

IMPACT OF CHANGES IN CUSTOMERS' LOAD TO THE SOLUTION OF DISTRIBUTION NETWORKS PLANNING MODEL

UTICAJ PROMJENE OPTEREĆENJA POTROŠAČA NA RJEŠENJE MODELA PLANIRANJA DISTRIBUTIVNIH MREŽA

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Abstract: Construction and reconstruction of distribution networks requires planning. During the construction of new networks, planning primarily consists of determining the size and location of substation through which a power supply of customers will be conducted, determining the types of conductors which will be used in the construction of the network, as well as determining the spatial configuration of the distribution network. The ultimate goal is to obtain the optimal configuration of the distribution network, with minimal power losses in the network and prescribed voltage drops at all customers. The paper describes one improved model of planning the construction of distribution networks based on multiple criteria decision making (AHP – Analytic Hierarchy Process), with the application of modern optimization methods (fuzzy logic, simulated annealing). Considering that one of the criteria that has an impact on the final solution of proposed planning model is individual customers' load, the paper gives the answer to the question whether the changes in customers' load get different solutions in comparison with the solution obtained with initial values of customers' loads. The application of this planning model is shown on the example of low-voltage (0.4 kV) distribution network, which does not mean that the model is not applicable to the middle-voltage (10(20) kV) distribution networks. In addition, besides planning the construction of new networks, the model can be applied to the reconstruction of existing networks. Also, it is suitable for detecting problems in existing networks. Therefore, due to wide possibilities of application, this planning model can serve to experienced engineers as a very useful tool.

Keywords: power system, planning of distribution networks, fuzzy logic, AHP, simulated annealing

Sažetak: Izgradnja i rekonstrukcija distributivnih mreža zahtijeva planiranje. Pri izgradnji novih mreža planiranje se prevashodno sastoji od određivanja veličine i lokacije transformatorske stanice preko koje će se vršiti napajanje potrošača, određivanja tipova vodiča koji će biti upotrijebljeni pri konstruisanju mreže, kao i određivanja prostorne konfiguracije distributivne mreže. Krajnji cilj je dobivanje optimalne konfiguracije distributivne mreže, uz minimalne gubitke snage u mreži i propisane padove napona kod svih potrošača. Rad opisuje jedan poboljšani model planiranja izgradnje distributivnih mreža koji se temelji na višekriterijskom odlučivanju (AHP – Analitički Hijerarhijski Postupak), uz primjenu savremenih optimizacionih metoda (fuzzy logika, simulirano kaljenje). S obzirom da je jedan od kriterija koji ima uticaj na konačno rješenje predloženog modela planiranja individualno opterećenje potrošača, rad daje odgovor na pitanje da li se promjenama opterećenja potrošača dobivaju drugačija rješenja u poređenju s rješenjem dobivenim s polaznim vrijednostima opterećenja potrošača. Aplikacija ovakvog modela planiranja prikazana je na primjeru niskonaponske (0.4 kV) distributivne mreže, što ne znači da model nije primjenjiv i na sredjonaponske (10(20) kV) distributivne mreže. Osim planiranja izgradnje novih mreža, model je primjenjiv i pri rekonstrukcijama postojećih mreža. Isto tako, pogodan je za detektovanje problema u postojećim mrežama. Stoga, zbog širokih mogućnosti primjene ovakav model planiranja može poslužiti iskusnim inženjerima kao vrlo koristan alat.

Ključne riječi: elektroenergetski sistem, planiranje distributivnih mreža, fuzzy logika, AHP, simulirano kaljenje

INTRODUCTION

The continuous increase in electricity demand creates the need for construction of new and improvement of existing facilities in the power system. In the new market conditions system planning plays an important role in the over-

all strategy of the power companies. The best solutions, which are most efficient for the company, can be obtained by creating mathematical models that describe the current state of the system. Most of the available models are based on evolutionary programming, genetic algorithms, dynamic optimization, stochastic approaches, AHP, fuzzy logic, simulated annealing etc. [1]-[7]. However, in the market conditions these solutions have to provide the highest quality and most reliable supply of electricity to the customers. The decision about the selection of model or simulation technique depends on the characteristics of

