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Choice Of An Optimal Variant For Incorporation Of Decentralized Energy Sources Into Electrical Networks

Stefka Nedeltcheva
Technical University - Sofia,
EPF-Sliven,
Sliven, Bulgaria
stefned@abv,bg

Misho Matsankov
Technical University - Sofia,
EPF-Sliven,
Sliven, Bulgaria
misho.ivanov@abv.bg

Mehmed Hassan
Technical University - Sofia,
EPF-Sliven,
Sliven, Bulgaria
mehmedkadirhsn70@gmail.com

Abstract. The criteria for choosing the optimal variant for connecting decentralized energy sources to distribution networks are justified. These are the discounted costs, the power losses and the additional costs of ensuring the throughput of the power lines. Software has been developed to pre-rank the importance of each of the selected criteria for the possible variants for connecting decentralized energy sources to the distribution network. The weight coefficients of the selected criteria are determined. The hierarchical approach of the mathematical game theory is applied. The combined weights for the selected criteria, calculated for each of the variants, are determined. The obtained results allow for choosing the optimal variant for connecting decentralized energy sources to the electricity networks.

I. Introduction

In case of connecting decentralized energy sources (DES) to electricity networks, an analysis of the variants is carried out. The choice of an variant for connecting a DES to a distribution network depends on the magnitude of the connected power and is limited to considering the following possible technical solutions [1,2]:

- direct connection to a low-voltage (LV) power line, which is possible for closely located DESs;

- transformation from LV to medium voltage (MV) and connection to the nearest MV power line;

- connection to a the high-voltage (HV) power line.

The current stage of deregulation and decentralization in the electricity sector uses the discounted cost criterion when evaluating the variants because the owners of the DESs and the network are different and the best techno-economic variant for the one side is not always appropriate for the other side. The criterion should be applied separately to the distribution system owner and the DES owner.

The selection of the cross-sections of the wires in the LV and MV electrical networks is carried out in compliance with the condition for permissible loss of voltage, which is normalized (5% in LV networks and 8% of the rated voltage in MV networks, according to the current regulation in Bulgaria) [3].

The main influential factors when determining voltage losses are: the magnitude of the transmitted power, the rated voltage of the power line, the type and cross-section of the conductor or cable used.

The permissible loss of voltage and achieving it are the basic conditions, answering the question to what values of transmitted capacities and at what distances it is possible to establish a connection of a DES to a LV network and when transformation and connection to a MV network should be considered.

The recommended limits of power capacity for connecting DES to the distribution networks in Bulgaria are [1,2]:

- up to 250 kW for LV networks;
- from 250 kW to 20 MW for MV networks;
- over 20MW for HV network.

The incorporation of DES is related to the construction of new interconnectors. It is particularly important to have minimum power losses in the electricity network when realizing this incorporation.

Generally, DESs are connected to LV and MV distribution networks, which are open and branched. Such networks are dimensioned by the cross-sections of the conductors, selected without taking into account the DES power. Its joining causes a redistribution of the capacities in the branches. In some sections the existing cross-sections of the conductors may not be suitable for transmitting the new capacities. One of the problems with the connection of the DES to the electrical network thus occurs: the need to check the throughput of the power lines.

The purpose of this paper is to analyze and justify the criteria and to develop a software product for selecting the optimal variant for connecting a DES to an electrical network, using the mathematical game theory.

II. Criteria for selecting the optimal variant for connection of DES to electricity distribution networks

In order to select the criteria and to evaluate their relevance to each of the DES connection variants, the following steps are performed:.

