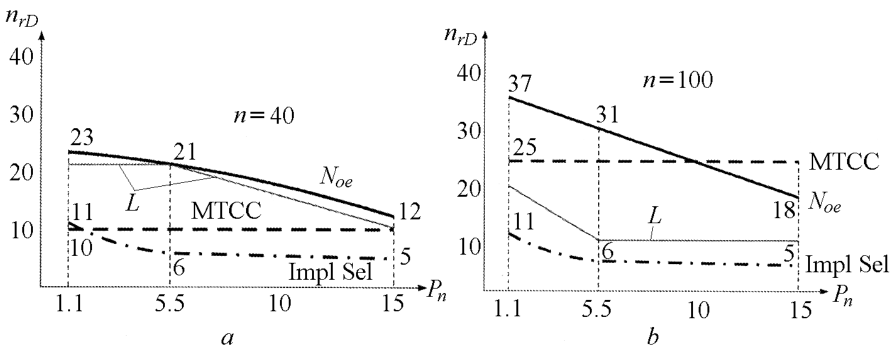

Fig. 4 – Number of receivers/DP variation *versus* the rated power of the equivalent receiver and the calculus method: *a* – for n = 40; *b* – for n = 100; the economical implementation impact.

The graphical representation is completed by the economical implementation (bill of materials and power losses dumping factor) version one (L line), which confers more accuracy in deciding the optimum method to use in electrical installation design.

3.3. Economical Implementation

Previously the EDSA simulation, unitary circuits elements have been implemented accordingly to usual costs. The distribution elements and also the equivalent receptors costs have been deliberately omitted, all of these having no impact over the cost balance.

Thus, in the ATC relations (9) and (10) the following components have been introduced: *a* – updating rate; it does not include the maintenance costs, so its value is 0.1; τ – maximum power losses period $(t_{PM}, \cos\varphi_{nat})$ is 3,400; $\rho_{Cu} = 1.7 \times 10^{-8}$ Ω.m; *b* ' – specific cost for the energy losses = 0.24 Eur/kWh tax included (home consumer, Italy, February 2008); The ramifications total cost includes the cables cost (Helukabel), separators (Schneider) and fuses plus sockets costs, all other components being deliberately omitted.

In order to have a better scalability (a real one) and a calculus accuracy as high as possible, the initial catalog prices have been used regardless of the special offers.

The variation of the DP number reported to the equivalent receiver rated power, on the ATC evolution basis, is represented in Fig. 5.

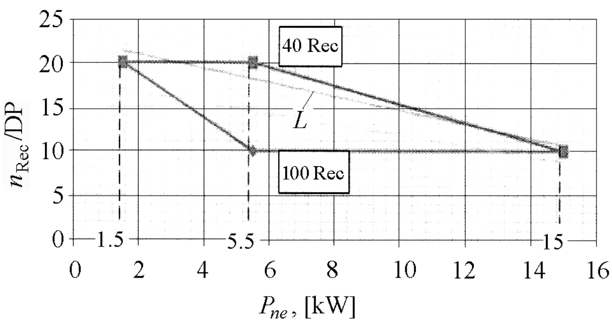

Fig. 5 – The receivers/TD number variation *versus* the rated power of the equivalent receiver.

According to Fig. 5 it can be observed that the total receivers number per DP, determined using the two analytical methods and also the EDSA economical implementation, meets in all cases (a single exception) the implicit selectivity condition (which is extremely favourable). The exception is for the inferior limit rated power of the equivalent receiver. The one unit difference between the n_{rD} = 10 number, determined using MTCC method and n_{rD} = 11 minimum number, indicated by the implicit selectivity method, can be considered without importance.

As a general observation it is remarkable the fact that MTCC leads to a constant number of receivers per DP regardless of the equivalent receiver rated power. The economical implementation has also constant sectors (the first values for the equivalent receiver in the n = 40 and n = 100 receiver cases).