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the system and desired input, or output parameters. The development of the power system must satisfy a number of different objectives. First of all, the power system has to be economically efficient; it has to ensure a reliable supply of ultimate customers and should not have a negative impact on the environment. Beside these general objectives, there are also several additional objectives and criteria. At the same time, the operation and development of the system is influenced by various uncertain and random factors. Therefore, the task of the planner is to find an optimal alternative (variant). In essence, it is a complex problem associated with multiple objectives, uncertainties, and a number of variables. Considering that this is a complex problem, the planner, in fact, is faced with multi-criteria optimization task. In order to obtain suitable alternatives (solutions), it is necessary to abide a certain criteria. Defining of criteria is based on planners' estimation, where he has to take into account both the interests of customers and the interests of the company. In contrast to the monopolistic system, in market conditions, customers' demands for quality and safe delivery of electricity are coming in first plan. So, in order to obtain a suitable alternatives a certain criteria should be considered, such as voltage drops at ultimate customers (customers at the end of the feeder), active power losses in distribution power lines, investment costs of building the network, power lines transmission capacity etc. Determination of optimal network configuration for electricity supply of customers, spread over specific geographic area, is the main objective in the planning of distribution networks. Planning of low-voltage distribution networks essentially consists of determining the size and location of substation, types of conductors that have to be used, and the spatial configuration of the network. In the market conditions, when quality of the electricity delivered to the ultimate customers has one of the most important roles, the primary objective of the planning is bringing the voltage level at each customer within the limits, prescribed by the standard. After that, from the distribution company point of view, the next objective is bringing network losses to the minimum, which can be achieved by proper selection of the type of conductors and optimal spatial distribution of the distribution network. Of course, the construction costs of such network are important to the distribution company, but in market conditions customers' requirements have priority, so these costs are not in first plan. At the end, the capacity or throughput of low-voltage power lines, which limits the amount of loads that can be transferred to ultimate customers, which can be solved by selecting the appropriate types and cross sections, is important as well. So, it is a complex problem which has to be solved, taking into account mentioned criteria. The objective of the planning of low-voltage distribution networks is to construct a network that will meet the projected needs of customers for electricity, in a safe, reliable and efficient manner. In order to achieve this objective the intention is to minimize the

investment and losses costs, taking into account the constraints that include the capacity of the equipment (power lines), maximum voltage drops and radial configuration of distribution network [8].

1. SHORT THEORETICAL REMARKS

This paper presents an improved planning model which uses several modern hierarchical and stochastic optimization algorithms.

1.1. Fuzzy clustering algorithm

The primary purpose of fuzzy clustering is grouping of data (objects) with respect to a certain predetermined selection criteria. The obtained groups (clusters) should have high internal similarity (inside clusters) and high external diversity (between clusters) [9]. There are two types of grouping, namely: hard clustering, where objects are divided into separate groups and each object belongs to only one group, and soft clustering, where object can belong to several groups [10]. Depending on the nature and purpose of data different measures are used to assess the similarity of data stored in the groups. Some examples of measures are distance, connectivity or intensity [11]. The most commonly used measure is the distance between the objects. Direct way to determine the closeness of two objects is drawing the straight line between them. This type of distance, which is the most commonly used, is called the *Euclidean distance (straight-line distance)*. This distance between two objects, with spatial coordinates $\{x_i, y_i\}$ and $\{x_j, y_j\}$, is calculated as [12]:

$$d_{Euclidean}(i, j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (1)$$

This distance corresponds to the length of straight line that connects objects 1 and 2. All distances between objects are presented in the form of a matrix of distances. Non-diagonal elements of matrix represent the distances between pairs of objects and diagonal elements are 0 (object distance from itself). Since the distance between objects i and j is identical as well as the distance between objects j and i a matrix of distances is symmetric. So, matrix of distances for m objects is:

$$\begin{bmatrix} 0 & d_{1,2} & L & d_{1,i} & L & d_{1,m} \\ d_{2,1} & 0 & L & d_{2,i} & L & d_{2,m} \\ M & M & O & M & L & M \\ d_{i,1} & d_{i,2} & L & 0 & L & d_{i,m} \\ M & M & L & M & O & M \\ d_{m,1} & d_{m,2} & L & d_{m,i} & L & 0 \end{bmatrix}$$

There are other, alternative measures of distances. One is so called the City-block distance, which uses the sum of absolute differences. It is often called the Manhattan met-

ric because it can be compared to the walking distance between two points of the city, such as New York, Manhattan District, where the distance is equal to the number of blocks in the direction of North-South and East-West. Using City-block distance to calculate the distance between objects i and j gives:

$$d_{City-block}(i, j) = |x_i - x_j| + |y_i - y_j| \quad (2)$$

Another measure of a distance, that is commonly used, is so called the Chebychev distance. It represents the maximum of absolute differences:

$$d_{Chebychev}(i, j) = \max(|x_i - x_j|, |y_i - y_j|) \quad (3)$$

Figure 1 shows an example of these three types of distance measures.