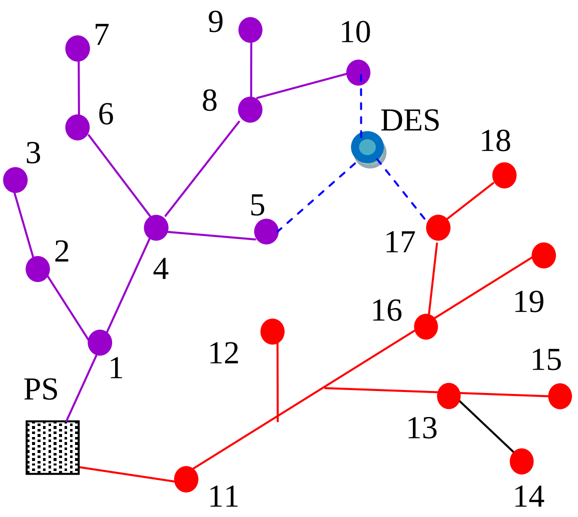

Fig.1. Variants for connection of a DES to the power network: PS-power sub-station; 1-18 - consumer nodes; DES - decentralized energy source

Step 1 – A list of all possible variants for joining a DES to the power network is made. For the scheme in Figure 1 the variants are:

- Variant 1 - connection of the DES to node 10;
- Variant 2 - connection of the DES to node 5;
- Variant 3 - connection of the DES to node 17.

Step 2 - The criteria for choosing the best variant are determined. The most appropriate criteria for choosing the optimal variant for connection of DES to distribution networks are:

- Criterion A - discounted costs;
- Criterion B - energy efficiency;
- Criterion C – Throughput (additional costs for replacement of wires in some sections).

Step 3 - Determining the weighting coefficients for each variant when applying the A criterion – the discounted costs. Especially developed software calculates the discounted costs by inputting data about the consumers' power capacities and the lengths of the connected sections; the type and the cross-sections of the conductors; the investments per 1 km for each cross-section; the rated voltage; the maximum load; the hourly maximum load usability; the discount factor 0,12; electricity tariffs; the location and capacity of the interconnected DES, and the stage of its construction. The results from the calculations of the discounted costs for the three variants for connecting the DES from Figure 1, are shown in Figure 2. The discounted cost ratio for the three variants is expressed in relative units (r.u). The minimum calculated value for one of the variants is chosen as a base one.

Step 4 - Determining the weight coefficients for each variant when applying criterion B – the power loss. The developed software calculates the power losses in the connection branches of the DES by means of data about consumers' capacities and the length of the sections; the type and the cross-section of the conductors; the rated voltage; the location and power of the connected DES. The results from the power loss calculations for the three DES connection variants, presented in Figure 1, are shown in Figure 3. The ratio of the calculated values of the power losses for the three variants are expressed in r.u. The minimum calculated value for one of the variants is chosen to be the base one.

Step 5 - Determining the weighting coefficients for each variant when applying the C criterion – the throughput of the power lines. When a DES is put into service, it may be possible to incur in some sections additional costs to replace the wires where the chosen cross-sections are insufficient to take the new capacity imported from the DES. The developed software checks the throughput condition for the sections in the DES branches. Data about the consumer's capacities and the lengths of the sections are also used, as well as: the type and the cross-section of the conductors; the rated voltage; the permissible values of the currents depending on the type and the cross-section of the conductor; the location and power of the connected DES.

The power, transferred to the branches after joining the DES, is calculated. The obtained currents in the branches are compared with the permissible currents and a decision is made which sections need a change in the cross-section of the wires. For these sections, the additional cost of changing the cross-sections of the wires is calculated. The results from the calculations for the three DES connection variants, presented in Figure 1, are shown in Figure 4.

