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DISTRIBUTION NETWORK PLANNING METHODOLOGY WITH ED MOSTAR CASE STUDY

METODOLOGIJA PLANIRANJA RAZVOJA ELEKTRODISTRIBUTIVNE MREŽE S PRIMJEROM ED MOSTAR

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Abstract: Power systems around the world have undergone a number of important organizational, structural and technological changes over the past few decades; they are a direct consequence of the electricity market liberalization and transition from conventional energy conversion technologies towards renewable resources. These changes represent many advantages as well as challenges for the Distribution System Operator (DSO). The aim of this paper is to review the most important principles, objectives and technical criteria used in planning the development of the electricity distribution network. Presented principles can be used as basic guidelines when developing short-term and long-term plans for the construction and reconstruction of power distribution facilities. This paper also presents a methodological approach to the planning and ranking of proposed electricity facilities with an example from practice that is based on the real planning problem in ED Mostar. The basic conclusion of the paper is that the identification of objectives, criteria and the application of an appropriate and unique methodology is of the utmost importance for formulating the framework of the planning process.

Keywords: criterion, development, methodology, objective, planning, power distribution system

Sažetak: Elektroenergetski sistemi u svijetu prolaze kroz niz strukturalnih i tehnoloških promjena koje su direktna posljedica procesa liberalizacija tržišta električne energije, te procesa tranzicije s konvencionalnih tehnologija konverzije prema obnovljivim izvorima. Ove promjene predstavljaju mnogobrojne prednosti ali i izazove za ODS. Jedan od važnijih izazova jeste proces planiranja razvoja elektrodistributivnog sistema u uslovima nepotpunih i nepouzdanih podataka vezanih za poslovno okruženje, porast potrošnje i distribuirane proizvodnje, planovi i interesi privatnih investitora, kao i promjene regulatornog okruženja. Cilj ovoga rada je pregled najvažnijih principa, ciljeva i tehničkih kriterija koji se koriste kod planiranja razvoja elektrodistributivne mreže, a koji se mogu koristiti kao osnovne smjernice prilikom izrade kratkoročnih i dugoročnih planova izgradnje i rekonstrukcije elektrodistributivnih objekata. U ovome radu također je predstavljen metodološki pristup planiranju i rangiranju predloženih elektroenergetskih objekata s primjerom iz prakse koji je baziran na realnom problemu planiranja. Kao osnovni zaključak rada ističe se činjenica da su identifikacija ciljeva i kriterija, te primjena odgovarajuće metodologije, od najveće važnosti kod uspješne izrade planova razvoja elektrodistributivnog sistema.

Ključne riječi: kriterij, razvoj, metodologija, cilj, planiranje, elektrodistributivni sistem

INTRODUCTION

Distribution system development and reconstruction planning is a complex process. It requires management of substantial amounts of data that need to be collected, maintained and as interpreted appropriately. The process of electrical distribution system (EDS) planning can be defined as a complex optimization process, which requires finding the appropriate balance between set goals and given system constraints caused by the network technical parameters to be achieved. In practice, the decision-making process, related to the EDS development planning, takes place under conditions of extreme inaccuracy, uncertainty, and incompleteness of the input parameters and the attribute of the system (which is a variable and non- linear). Also, it requires consideration of the future business and regulatory environment. The existence of a coherent and logical decision-making framework containing a clearly defined methodology, planning criteria and objectives represents a mandatory tool, which can assist during design and approval of a long-term EDS development plan. Using this type of tools, it is possible to perform project categorization, data interpretation and ranking of the alternatives.