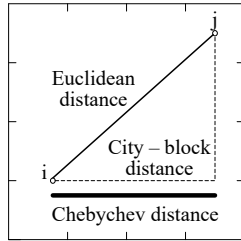


Figure 1: An example of distance measures

1.2. Analytic hierarchy process

Analytic Hierarchy Process (AHP) was developed by Thomas L. Saaty, a professor at the University of Pittsburgh, in 70-ies and 80-ies of 20th century and in the literature it can often be found as *Saatys' method*. This method allows to the user to assess the relative weight of multiple criteria, with respect to a given criterion, in an intuitive way. In case that those quantitative evaluations are not available, the assessor can still recognize if one criterion is more important than another [13]. Saaty has established a consistent way of converting the comparisons (X is more important than Y) in a set of numbers that represents the relative priorities of each criterion. Criteria can be classified into one or more levels (first, second, ...), which result in a hierarchy of criteria, where the criteria from first level have the highest influence on the decision. Figure 2 shows an example with three criteria in first level, eight criteria in second level and two alternatives.

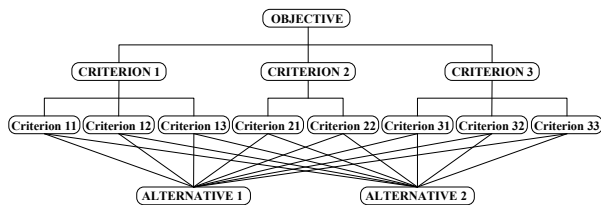


Figure 2: Decomposition of the problem

AHP method can be presented in three basic steps:

1. Establishment of alternatives and selection of criteria;
2. Evaluation of criteria by comparing the pairs of criteria and consistency checking;
3. Evaluation of alternatives according to each criterion and obtaining the best solution (alternative).

To make a comparison, a quantitative measure that indicates how much one element is more important than another are needed. Any decision can be presented by number. One common scale is presented in Table I [14].

Table I: Example of Saaty's scale of relative importance

Intensity of importance	Definition of importance	Explanation
1	Equal	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong	An activity is favoured very strongly over another
8	Very, very strong	
9	Extreme	An activity is favoured extremely over another

1.3. Simulated annealing algorithm

Simulated annealing algorithm is based on the analogy between the annealing of metals and combinatorial optimization problems. In the physics of solids, annealing is a process in which the material is heated to a maximum temperature (annealing temperature), at which the internal structure of the material is organized stochastically. Slow cooling procedure cause that the internal configuration of units takes less energy states, adjusting to the temperature (internal energy is proportional to the temperature) [15]. Some of the analogies between physical process of annealing and artificial simulated annealing process are given in Table II [16].

Table II: The analogies between simulated and physical annealing

OPTIMIZATION PROBLEM	PHYSICAL SYSTEM
Initial solution x	Current state of the material
Objective function $f(x)$	Energy of the current state
Control parameter T	Temperature
Optimal solution x_{opt}	Basic state
Simulated annealing	Gradually cooling

The algorithm begins at a very high temperature. As the temperature decreases, the algorithm rarely accepts solutions that lead to increasing of objective function. In principle, the algorithm can be coded in only a few lines, as it is shown in the pseudo C code [17]-[19]:

```
x = Initial_State ;
f = Cost (x) ;
T = Initial_Temperature ( ) ;
do {
    do {
        new_x = Apply_Perturbation_To (x) ;
        Δf = Cost (new_x) - f ;
        if ( (Δf < 0) OR (random [0,1] < exp (-Δf/T)) ) {
            x = new_x ;
            f = f + Δf ;
        }
    } while Not_At_Equilibrium ( ) ;
    T = Update_Temperature (T);
} while Exit_Condition_not_Met ( ) ;
```

2. PLANNING MODEL

Planning model of distribution networks should offer the optimal configuration of distribution network. Flowchart of such model, which can be used for planning and construction of distribution networks, is shown in Figure 3 [20].