The DP number will result constant for the real implementation for n_D = 4 in the MTCC case and n_D = 2 in the practical implementation. Taking into account that the consumption characteristics and the area geometry of the receivers are constant, it can be concluded that in the initial hypothesis, the receiver number/Dp, n_{rD} , does not depend on the nominal power of the equivalent receiver, at least in the considered power domain.

According to Fig. 5 it can be noticed that the convergence is obtained when the rated powers, P_n , tends to the maximum values (15 kW), when the total receivers numbers is n = 40 (Fig. 4 *a*). For the lower power values, $P_n \in$ {1.1; 5.5} kW, the n_{rD} number determined using N_{oe} method is approximately twice greater than the value determined using the MTCC method, but the first mentioned method is confirmed also by the economical implementation (EDSA – bills of materials report) on all receiver scale in the n = 40 receivers case.

In the n = 100 total receivers number (Fig. 4 *b*) the two optimum methods graphics intersect, giving identical results in the P_n = 10 kW point; the $n_{rD}(P_n)$ curve obtained using N_{oe} method is situated, for the lower than 10 kW rated power, above the n_{rD} = 25 line, accentuated by the MTCC method and under this line for P_n > 10 kW power. The practical economic factor has confirmed the analytical methods in above 75% proportion in the n = 40 case (practically the N_{oe} method is verified on more than 90% cases), n = 100 (Fig. 4 *b*) case confirming only the values trends of the implicit selection method.

One of the interpretations of results difficulties is the fact than, even though the N_{oe} method indicates the calculus method for the optimum receiver number per DP (relation (5)), no demonstration was provided for it, important results significations being lost.

4. Conclusions

On the LV side, the receivers organization from the electric power point of view, can be analysed from the optimal condition perspective. The “Minimization of the Demand Currents Total Moment” and the “DP Economic Optimum Number” methods are presented only in brief forms in this paper, being treated in depth in other works (Maier *et al*., 2006; Mateiaş, 2010).

The common element of these two methods is the economical aspect, the first method following the actualized total costs minimum, and in the second one the minimum of the power losses in the distribution network and its minimum material conductor volume.

Their utility and applicability are also confirmed by the fact that the two methods results in addition with the economic analysis, assure the implicit selectivity condition. In practical design it will be important to apply in parallel both of the optimum methods, with, in addition, an anticipated economic analysis, the final solutions resulting after the final data comparison.

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ANALIZA TEHNICO-ECONOMICĂ A METODELOR DE ORGANIZARE A REŢELELOR ELECTRICE DE JOASĂ TENSIUNE

(Rezumat)

Principalele obiective ale lucrării sunt: trecerea în revistă a metodelor analitice cunoscute, pentru alegerea numărului de tablouri de distribuţie (TD) şi analiza comparativă a acestora cu metoda bazată pe evaluarea cheltuielilor totale actualizate.

Metodele analitice, pentru alegerea numărului de TD, sunt următoarele: metoda numărului optim economic de receptoare pe un TD, minimizarea momentului total al curenţilor ceruţi pentru reţeaua radială în două trepte şi metoda determinării numărului minim de receptoare pe un TD din condiţia de selectivitate implicită.

Calculul costurilor de investiţii, pentru acea parte a reţelei de distribuţie care depinde de numărul de TD, se realizează utilizând facilităţile programului EDSA. Prin varierea numărului de puncte de distribuţie, se procedează la căutarea numerică a minimului funcţiei obiectiv, reprezetată de cheltuielile totale actualizate, pentru caracteristici tehnice date ale consumatorului.

Se consideră echiparea coloanelor electrice, care fac legătura de la Tabloul General (TG) la TD, în varianta cea mai simplă şi fiabilă, implicând protecţia prin siguranţe fuzibile la capătul amonte şi echiparea cu separator la intrarea în TD alimentat. Componenta de costuri corespunzătoare pierderilor se consideră atât de pe subreţeaua coloanelor, cât şi din cea a circuitelor de receptor.