Choice Of The Type Of Grounding The Neutral In A Medium Voltage Electrical Network

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***Abstract*—The paper presents the application of the method of hierarchical analysis from the mathematical theory of games for selecting an optimal variant for grounding the neutral in medium voltage distribution networks. Three options have been considered: an insulated neutral; a neutral, grounded through a resistor; and a neutral, grounded through a reactor. The criteria, used for selecting the optimal type of neutral grounding are: the efficiency indicator for the particular mode of operation; and the additional costs for construction of the respective type of neutral grounding. The mathematical apparatus of the game theory has been applied to the three variants in accordance with the two criteria. An algorithm has been developed, allowing to introduce a different weighting coefficient for the two criteria, taking into account the specific electrical network under consideration. The results from the calculations give the optimal variant of grounding the neutral in the medium voltage network, corresponding to the selected criteria.**

Keywords—electrical network, medium voltage, grounding of the neutral, mathematical game theory

I. Introduction

Medium voltage (MV) electrical networks use three types of grounding the neutral (GN): insulation, grounding through a resistor, and grounding through a reactor (GR) [1], [2].

The introduction of a large number of sources of decentralized generation (DG), connected to the MV distribution networks, changes both the configuration and the mode parameters in their connecting branches [3]. The choice of the optimal mode for GN in the changed conditions must be made on the basis of well-founded optimality criteria [4].

In order to choose the optimal mode for GN in real operating conditions, it is necessary to assess the influencing factors on the modes of GN under the changed operating conditions. Distribution networks without DG are usually unilaterally supplied and with a large number of branches. The connection of DG to them creates sections with two-way power supply. The capacities in the branches, the short-circuit currents, the voltages in the nodes, the emerging overvoltages and other mode parameters undergo changes [3],[5],[6],[7]. Restructuring and construction of a smart grid is the forthcoming step [8] ÷ [12].

Thus, to determine the optimal mode for GN in real operating conditions, it is necessary to assess the influencing factors on the mode parameters in the changed conditions and to choose optimality criteria.

The aim of this paper is to propose an approach for choosing the optimal mode for GN in MV distribution networks in accordance with well-justified criteria and by application of appropriate mathematical apparatus.

II. Criteria for choosing a particular GN type

The process of criteria justification for finding out the optimal GN type shows that the most appropriate for the purposes of the study are the following criteria:

- the performance indicator of the mode of operation of the grounded neutral;
- the additional costs of building the relevant GN type [4].

The efficiency indicator of the GN mode characterizes the reliability of operation of the MV electrical network in single-phase ground connections (SGC) and is evaluated by the equation

$$E_{ef} = 1 - N_2 + \frac{N_3}{N_1}, \qquad (1)$$

where N_1 is the total number of SGCs; N_2 - the number of SGCs, turning into double ground connections; N_3 - the number of SGCs, turning into interphase short circuits.

The efficiency indicator for MV electrical networks with insulated GN is E_{ef}<0,7. The specified value is higher for overhead power lines and significantly lower for cable lines in the presence of electric motors, since their insulation levels are lower, compared to the other elements in the circuit.

The values of the efficiency indicator E_{ef} in case of GN through a reactor (GR) are comparable or lower than they are in the mode of insulated GN, but in some specific cases they reach 0.8 ÷ 0.9. The efficiency index E_{ef} for GN through a resistor is comparable to that of GN through a reactor.

Additional costs and equipment are not required for insulated GN networks. GN through GR requires additional grounding costs and devices for automatic control of the compensation setting. Additional costs are also required for GN through a resistor.

III. Choosing a variant for GN by applying the mathematical theory of games

The choice of the optimal variant depends on the used data and the applied calculation method. According to the mathematical game theory, the optimal decision is made [13],[14]:

- under conditions of certainty with precisely set parameters;
- under conditions of risk, when the data are described by probability distributions;
- under conditions of uncertainty, when weighing coefficients are assigned to the data, taking into account their significance in the optimization process [15] ÷ [20].

The following criteria are selected as criteria for selecting the optimal type of GN: the mode efficiency indicator and the additional costs for building the respective type of GN. When solving the problem, not all data are precisely defined. The difficulty arises when assessing the degree of significance of the criteria through the method of hierarchical analysis. It is appropriate in these cases to apply the method of hierarchical analysis from the mathematical game theory [15].

For real studies of a MV distribution network, the modes for the different variants of GN must be considered. Three variants of GN in MV networks with DG have been developed for the purpose: A, B and C.

- Variant A - insulated GN;
- Variant B - GN through active resistance;
- Variant C - GN through GR.

In order to choose the optimal operating mode of GN, these two main criteria have been formulated:

- Criterion 1 - GN mode efficiency indicator;
- Criterion 2 - additional costs for construction of the corresponding GN variants.

Both the preliminary analysis of the criteria and the conducted expert assessment show that the efficiency indicator for the different modes of GN is as it follows: for variant A - 0.7; for variant B - 0.84; for variant C - 0.91. If variant A is accepted as a basic one, its calculated values are compared to the obtained values for variants B and C. The result in relative units (r.u.) is, respectively: variant A - 1; variant B - 1,2; variant C – 1,3 (table 1). The additional costs for GN in the three variants are also presented in r.u., namely: variant A - 1; variant B - 1.2; variant C - 1.4.