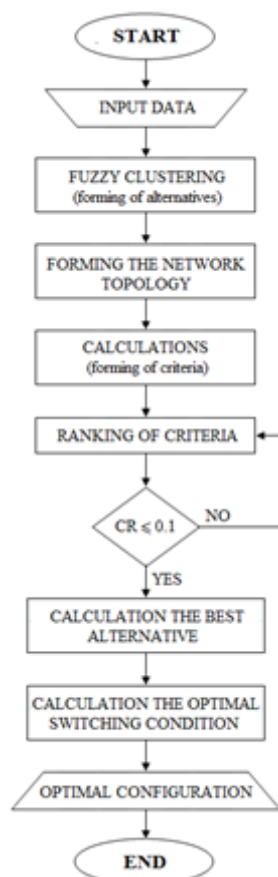


Figure 3: Flowchart of planning model

The main task of the model is to select the best alternative of all constructed alternatives (variants with a different number of low-voltage feeders), obtained by fuzzy clustering and determining the optimal network topology, respectively the optimal switching condition. Functioning of the proposed model requires the following inputs:

- Spatial coordinates of the objects (measurement points) – they can be obtained from geo-referenced geographic maps, imported in AutoCAD (Figure 4);

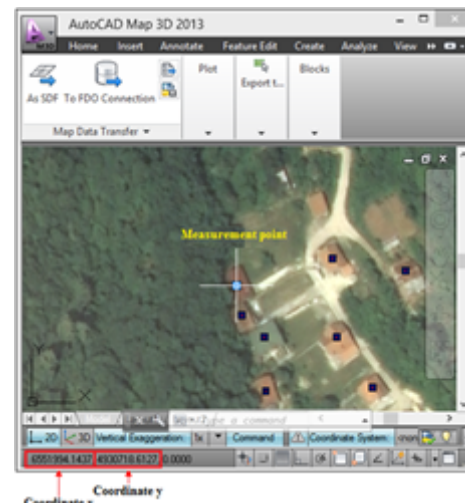


Figure 4: Spatial coordinates of measurement points

- Individual customers' loads – they are required for load flow calculations and can be obtained in three ways:

1. By peak loads method – it is necessary to have a data about realized annual energy for each customer and one-day, hourly measured load of each low-voltage feeder and substation. This method can be used for existing consum.
2. By assessment – by coincidence factor. It is used for completely new consum.
3. Using load curves – customers' load is recorded in time period. The results are consumption diagrams for different types of customers.

In this paper, these data are obtained by peak loads method and by assessment for simultaneous participation of loads.

- Network parameters - the characteristics of standard substations, standard cross-sections of conductors and conductors' parameters R, X, B.

A fuzzy clustering algorithm is used to determine the best alternative (variant). Alternatives are networks with two, three, four or more low-voltage feeders. In this model, this algorithm is used for:

1. determining the location of substation (in spatial centre of consumption),
2. determining the number of low-voltage feeders (by spatial grouping of customers).

Network topology is formed after forming of alternatives and by drawing of network on geo-referenced geographic maps. The most suitable software for network drawing is AutoCAD. Evaluation of established alternatives is based on certain criteria such as voltage drops at ultimate customers, power lines losses, investment costs, maintenance costs, reliability, profitability of investment etc. Basic calculation that is used when establishing certain criteria is power flow calculation that can be performed by any software package designed for it (Matpower, PowerCAD etc.). After forming the criteria their marks (a numerical values) have to be given. It is a matter of subjective engineering assessment by which the importance or impact of each criterion is assessed. To obtain a final decision, or choosing the best alternative, it is necessary to harmonize the criteria and make a ranking of all offered solutions. As a very convenient tool for this is the AHP method. This method is based on selecting the best solution (alternative) by evaluation of each solution with a certain set criteria because each criterion has not an equal influence on the final decision. The procedure used by this method is carried out in several steps:

1. Evaluation of criteria – it is a matter of subjective engineering assessment by which the importance or influence of each criterion is assessed, because each criterion has different influence on final solution;
2. Ranking of criteria – mutual comparison of criteria;
3. Consistency checking – determining if ranking of criteria was performed correctly (checking of consistency index CR by application of AHP method – if $CR \leq 0.1$ ranking was done correctly, if not, it is necessary to perform re-ranking until obtaining a satisfactory solution);
4. Ranking of alternatives – it is performing for each criterion, separately. In this way, the assessment of how much each criterion has an influence on each alternative, is obtained. Summing of these assessments a priority marks of each alternative are obtained. The alternative with highest mark is considered as the best.

The best spatial topology solution of the distribution network is obtained by applying of AHP method, but it can not be said that it is optimal from energy point of view. Therefore, it is necessary, for the best spatial alternative, to determine the optimal switching condition, which is the ultimate goal of application of the proposed model. Optimal configuration in this model is obtained by using of simulated annealing method.