Historically, EDSs have not been the focus of reliability and long- term planning studies. Therefore, most modern analysis and models for power system planning are dedicated mainly to generation facilities and transmis-

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sion networks because of economies of scale, but also because of the belief that their failures have a greater financial and social impact. However, the new energy paradigm represents a whole new approach and understanding of the distribution network requirements, which primarily reflects on customer and regulatory pressures for the ever-increasing EDS reliability standards. Furthermore, the analysis of power outage statistics shows that EDS provides the largest individual contribution to unavailability of customer supply. This is important information, which indicates that more attention should be paid to the issue of EDS reliability. On the other hand, the cost of electricity distribution represents a significant portion of the total electricity cost [1]. Investments in the power system can be roughly divided into two groups: investments in construction of new facilities and investment in reconstruction of the existing facilities. It is estimated that 30 – 40% of total investments in the power sector have been allocated in investment of the distribution system [2], which cannot be neglected.

In addition to these problems and their specificity, the integration of distributed energy sources is of particular importance. The problem of their optimal allocation essentially arises from three questions:

1) Does the interest of private investors (in distributed energy sources) coincide with the interests of the DSO?
2) Does the DG (distribution generation) owner's operation strategy coincide with the interests of the DSO?
3) Is it possible to obtain complete information on plans of private investors in time?

Pursuant to the current laws and regulations, the responsibility of the DSO is to ensure the operation of the distribution system in accordance with the prescribed electricity quality and reliability parameters, to provide access to the network to end customers and producers in a transparent and non-discriminatory manner as well as to create, adopt and publish short and long-term plans for development of the distribution system. The long-term EDS development plan must promote the economic development of society and industry along with promotion and application of modern and advanced technologies. During this process, the appropriate consideration must be paid to trends in the electricity production and consumption growth patterns, financial possibilities, external influences, the restructuring process as well as plans of local authorities and transmission system operators. The quality of a long-term plan largely depends on definition and application of an appropriate planning methodology as well as definition of solid planning objectives and criteria. This approach ensures the application of uniform rules and procedures throughout the DSO area of responsibility. In essence, the process of developing and adopting an investment plan is a decision-making process that can be divided into the following main stages:

1) Defining goals,
2) Consideration of alternatives,
3) Development of alternatives,
4) The direction of choices (decision-making).

This paper explains some of the most important EDS planning stages, highlighting the objectives, criteria and methodology. Further, this paper presents an application example of EDS planning, using a realistic case study. Finally, a number of future researches are proposed, together with the most important conclusions of this paper.

The purpose of this paper is to review the most important principles, objectives and technical criteria used in planning the development of the electricity distribution network. Additionally, the paper will present a methodological approach to the planning and ranking of proposed electricity facilities with an example from practice, which is based on the real planning problem in ED Mostar. It is expected that this paper will contribute toward more effective management of power distribution network planning process by developing and testing a fuzzy logic based model for network planning.

This paper can be divided in two parts. The first part is a review of the most important principles, objectives and technical criteria used in planning the development of the EDS. During this stage of the research, the most relevant scientific and practical literature was surveyed in order to identify and present the most important planning principles, criteria and methods. The second part presents a fuzzy system used for decision-making in the area of EDS reconstruction planning. The methodology used in this part is based on mixed method approach to address different issues appearing along the model design and testing. The most frequently used methods are modelling methods, analytical methods and numerical calculation methods.

1. OBJECTIVES AND CRITERIA USED IN EDS PLANNING

1.1. Planning objectives

During the development of short and long-term plans for EDS reconstruction and general development, a clear definition of planning objectives is of critical importance. Law regulation and strategic commitments of the DSO are just some of the factors affecting the type and number of objectives presented to the experts involved in the creation of the development plan. The definition of planning objectives is performed at the highest executive level of the DSO when designing a project assignment, and was entirely conducted in accordance with the existing laws and regulations. The fundamental objectives of EDS development and reconstruction planning are:

1) Fulfilment of all legal obligations, and particularly in terms of electrical energy quality, reliability and security,
2) Provision of transparent and unhindered access to the EDS,
3) Maximization of reliability function and minimization of cost function of the power system,

4) Increase the efficiency of the DSO operations,
5) Promotion and use of modern and advanced technologies.