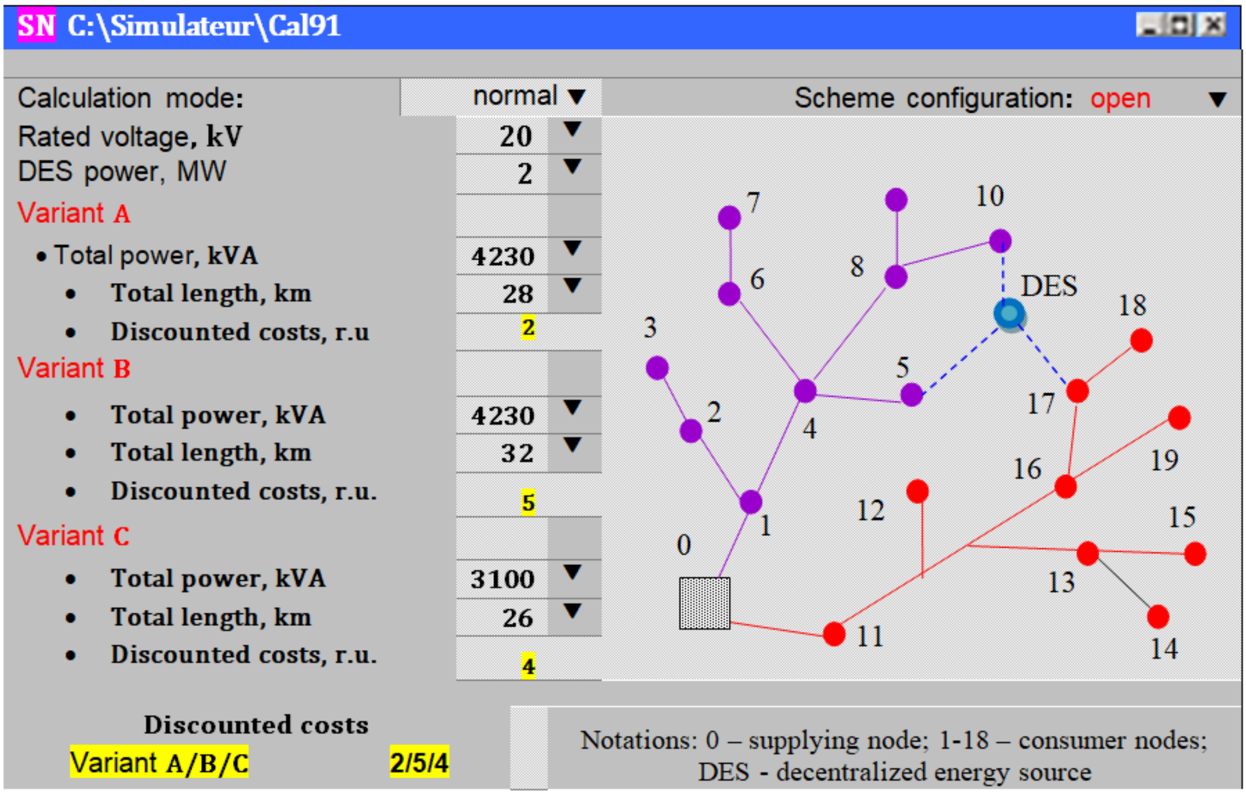

Fig.2. Calculation of the discounted costs for the variants of connecting DES to MV networks