3. PRACTICAL EXAMPLE OF MODEL APPLICATION

Functionality of proposed model was verified using the example of low-voltage distribution network for supplying the customers of geographical area located in the town Tuzla, Bosnia and Herzegovina (geographical coordinates of substation: $x = 6551666.70$, $y = 4931319.85$). Through this network 270 electricity customers, mainly from the category of households, were supplied. The network is loaded from the substation 10(20)/0.4 kV, rated power

of 400 kVA, through 5 low-voltage feeders. Spatial view of existing network is shown in Figure 5, where each low-voltage feeder is colored in different color.

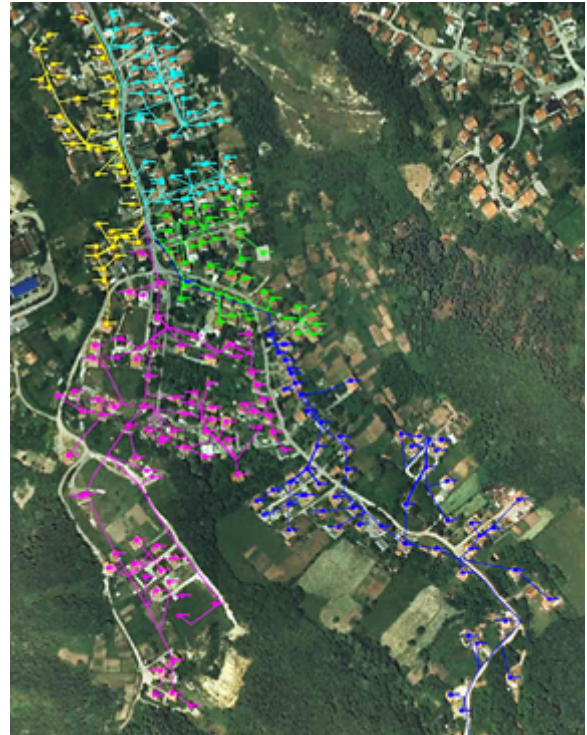


Figure 5: Spatial view of existing low-voltage distribution network

To verify functionality, it is necessary to construct a new low-voltage distribution network of this area by using the proposed model. First, the rated power of substation has to be determined. Experience shows that at customers which mostly belong to the category of households, simultaneous participation of one customer is from 0.8 kW to 1.4 kW in the total load of the whole area. So, the entire area, in a given time period, can be loaded with $0.8 \times 270 \text{ kW} \leq P \leq 1.4 \times 270 \text{ kW}$ or $216 \text{ kW} \leq P \leq 378 \text{ kW}$. Assuming that total average load is between these limits, then can be said that for supplying of such geographical area a typical substation with rated power $S = 400 \text{ kVA}$ has to be installed. After determining the size of substation it is necessary to determine its location. Fuzzy clustering algorithm is used for this. Substation is located in the spatial centre of consumption. After that, the spatial clustering of customers has to be performed. Number of these groups, in this model, defines the number of low-voltage feeders of the substation. After defining the groups, a spatial centre of each of them can be defined. If necessary, within a single group the subgroups with their spatial sub-centres can be defined, as it is shown in Figure 6, for the network with 8 groups, each with 4 subgroups. Centres of groups are marked with $\times$ ($C_1, C_2, \dots, C_8$), while subgroups are coloured in different colours and their sub-centres are marked with $\diamond$ ($C_{11}, C_{12}, C_{13}, C_{14}, \dots, C_{81}, C_{82}, C_{83}, C_{84}$).