In addition to these fundamental objectives, the particular importance is dedicated to the strategic commitment of individual companies. When it comes to the DSO from Bosnia and Herzegovina (BiH), the basic strategic commitments include a transition towards a unique 110/20 kV transformations, neutral point treatment, reduction of losses, responding to challenges of the electricity market, integration of renewable energy based distributed generators and finally, promotion and development of new technologies and methods in operation, management, and planning of the EDS.

1.2. Planning criteria

1.2.1. Voltage levels

Voltage level and quality are among the most important parameters in an electrical power system (EPS). Adequate voltage quality in each node is of great importance for the safe and efficient operation of the EPS and is one of the main criteria in the process of development and reconstruction planning. A large part of the efforts and activities of maintenance, management, and planning of the EPS are dedicated to ensuring that voltage levels remain within the prescribed limits. These limits are defined by the EN 50160 standard and are integrated in the domestic legislation (in BiH) [3]. This is a European standard that defines, describes and specifies the main voltage characteristics at the points of connection of users of public low-voltage, medium-voltage and high-voltage power grids under normal operating conditions. This standard also describes the permitted limits of voltage variations in distribution networks in Europe.

1.2.2. Current limits for components of the distribution system

The acceptable load current for each of the system components is one of the basic limitations to be considered when analyzing a system. Furthermore, the current limit is the most important and commonly used criterion for reconstruction project selection and investment plans development. Based on these facts, the load increase of the power system (using the appropriate methodology) is of great importance for the proper assessment of the future power system state. Calculation the maximum current especially applies to the following components:

1) Power system lines - the maximum current flowing through the line must be less than or equal the rated current for each power line of the system,
2) Power transformers - the maximum current flowing through transformer must be less than or equal the rated current for each transformer,
3) Measuring devices - it is obligatory to regularly check and monitor the load of consumers who have certain types of measuring devices installed, as well as measuring devices in DSO plants.

1.2.3. Reliability parameters

Generally, most of the power system reliability analyses have focused on generating plants due to economies of scale and due to the fact that their downtime had a greater financial and social impact. In the recent times, however, the increasing attention is dedicated to distribution system as the analysis of the customer failure statistics of most power utilities revealed that the power distribution system actually makes the single largest contribution to the interruption of electrical energy supply to the end customers. Therefore, reliability analysis, which is mainly represented by standard indicators (SAIDI, SAIFI, etc.) is an important criterion for project nominations and ranking. Particular attention is paid to the classification of reliability parameters according to the following categories:

1) Urban areas,
2) Rural environments,
3) Sensitive customers and areas of particular importance (e.g. hospitals),
4) Implementation of the n-1 criteria.

1.2.4. Connection of large end load customers and distributed generators

Creating technical conditions for connecting the new load and generation customers to the distribution network are among the main roles of a DSO. Proposing the pre-investment in the distribution network in collaboration with the local community is a key task for any planning engineer. Furthermore, information about individual major load and generation customers is an important criterion for making decisions related to distribution system development and reconstruction planning.

1.2.5. New technologies and power system components

New technologies and components of the power distribution system and their inclusion in the investment plant present a significant challenge. It is also an important strategic direction for development of the future systems. This area of strategy development primarily refers to electric vehicles and electrical energy storage systems, smart-grid technologies, operation and managements technologies, demand response and renewable energy based distributed generation.

1.2.6. The criterion of financial viability of an investment

Making a business decision based on the financial justification of the investment should be preceded by financial analysis. Even though electricity distribution is a regulated area, financial parameters have recently been receiving an increased attention by managers and regulators. It is possible to invest in financial forms of assets and make an investment equal to their value. It is also possible to invest in real forms of assets that enable the realization of benefits through productive business activities. In the following paragraphs, some of the most important parameters that indicate the financial viability of investing in EDS are presented.