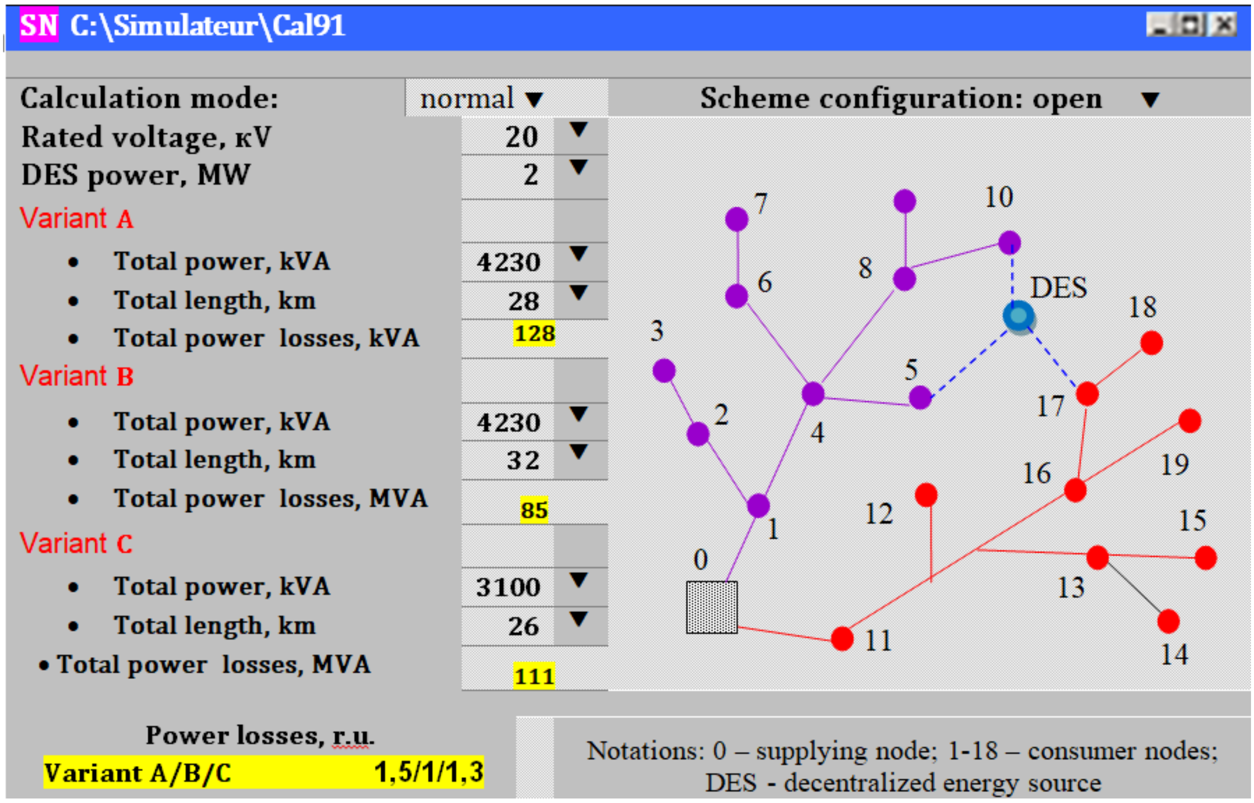

Fig.3. Calculation of the power losses for DES connection variants in MV networks