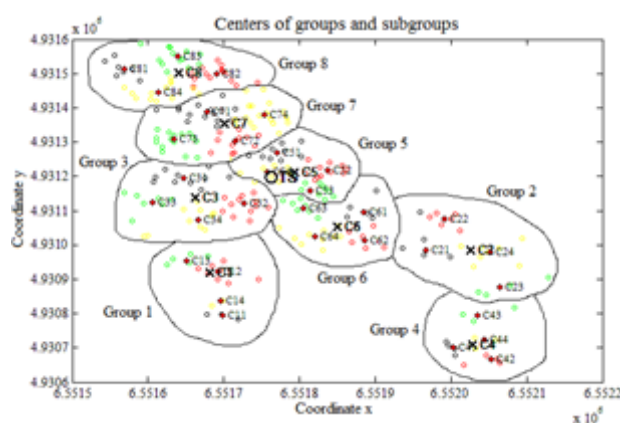


Figure 6: An example of consumption distribution

All of this serves as an orientation in which direction it is necessary to carry out the construction of the network, and what types of conductors is necessary to select. In this way, the required number of alternatives (networks with different number of low-voltage feeders) can be obtained, and based on them, in the next step, forming a network topology is performed. In this example of network, the alternatives with five, six, seven and eight low-voltage feeders are formed. Network topologies of all alternatives are formed on the geo-referenced maps with a spatial view in which can be seen the spatial distribution of objects, roads, forests, rivers etc. They are formed by drawing of networks in AutoCAD. First step is colouring (assigning) of groups, subgroups and their centres, respectively sub-centres, and then networks can be drawn, according to the propagation guidelines obtained in the first step. Conceptual design of the low-voltage distribution network of alternative from Figure 6 is shown in Figure 7. Each low-voltage feeder is coloured in different colour.



Figure 7: Conceptual design of distribution network with eight low-voltage feeders

Forming of the spatial layouts for all alternatives do not give the answer to the question which of them is the best? Therefore, it is necessary to evaluate each solution and perform their mutual comparison. That is why the evaluation of alternatives has to be done in accordance with established criteria. The criteria for the evaluation of alternatives may be different. In the concrete example four criteria are selected and they are:

1. Voltage drops at ultimate customers;
2. Power losses in low-voltage power lines;
3. Average load of low-voltage power lines;
4. Investment costs.

The values of criteria are given in Table III.

Table III: Values of the criteria

Number of LV feeders	Calculated values						Investm. costs (€)
	ΔU (V)	ΔU (%)	P_{loss} (kW)	P_{loss} (%)	$I_{average}$ (A)	$I_{average}$ (%)	
5	-46.8	-11.7	20.92	5.41	114.5	57.80	207395
6	-44.0	-11.0	18.71	4.87	94.84	47.90	238631
7	-43.2	-10.8	18.68	4.86	81.28	41.05	263265
8	-40.4	-10.1	17.38	4.54	70.88	35.80	268912

The first three criteria are obtained by power flow calculation in Matlab-Matpower. ΔU are the voltage drops at the end of low-voltage feeders, P_{loss} are the total losses in low-voltage power lines, and $I_{average}$ are the average loads of all low-voltage feeders together. The fourth criterion (investments) represents calculated (after network drawing) material costs (substation, overhead lines (cables), poles, etc.) and their installation costs, for each alternative.

After obtaining the quantitative values of criteria it is necessary to do:

1. ranking of criteria,
2. ranking of alternatives.

These steps are carried out using the AHP method. First, the evaluation of importance of each criterion was done, as it is shown in Table IV.

Table IV: Evaluation of importance of each criterion

Criterion	Mark	Explanation
Voltage drop	1	Highest importance
Power losses	2	Slightly less importance
Average power lines load	4	Less importance
Investment costs	5	The smallest importance

After implementation examining of consistency obtained consistency ratio is $CR = 0.0329 < 0.1$ and it can be concluded that marks of criteria importance are consistent, respectively that ranking of criteria was performed properly.

Determination of criteria consistency furthermore provides a ranking of the alternatives. The procedure must be carried out for each criterion, in particular, using the procedure defined by AHP method. Method is similar to the method of criteria ranking. Finally, the following solutions are obtained:

$$\begin{bmatrix} S_5 \\ S_6 \\ S_7 \\ S_8 \end{bmatrix} = \begin{bmatrix} 0.22947 \\ 0.24725 \\ 0.25223 \\ 0.27105 \end{bmatrix}$$

where solution S_5 is referred to alternative with five, S_6 with six, S_7 with seven and S_8 with eight low-voltage feeders. It is obvious that solution S_8 gives the best result. So, the alternative with eight low-voltage feeders, according to the given criteria, represents the best spatial solution of low-voltage distribution network. However, this does not mean that this is the optimal switching condition, so it is necessary to find it. For obtaining the optimal solution proposed planning model uses simulated annealing algorithm. To obtain the optimal switching condition, according to this algorithm, it is only necessary, at selected spatial solution, to add a certain number of interconnections between power lines (power lines coloured in black - Figure 8). Also, a certain number of existing sections must be defined and they will be used for breaking loops that are formed by switching on newly created sections (sections coloured in red - Figure 8). Their switching on/off will re-establish the radial network configuration.