1.2.6.1. Return on investment

Return on investment can be defined as a return on total capital, return on invested long-term capital and return on equity. From the standpoint of an individual investment, that is, an investment project in EDS, its profitability can be measured by the return on investment (*ROI*), which is defined as follows:

$$ROI = \frac{Investment\ profit\ -\ investment\ \text{cost}}{investment\ \text{cost}} \quad (1)$$

1.2.6.2. The payback method

The payback method is one of the simplest methods and is often used to quickly calculate the payoff of an EDS investment. It is a method that determines the period of time required for the cash flow to recover the original investment, i.e. how much time it will actually take to get the money back. In order for the investment to be profitable, the return must be less than the project's duration. Speed and simplicity are the main advantages and it is suitable for preliminary analysis. If the project does not pass the cost-effectiveness test, then no further analysis is required. However, its weakness is that it does not reveal much and does not tell us how much the total profit or (saving) would be.

1.2.6.3. Net present value (NPV) method

This method is a more complete tool compared to the payoff method. Its key feature and advantage are that it takes into account the time value of money by discounting future cash flows and takes into consideration the present value of money. With this method, it is possible to obtain a realistic outlook of the fulfilment of the leap rate set by the investor. It is also possible to compare the present value of the initial expenditure with the present value of future returns.

The *NPV* method is equal to the present value from which the initial cash outlay is to be deducted. It is also possible to use different values of the discount rate, which is inversely proportional to the *NPV*. The discount equation can be represented as follows:

$$PV = \sum_{n=1}^{N} \frac{Cn}{(1+i)^n} \quad (2)$$

$$NPV = PV - Initial\ investment \quad (3)$$

where: *PV* present value, C_n cash flow for the observed period, *NPV* net present value and discount rate, *n* number of time periods (years) considered.

1.2.6.4. Internal rate of return method

The internal rate of return (or profitability) method is another method for evaluating the viability of an investment. This method is similar to the calculation of the *NPV* with the only difference being the variable. The internal rate of return calculates the current level of return obtained with the projected cash flow. The value obtained in this way is compared with the leap rate to determine the return on investment. The practical way to look at the internal rate of return is as a discount rate that makes the net present value equal to zero, i.e.:

$$NPV = 0 \quad (4)$$

$$PV - initial\ investment = 0$$

$$\sum_{n=1}^{N} \frac{Cn}{(1+i)^n} - initial\ investment = 0$$

$$\sum_{n=0}^{N} \frac{Cn}{(1+i)^n} = 0$$

1.2.6.5. Sensitivity analysis

Business decisions are often made in conditions of great uncertainty due to the unavailability of data at the required periods of time. Each investment project contains a certain degree of risk due to the inability to predict future events. Sensitivity analysis shows how sensitive a proposed solution is when the parameters of a problem change. A characteristic of sensitivity analysis is that some parameters may vary within a given range and have a greater or lesser impact on business results. In the case of important managerial decisions, sensitivity analysis can indicate the degree of risk and help avoid decisions that have negative consequences.

1.2.6.6. Benefit to cost analysis

The last criterion to be considered in evaluating the return on investment is the benefit/cost ratio (*B/C*), which is defined as the ratio of the total present value of income to expenses, ie:

$$B/C = PV\ in / PV\ out \quad (5)$$

In addition to the cost of the investment itself, it is necessary to take into account the cost of losses of power and electrical energy, the cost of undelivered energy, as well as the cost of operating and maintaining the system. Summing all the cost and benefits and allocating them to a particular investment project can be a daunting task. It is sometimes very difficult to place a quantitative value on a project because of the complex interconnections between various technical, social and financial aspects of project.