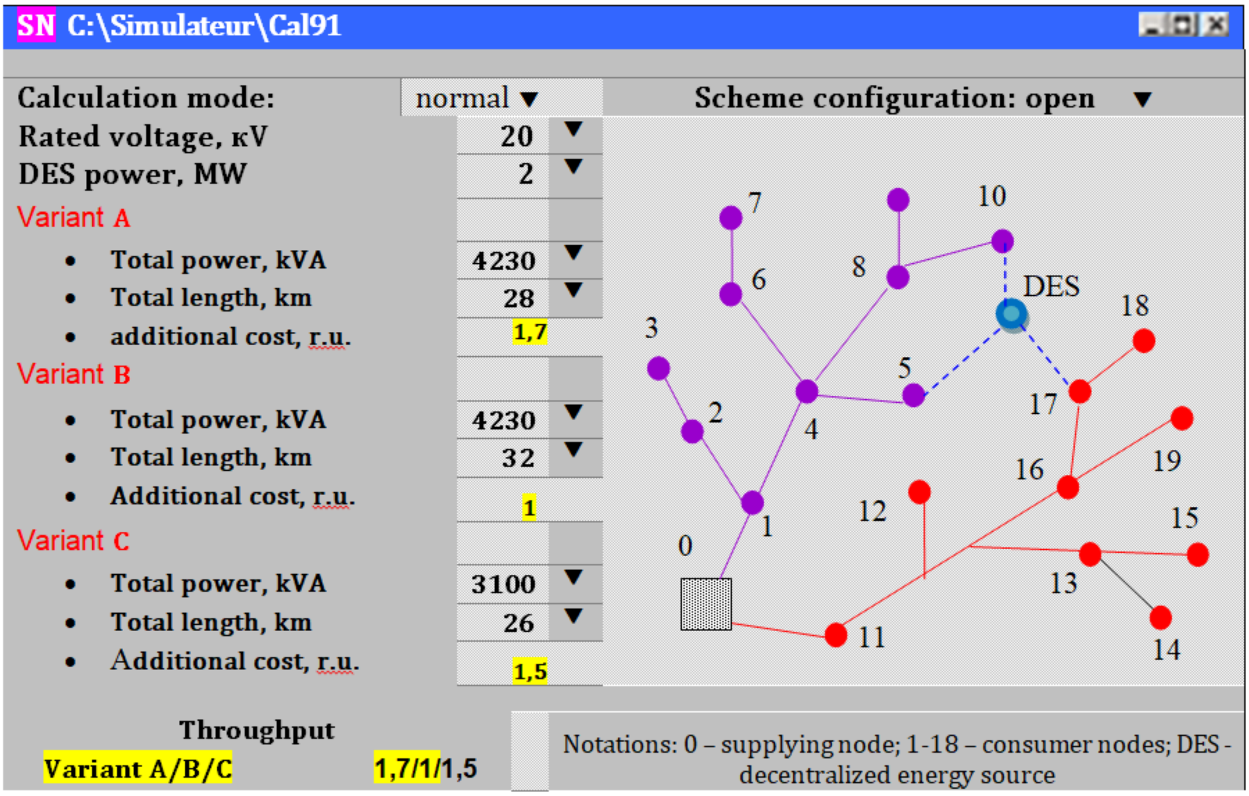

Fig.4. Calculation of the additional cost for providing throughput of the DES connection variants in MV networks

The ratio of the calculated values for the additional costs for replacing the cross-sections of the wires in the sections where necessary for the three variants, is expressed in r.u. The minimum calculated value for one of the variants is chosen as the base one.

From the conducted study for the scheme in Figure 1, the following weight coefficients of the A, B and C criteria were established:

- Criterion A for variants A / B / C – 2 / 5 / 4;
- Criterion B for variants A / B / C –1.5 / 1 / 1.3
- Criterion C for variants A / B / C –1.7 / 1 / 1.5

The developed software makes it possible to calculate the value of the criteria for each variant of the DES connection to the electrical network.

III. Choosing the best variant for connecting decentralized energy sources

The method for hierarchical analysis from the mathematical game theory [4] was used to find the optimal variant for joining DES to electrical networks.

According to the game theory, the weighting coefficients for the three selected criteria are given corresponding symbols: for the discounted costs - p_1, for the power losses - p_2, and for the additional costs for providing the throughput capacity of the power lines - p_3.

A. Determining the weight coefficients of the three selected criteria

The hierarchical analysis method of the game theory consists in determining the relative weights for evaluating the alternative solutions. If there are n criteria on a given hierarchical level, the corresponding procedure creates a matrix A with dimensions n x n, called a matrix of pairwise comparisons, which reflects the importance of the different criteria. The pairwise comparison is performed so that the criterion in row i (i = 1, 2, ., n) is evaluated against each of the criteria presented in n columns.

First, the matrix of comparisons A for the first two criteria is determined. The determination starts from the main hierarchical level, which contains the following criteria: the discounted costs, the power losses, and the additional costs for ensuring the throughput of the power lines. The procedure is repeated for each pair of the specified criteria.

According to the theory of hierarchical analysis, the element of the matrix A, located at the intersection of the i-th row and the j-th column, is denoted by a_{ij}. Whole numbers from 1 to 9 are used to describe these estimates. For a_{ij} = 1, the i-th and j-th criteria are assumed to be equally important, a_{ij} = 5 means that the i-th criterion is more important than the j-th, and a_{ij} = 9 indicates that the i-th criterion is too important in comparison with the j-th. The other values between 1 and 9 are interpreted analogously. The consistency of the notation is ensured by the condition: if a_{ij} = k, then a_{ji} = 1/k. All diagonal elements a_{ii} of the matrix A are equal to 1 because they express an estimate of the criterion with respect to itself.

The techno-economic assessment of the three selected criteria A/B/C by means of the compiled software is 4 / 1 / 2, respectively. Then the weighting coefficients are correspondingly: p_1 = 0.572; p_2 = 0.143 and p_3 = 0.285.