Table 1. Assessment of the variants in r.u. in accordance with the criteria and weighting coefficients for choosing a variant of GN

Criteria	Variants			Weighing coefficient
	A	B	C	
Criterion 1 – Efficiency indicator of the mode of GN	1	1,2	1,4	5
Criterion 2 – Additional costs for a variant of GN	1	1,2	1,3	1

The mode efficiency indicator is more significant than the additional costs for building the variants of GN. The efficiency of the mode is an indicator, related to the operating costs for the entire period of operation of the electricity network, and the additional costs are just one-time investments for construction of the facilities. The corresponding weighting coefficients for criteria 1 and 2 are respectively 5 and 1. (Table 1).

The analysis, aiming at assessing the three variants, is performed from the point of view of the two criteria (Table 2). For the criterion, related to mode eficiency, the weighting coefficient is p_1, while for the additional costs it is p_2.

The structure of the problem for making the optimal decision is given in Fig.1.

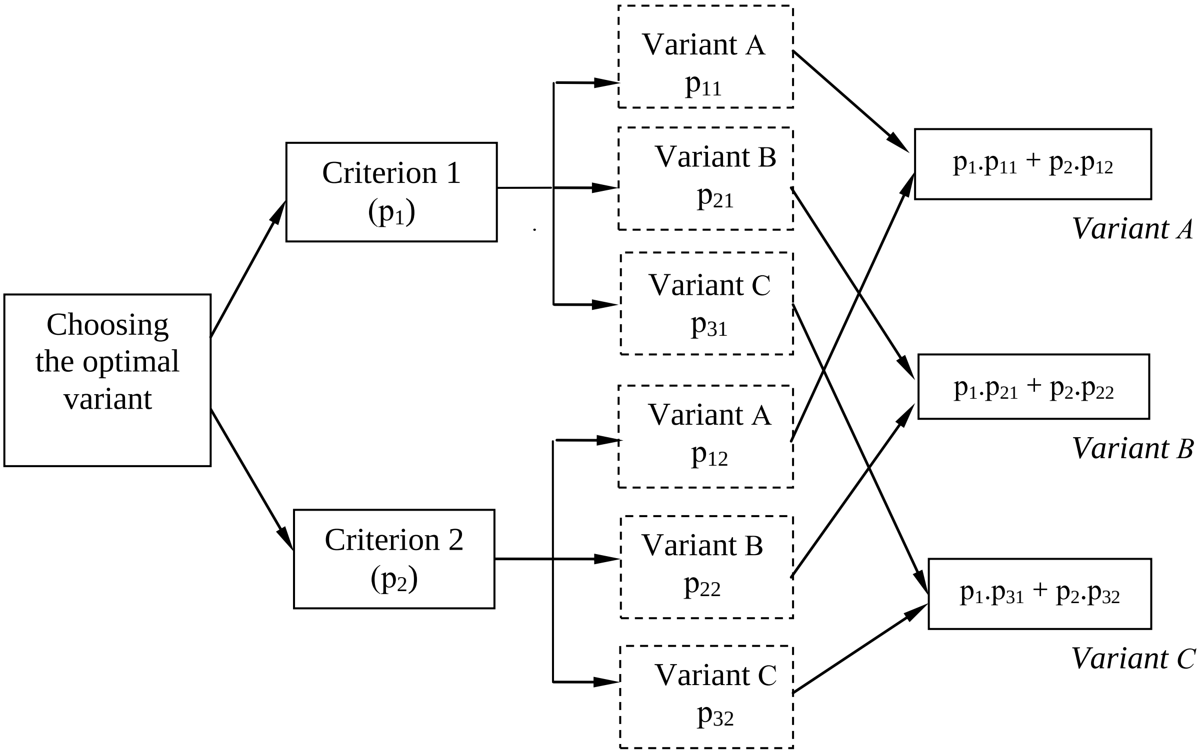

Figure 1. *Structure for choosing the optimal variant for GN*

Table 2. Variants and criteria for choosing a type of GN

	Variants		
Criterions	A	B	C
Criterion 1 - p_1	p_{11}	p_{21}	p_{31}
Criterion 2 - p_2	p_{12}	p_{22}	p_{32}

Determination of the weighting coefficients

The matrix of comparisons A is determined, and according to summarizing data from 7 expert assessments, a weighting coefficient of 5 is assigned to criterion 1 (the mode efficieny parameter), and a weighting coefficient of 1 - to criterion 2 (additional costs).

The criteria *R* and *L* for the efficiency of the mode, the additional costs and the matrix of comparisons **A** are expressed by:

$$A = \begin{array}{c} L \\ R \end{array} \begin{pmatrix} 1 & 1/5 \\ 5 & 1 \end{pmatrix}.$$

For the normalized matrix **N** it is obtained

$$N = \begin{array}{c} L \\ R \end{array} \begin{pmatrix} 0{,}17 & 0{,}17 \\ 0{,}83 & 0{,}83 \end{pmatrix}.$$

The average values of the elements in the rows are: w_R = 0,83; w_L = 0,17, i.e. the weights p_1 and p_2,, which are shown in Fig.1.