1.2.7. Power and electrical energy losses

Reducing the power and electrical energy losses is one of the most important aims for the DSO. Taking measures and activities to achieve this is a continuous task. When designing a reconstruction and development plan of a power grid, projects that contribute to reducing losses always receive special attention. Even though, in BiH, the distribution activity is a certain type of regulated monopoly, the profit from investing in the electricity distribution activity is significant factor and most often comes from a reduction in the cost of electricity distribution. Examples of investment projects that potentially contribute to reducing the electrical energy losses include low-voltage grid reconstruction, including power metering and billing systems, cabling of densely populated and urban areas, increasing cross-sections of power lines, reactive power compensation, distributed generation and consumption management, optimization of system operating state, etc.

1.2.8. Reactive power compensation

Reactive power compensation is one of the most effective measures for reducing electrical energy losses in a power distribution network, extending the life of the system components and improving the general operating conditions of the system. Therefore, reactive power compensation is one of the significant measures in system development plans. The allocation (location and size) of the devices for reactive power compensation is determined based on the result of the power flow analysis. Based on practical experience, the best effects are achieved by compensation at the point of customer's connection with low power factor and on the low-voltage side of distribution transformers fed by long overhead power lines. Proper allocation of power compensation devices remains one of the main measures for the overall increase of energy efficiency of the power distribution system as well as its overall controllability.

2. EDS PLANNING METHODOLOGY WITH PRACTICAL APPLICATION

2.1. Methodology

The development of the distribution network is planned according to the criterion of optimal supply of electricity to the customers, which ensures the losses minimization, as well as reliability and continuity of power supply maximization. Generally, there are two approaches to distribution network planning, namely deterministic and probabilistic. The deterministic approach requires the continuous supply to all customers in the event of unavailability of a single network element such as a transformer, transmission line, etc. In this case, known as the N-1 condition, failure of one element can be tolerated without significantly affecting the security of the system. However, strict adherence to this condition may lead to underinvestment as the cost of a possible interruption to customers or the cost of using alternative options is not taken into account.

The probabilistic approach, on the other hand, is more relaxed compared to the N-1 condition and is based on the analyses of power load flows, which take into consideration the amount of energy not supplied in the event of failure of one component of the system. In this way, there is a delay in investment projects that would have been implemented should a deterministic planning approach has been used.

In the probabilistic approach, there are conditions under which energy cannot be distributed through components that are out of service and the amount of energy delivered is rather small given the likelihood that his event will actually occur. Using a probabilistic approach, the risk of a power loss under normal operating conditions (known as the „N" condition) is evaluated for when the load exceeds the total system capacity. To solve this situation, a number of options are explored, all used to keep the system under normal operating conditions until the completion of the projects related to the distribution system capacity extension. The probabilistic planning approach involves estimation of the likelihood that a power outage will occur during the peak period and estimates the cost of such an event, in order to evaluate:

1) The expected cost to be incurred if no action is taken to address the resulting limitation,
2) Whether it is economically viable to increase the network capacity to reduce the unexpected costs caused by a power outage.

The amount of energy not delivered due to this type of failure is a critical parameter in assessing potential network investment or other measures such as power management or distributed resources. The probabilistic approach to planning is essential to finding a compromise between:

1) Expansion of distribution capacity,
2) The cost of not being able to deliver electricity.

Considering the fact that the peak load occurs on average 3% of total time during the year [4], it may not be economically viable to invest in distribution system capacity extension expanding in order to eliminate the risks of power outages during the most sensitive periods. Furthermore, the probabilistic approach requires justification for such investments that must be provided by estimating the present value of the proposed investment. Ultimately, investing in distribution system capacity expansion in order to reduce risk is a matter of judgment. It is based on EDS analysis, potential failures, costs, and the ability to use distributed resource programs.

2.2. Example of the methodology applied in practice

The basic principle of the JP EP BiH-d.d Sarajevo, Podružnica „Elektrodistribucija" Mostar (ED Mostar) is to plan the development of the distribution system in an efficient manner minimising the total operational cost of the system. In line with this commitment, particular attention is paid to the overall energy consumption and maximum power demand (taking into consideration the predicted growth trends), energy efficiency,

system reliability indicators, electrical energy quality, and emission reductions.