From the conducted study for the specific scheme of Figure 1, the following weight coefficients of the criteria A, B and C were established:

• Criterion A for variants A / B / C –2 / 5 / 4;

• Criterion B for variants A / B / C –1.5 / 1 / 1.3;

• Criterion C for variants A / B / C –1.7 / 1 / 1.5.

The analysis of the evaluation of the three variants with weight coefficients p1 = 0.572; p2= 0,143 and p3=0,285, is conducted from the view of the A, B and C criteria with weight coefficients, as given in Table 1.

TABLE 1. WEIGHTING COEFFICIENTS OF THE CRITERIA FOR THE DES CONNECTION VARIANTS

Criteria	**Variants**		
	A	**B**	**C**
1 - Discounted costs	p_{11}=0,18	p_{21}=0,4	p_{31}=0,4
2 - Power losses	p_{12}=0,46	p_{22}=0,26	p_{32}=0,24
3 - Throughput	p_{13}=0,36	p_{23}=0,34	p_{33}=0,36

The structure of the decision-making problem is presented in Figure 5. The problem has an only hierarchical level with three criteria and three variants (A, B, and C) as given in Table 1.

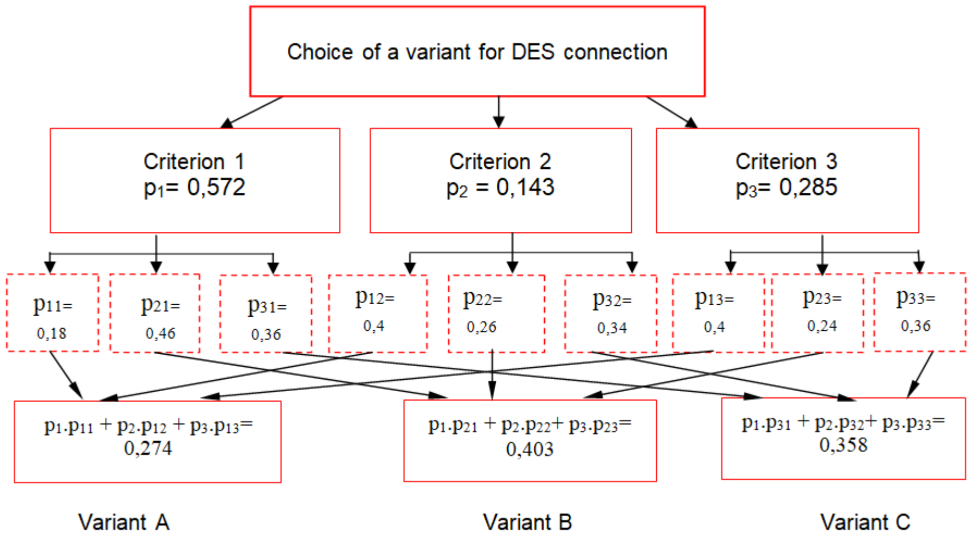

Fig.5. Hierarchy of the structure for choosing the optimal variant

B. Determining the combined weight coefficients for each of the variants

The evaluation of the three variants is based on the calculation of the combined weight coefficients for each of them.

• Variant A: $p_1.p_{11} + p_2.p_{12} + p_3.p_{13}$ =

= 0,274;

• Variant B: $p_1.p_{21} + p_2.p_{22} + p_3.p_{23}$ =

= 0.403;

• Variant C: $p_1.p_{31} + p_2.p_{32} + p_3.p_{33}$ =

= 0.358.

Based on these calculations, Variant A has the lowest combined weight and Variant B -the highest combined weight. Since the aim is to have a minimal cost and power loss, the optimal choice is Variant A.

Conclusions • Criteria for choosing the optimal variant for connection of DESs to distribution networks have been justified. They are the discounted costs, the power losses and the additional costs for providing the throughput of the power lines.

• The developed software allows for preliminary ranking of the significance of each of the criteria for the possible variants of DES connection to electrical networks.

• The determination of the combined weighting coefficients for the selected criteria, calculated for each of the variants, using the mathematical apparatus of the game theory, allows for choosing the optimal variant for connecting a DES to electrical networks.

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