The relative weights of the variant solutions A, B and C are calculated within each of the criteria *R* and *L* by using the two matrices of comparisons:

$$A_L = \begin{array}{c} A \\ B \\ C \end{array} \begin{pmatrix} 1 & 1/1{,}2 & 1/1{,}3 \\ 1{,}2 & 1 & 1/1{,}2 \\ 1{,}3 & 1{,}2 & 1 \end{pmatrix};$$

$$A_R = \begin{array}{c} A \\ B \\ C \end{array} \begin{pmatrix} 1 & 1{,}2 & 1{,}3 \\ 1/1{,}2 & 1 & 1{,}2/1{,}3 \\ 1/1{,}3 & 1{,}2/1{,}3 & 1 \end{pmatrix}.$$

The elements of the matrices $\mathbf{A}_R$ and $\mathbf{A}_L$ are determined on the basis of the relative importance of the three variants A, B and C

$$N_L = \begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{ccc} A & B & C \end{array} \\ \begin{pmatrix} 0{,}285 & 0{,}275 & 0{,}296 \\ 0{,}343 & 0{,}330 & 0{,}320 \\ 0{,}371 & 0{,}396 & 0{,}385 \end{pmatrix} \end{array}$$

with average values of the elements in the rows: w_{LA}=0,285; w_{LB}=0,331; w_{LC}=0,384 and

$$N_R = \begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{ccc} A & B & C \end{array} \\ \begin{pmatrix} 0{,}385 & 0{,}385 & 0{,}404 \\ 0{,}320 & 0{,}320 & 0{,}287 \\ 0{,}296 & 0{,}296 & 0{,}310 \end{pmatrix} \end{array}$$

with the average values of the elements in the rows:

$$w_{RA} = 0{,}391;\ w_{RB} = 0{,}309;\ w_{RC} = 0{,}300.$$

The values (w_{LA}, w_{LB}, w_{LC}) = (0.285, 0.331, 0.384) are the relative weights of the variants A, B and C, related to criterion 1.

The values (w_{RA}, w_{RB}, w_{RC}) = (0.391; 0.309; 0.300) are the corresponding relative weights for the variants A, B and C in terms of criterion 2.

Table 3. Relative weighting coefficients for the criteria

	Variants		
Criterions	A	B	C
Criterion 1	28,5%	33,1%	38,4%
Criterion 2	39,1%	30,9%	30,0%

Determination of the combined weighting coefficients for each of the variants

The assessment of the three different variants is based on the calculation of the combined weighing coefficients for each of them.

• Variant A: 0.17.0.285 + 0.83.0.391 = 0.373;

• Variant B: 0.17.0.331 + 0.83.0.309 = 0.312;

• Variant C: 0.17.0.384 + 0.83.0.3 = 0.314.

Based on these calculations, variant A receives the highest combined weight and is the optimal choice.

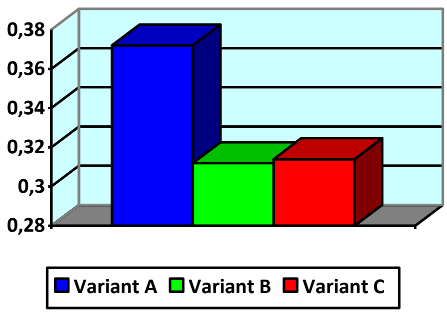

Figure 2. *Comparison of the results from the calculations for the three variants*

The optimal variant for the two criteria is the variant with insulated GN for MV distribution networks.

The developed algorithm allows to introduce a different weighting coefficient for each of the two criteria, in accordance with the specific electrical network under consideration. The results from the calculations give the optimal variant of GN of the MV electrical network in accordance with the chosen criteria.

When the calculations according to the developed algorithm are performed for weighing coefficients 3: 1 for the two criteria, then the results are the following:

The average values of the elements in the rows of the normalized matrix are: w_R = 0,75; w_L = 0,25. The combined weighing coefficients for the variants A, B and C are respectively: variant A - 0.364; variant B - 0.315; variant C - 0.332. Again, variant A has the highest combined weight and is therefore the optimal choice.

The GN variant, chosen for the MV electrical network by this method, should be tested for meeting the restrictive conditions, imposed by the current regulations.

Conclusions:

• The method of hierarchical analysis, taken from the mathematical theory of games is suitable for application in decision-making when not all parameters could be accurately quantified, but are subject to expert assessment on a digital scale.

• The correct choice of criteria and the degree of their significance should be made after a preliminary analysis and expert assessment or by ranking the influencing factors.

• The developed algorithm for choosing the optimal variant of GN allows to set different degrees of significance to the formulated basic decision-making criteria.

• The application of the method of hierarchical analysis from the game theory allows to determine the optimal variant of grounding the neutral in a MV electrical network according to the chosen criteria.

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