The criteria and standards used in elaboration of development plants significantly influence the level of investment required to meet the increase in energy consumption but also the increasingly stringent requirements for quality and security of power supply. Modern power system planning is an optimization problem needing to satisfy a number of technical and economic criteria. The existing practical experience indicates that plan is primarily an optimal compromise between different planning criteria. In addition to determining the optimal capacity of the distribution system, it is necessary to consider other criteria, primarily the financial and the power quality criteria. The financial criteria for distribution system planning implies the optimal construction and operation of the system, while the quality criterion implies the appropriate power quality levels, security of supply and environmental protection. Additionally, and all these goals must be achieved with a clear definition and without any preferential treatment, towards all entities and stakeholders.

The development plan is based on a probabilistic planning method that considers a combination of maximum load demand, allowable power system capacity and reliability parameters to identify risks in the distribution network and to rank investment projects according to their capability to deliver long-term benefits to both DSO and customers. The basis of this methodological approach is the power flow analysis taking into consideration the appropriate methods for energy consumption forecast. The main features of the planning standards adopted by ED Mostar, in addition to the basic criteria set out in the previous chapter are:

1) Compliance with the regulatory and legal framework as well as relevant technical regulations and standards,
2) Observing modern trends and guidelines arising from the strategic commitments of JE EP BiH- d.d. Sarajevo, primarily in terms of loss reduction, switching to 20 kV, perspective of the 35kV voltage level and neutral point treatment,
3) Monitoring the load of the distribution network and identifying risks,
4) Monitoring of reliability indicators of the electricity distribution network,
5) Monitoring of power quality parameters and customer complaints,
6) Planning of network configurations to allow optimum switching states (reconfiguration),
7) Optimization of the LV network in terms of interpolation of new 10(20)/0,4kV transformer stations, with the following sub-criteria (being primarily considered and not limited to):
    - Urban plans,
    - The current state of the power system,
    - Overload conditions,
    - Voltage drop,
    - Connecting new load and generation customers to the network.

The development of a low-voltage network should also be based on the following principles:

1) Short low-voltage connections for the existing networks are achieved by interpolations of the distribution transformer,
2) In areas with low load density, 10(20)/0,4kV transformer stations with small rated power and short low-voltage gird should be built.

The long-term goal in developing a low-voltage network can be defined as:

1) 2.5 km of low-voltage network per distribution transformer area (average per year: +100 TS throughout the system, network length -8.5%),
2) Rehabilitation of the low-voltage network so that the technical limitations (norms and standards) are fulfilled by 2030, including implementation of the AMI systems.

Further in this section, a fuzzy logic based approach for EDS project selection is shortly presented. This approach is widely recognised and has been extensively used in distribution system planning [5], reconfiguration [6] and DG allocation problems [7]. Fuzzy models for decision making are implemented as control algorithms even when their behaviour resembles expert systems more than fuzzy control algorithms. The main reason for this is them being modelled by human expert knowledge and it can only be verified by testing their outcomes. Using single valued quantities as inputs and outputs of fuzzy rule-based models in decision-making, significantly limits their ability to support decision-making [8]. Fuzzy control algorithms are particularly useful in EDS planning because they can represent qualitative information and are very useful in addressing the uncertainty and incompleteness of input information (criteria). The following example represents a results of fuzzy system application on a simple EDS model (Table I), based on [9]. The details of the model are presented in [9]. The additional examples of the actual practical application of advanced algorithms in the field of power system development are given in previous papers [9]-[12].

Figure 1 shows a single line diagram of a simple power distribution system. In the proposed model, customer number values are normalized into 0-1 range, where 1 is maximum, corresponding to 1000 customers and 0 is minimum, corresponding to 0 customers. This attribute is combined with rate of failure value, in order to obtain C1 according to the Mamdani type inference as shown in [8]. Similarly, the second criteria is output value of the inference model of two input attributes: age of distribution power line and its respective failure rates. It can be concluded that crisp values are obtained for representation of criteria for ranking distribution system reconstruction project.