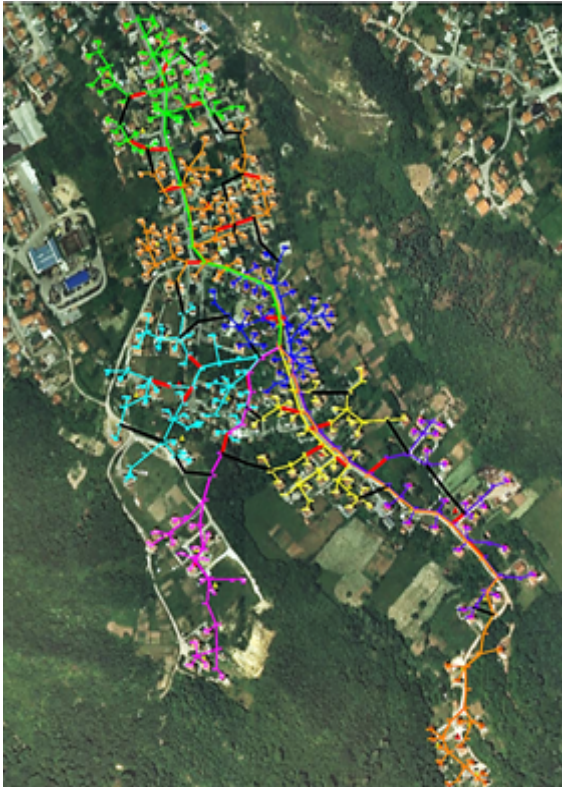


Figure 8: Establishing interconnections in low-voltage distribution network

In the given example, 42 switches are defined, from which 19 are switched off (sections coloured in black) and 23 are switched on (sections coloured in red). The selected starting annealing temperature was $T = 1,000$, and the final was $T = 0.000001$. The selected cooling factor was 0.95. Totally, 405 simulations were conducted and 310 configurations were successfully accepted, with remark that some configurations were repeated. The total duration of the simulations was 7.4 minutes. Table V shows a comparison between the value of voltage drops at the ultimate customers and power lines losses between best spatial and optimal solution.

Table V: Comparison of results between spatial and optimal solution

The best solution	ΔU (%)	P_{losses} (kW)
Spatial	-10.1	17.38
Optimal	-7.5	13.09
Difference:	2.6	4.29

It can be seen that the optimal solution gives better results. As conclusion of performed simulation process it can be said that the results do not depend on the selection of the starting annealing temperature. Namely, the same results are obtained when the process of simulated annealing starts at high temperature ($T = 1,000$), as well as at low temperature ($T = 100$). Likewise, the obtained results do not depend on the cooling speed, if cooling factors selected in the range [0.9 to 1]. There are many cooling functions proposed in the literature. The most commonly used and the simplest way is multiplication with cooling factor α smaller than 1, typically in the range [0.5 to 0.99]. That is mean that new temperature is obtained as $T_{\text{new}} = \alpha \times T_{\text{old}}$ where T_{new} is the temperature in new iteration and T_{old} is the temperature in previous iteration. The same results are obtained after establishment of rapid cooling (factor 0.95), as well as slow cooling (factor 0.99). Thus, an optimal switching condition of low-voltage distribution network is obtained by the application of the proposed planning model.

4. IMPACT OF CHANGE IN CUSTOMERS' LOAD TO THE FINAL SOLUTION

As it was mentioned above, the customers' load can be obtained by using the data obtained on the basis of one-day, hourly measured loads of low-voltage feeders (the day with the annual peak load of substation) and a total annual realized energy of each customer. Also, customers' load can be obtained over coincidence factor. In the above network example, for the simultaneous load of customers, three values were examined: average simultaneous load of 1.1 kW, maximum simultaneous load of 1.4 kW and minimum simultaneous load of 0.8 kW. In

this way, annual customers' loads and loads in particular annual periods were obtained. The question is: Do these changes in customers' loads affect to the obtained result, since that three of four specified criteria depend on these values? In order to verify this, it is necessary to perform identical calculations with different amounts of daily loads of substation. The objective function in these calculations was minimal power losses. Obtained results are shown in Table VI.