The results can be used as a business analysis/intelligence tools and a decision making support tool. The list of possible criteria is not exhausted by the attributes proposed in this model. It is possible to extend the existing model to include any other criteria to appropriately represent the complexity of EDS planning problem. The final results are

obtained based on the best compromise of the proposed criteria. One possible way to resolve the conflict between criteria is the use of fuzzy multi criteria decision making method, as described in more details in [12].

Table I: Results of the fuzzy model application

	Feeder 1	Feeder 2
Number of customers	481	111
Failure rate (times/year)	1.2	0.8
Age of the line (years)	18	48
Criteria 1	0.71	0.28
Criteria 2	0.55	0.75

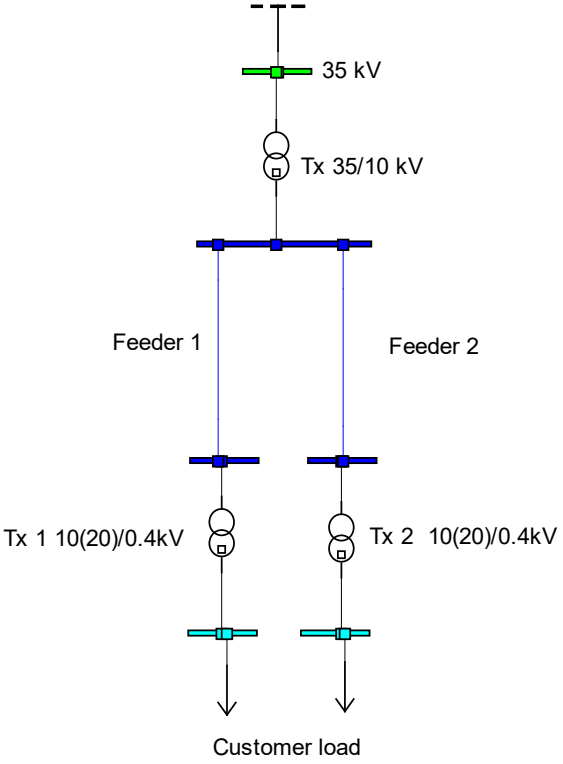

Figure 1: Single line diagram of the test system

2.3. Future direction for planning the development of the distribution system

Given the significant technical, economic, social and regulatory changes affecting the trend and philosophy of the development of the distribution system, it can be concluded with great certainty that this area will continue to attract the attention of both experts and informed audience learned public. The development of new algorithms and methods in this field and their practical application to real systems is one of the future research directions. The applications and integration of new technologies, especially in the fields of smart-grids, remote control, distribution resources, and electro mobility, and their inclusion in the plans for the development of the EDS, is one of the future challenges in this area. Finally, the application of similar computation methods and comparison of the results remains an important future research direction.

3. CONCLUSION

Planning for the development of power systems has recently received increasing attention due to new technical, economic, environmental and regulatory requirements. Therefore, BiH electricity distribution companies are increasingly committed to making long-term projections for system development. This paper presents an overview of the most important principles, goals and technical criteria used in planning the development of a power distribution network and it can be used as basic guidance in the preparation of short and long-term plans for the construction and reconstruction of power distribution facilities. In addition, this paper presents a possible methodological approach to planning and ranking proposed investment projects. Finally, it can be concluded that system planning is becoming a very important process within the business structure of electricity distribution companies in Bosnia and Herzegovina. It was also concluded that the identification of goals and criteria and the application of an appropriated methodology are of great importance for the successful development of plans for the development of the distribution system. In the future, it can be expected that more attention will be paid to the planning processes, especially in the field of new technologies, integration of distributed resources and electro mobility. Therefore, this topic deserves further attention and elaborations on the new examples, as well as additions to existing planning methods and approaches

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BIOGRAPHY

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