Table VI: Spatial solutions depending on customers' load

Loads of substation and low-voltage feeders	Solution			
	S5	S6	S7	S8
Annual maximum	0.22947	0.24725	0.25223	0.27105
Annual minimum	0.22883	0.24672	0.25633	0.26811
Spring maximum	0.23094	0.24766	0.25179	0.26962
Summer maximum	0.22985	0.24759	0.25170	0.27086
Autumn maximum	0.22870	0.24697	0.25094	0.27339
Winter maximum	0.22858	0.24834	0.25255	0.27053
Simultaneous– max.	0.22401	0.24757	0.25319	0.27523
Simultaneous – min.	0.22521	0.24734	0.25277	0.27468
Simultaneous–aver.	0.22522	0.24756	0.25316	0.27406

These results show that changes in customers' loads does not affect on the selection of the best spatial solution. The question now is: Do the loads changes affect on the optimal solution? Application of simulated annealing method to all presented customers' loads cases shows that in all cases identical optimal switching condition of the network was obtained. So, it can be concluded that the sensitivity of results to power changes is relatively small in terms of uncertainty of loads (within certain limits of 30% of load). Therefore, for obtaining the optimal solution any available data about customers' loads can be taken or if that is not available some average values, specific for particular types of networks, can be chosen.

In all cases, different amounts of active power losses and voltage drops at ultimate customers are obtained, because these values directly depend on the amount of loads. The data about voltage drops and active power losses in all cases of load changes are shown in Table VII.

At the end, it can be concluded that these results were expected, considering that the amounts of loads at low-voltage customers are relatively small. Considering that, in all presented cases loads changes are small too, and they are proportional in the same manner for all customers. Then, it can be said that such changes do not have influence on the final solution.

Table VII: Voltage drops and active power losses for different customers' loads

Loads of substation and low-voltage feeders	Spatial solution		Optimal solution		Difference	
	ΔU (%)	P_{loss} (kW)	ΔU (%)	P_{loss} (kW)	ΔU (%)	P_{loss} (kW)
Annual maximum	– 10.1	17.38	– 7.5	13.09	2.6	4.29
Annual minimum	– 5.5	5.26	– 4.1	4.08	1.4	1.18
Spring maximum	– 8.8	11.81	– 6.5	9.07	2.3	2.74
Summer maximum	– 9.5	16.67	– 7.1	12.64	2.4	4.03
Autumn maximum	– 7.7	11.64	– 5.8	8.81	1.9	2.83
Winter maximum	– 9.2	14.01	– 6.8	10.63	2.4	3.38
Construction of new network – maximum	– 8.4	15.38	– 6.4	12.93	2.0	2.45
Construction of new network – minimum	– 4.6	4.75	– 3.5	4.06	1.1	0.69
Construction of new network –average	– 6.5	9.22	– 4.9	7.82	1.6	1.40

5. CONCLUSION

Planning of distribution networks is an important issue, which seeks to enable an efficient use of the network in order to meet the requirements of all customers. In the planning process of distribution network there are a series of options that can improve the state of the network and some of them are building new or enhancing existing power lines, building new power points, modifying the network topology, the inclusion of distributed generation etc. Classic planning models of distribution networks are based on approximately predictable behaviour of customers to which network topology and transmission power are adjusted. Modern planning models of distribution networks include several, interrelated analysis. The basic requirement, which always has to be satisfied, is operation of the system in accordance with the technical regulations. Therefore, two basic criteria always have to be satisfied in the planning process, in the way that every customer has secured voltage within prescribed limits and any network element (power line or transformer) is not overloaded in regular operation. Moreover, modern models should include other criteria which affect to defining the best solution. Some of them are the criterion of minimum power and energy losses, the criterion of minimum cost of network construction, the criterion of quality electricity supply of customers, the criteria of reliability etc. Selection of the criteria that will be used when making a decision depends entirely on person who performs the planning. In general, the selection depends on the interests of customers and the interests of the distribution companies. In the market conditions interests of customers have a slight advantage, but the interests of the company in any case cannot be placed in the background. Furthermore, besides se-

lection of the criteria, it is very important the way in which the evaluation of criteria will be performed, or what will be their relationship by hierarchy. In the proposed model one criterion that is on the customers' side (voltage drops) and three criteria on the side of the distribution company (other criteria) are selected. Analysis of this simplified division would lead to the conclusion that model does not treat equally the interests of customers and company. Therefore, for the purpose of harmonization, the criterion related to the customers received the greatest importance, or mark. In this way, the equality was achieved. Modern planning models should be based on the use of modern algorithms and software solutions. Unique and generally accepted model does not exist. This paper presents a model that is based on a combination of modern hierarchical and stochastic algorithms. The results showed that the application of the model achieved significant improvements when it comes to energy parameters. Also, it is shown that on the analyzed example the results are not dependent on the min-max power consumption. The model is applicable both to low-voltage and medium-voltage distribution networks. Therefore, this model can serve to experienced engineers as a very useful tool.

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