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CALCULATIONS AND ANALYSIS OF POSSIBILITIES FOR INCREASE OF DISTRIBUTION SYSTEMS RELIABILITY

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INTRODUCTION

Developments of reliability calculation methods, as well as determinations and calculations of reliability parameters, are basic phases in study of distribution system reliability.
In the literature there are several methods for reliability analysis of power systems components (generators, substations, lines etc.), as well as for reliability of power system in global.
In the paper, programs written in MATLAB, which enable calculations and analysis of reliability parameters for distribution systems, have been made on the basis of mathematical models of Markov's state models method and block-scheme method. Application of these programs and comparison of their possibilities and characteristics are illustrated on the example of reliability parameters calculation for concrete distribution system of town Tivat. By using derived programs and accessible statistically processed data of exploitation of elements in this distribution system, characteristic reliability parameters have been calculated.
By using analysis of obtained results, beside comparison of applied methods, possibilities and suggestions for increase power reliability and supply assurance within observed distribution system, as well as optimal planning of its maintenance, have been presented, too.

RELIABILITY CALCULATION

The main aim of distribution system reliability analysis is obtaining of quantitative reliability characteristics such as number and duration of supply interruption during one year for the observed network point (node).
Number of power supply interruptions depends on system structure, network configuration, elements reliability, type of and reason for failure that causes interruption, automation level, possibilities for and duration of switching on backup supply, training level of staff and their efficiency, duration of elements reparation or their replacement, etc.
For system reliability assessment it is necessary to consider reliability of all elements and to establish how interruption in element function influences on reliability of subsequent elements and system in global, that is on supply interruption for the observed network point.

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Selection of model and methods for system reliability calculation depends on system complexity, possibilities to take into consideration different factors, data for system structure and elements and system reliability parameters, requested accuracy, goals and aims of computation etc.
In order to determine system reliability quantitative characteristics it is necessary to start from elements reliability, because power supply interruptions are caused by elements failures. The basic sources for objective (proper) quantitative characteristics of elements reliability are statistically processed data for network elements failures and planned maintenances.
Power supply system is realized as connected (from supply source to customers by means of hierarchic principle) technical modules (elements or group of elements). Within distribution system, most frequent structures of technical modules are:
1. Two parallel elements (for example: double lines that both are designed for full load). In practice, in the case of planned maintenance for one element there will not be interruption in customer supply. In the case of failure, in some situations, there may be interruptions in customer supply.
2. Two connected backup (spare) elements (for example: line semi-loops in ring configuration which both are designed for full load). In the case of failure or planned maintenance for one element, its load wiil be taken by backup element after time that is needed for its start. Duration of power supply interruption for customers, which were supplied through element without normal function, is equal to time that is needed for performing all manipulations in order to switch supply from one element to another. This time is about one second in the case of automation backup switching, but from minutes to one hour in the case of manual backup switching.
3. One element, or two elements in one block. Failure or planned maintenance for any one of these elements means power supply interruption, which duration is time needed for reparation or maintenance. Within series elements connection of this type, planned maintenances could be performed at the same time for all elements. In that case, duration of maintenance is equalled to time needed for maintenance for element that has longest maintenance time.

Block scheme method for computation of distribution system reliability

Reliability computation using block scheme method is based on replacement of electrical power supply scheme for the observed network node with block scheme that is composed of series and parallel blocks, by means of reliability calculation, and which represents one element or group of elements. On that way, reliability calculation is reduced on analysis of structure with series and parallel elements.
In order to compose block scheme it is necessary to collect all supply sources in one point and to perform elements numbering (usually from customers toward source) in electrical power supply scheme. Within reliability calculation of distribution system, supply sources are feeder bus of distribution substations. It is possible, by means of reliability calculations of this type, to treat supply sources as absolute reliable elements, or they can be replaced with blocks that have reliability parameters obtained from reliability calculations for sources.
Additionally, it is necessary to perform analysis of elements failure influence on observed node power supply by taking into consideration transmission possibilities and work states for each element. By using this analysis, it is possible to determine series and parallel connections of elements by means of reliability calculations.
Next step is to replace electrical elements with blocks that are connected according previous analysis. This is way how block scheme for reliability calculation of observed system node is composed.
At the end, composed block scheme is reduced on equivalent block with reliability parameters that represents reliability parameters by means of power supply reliability for observed node.

Markov's state models method

This reliability calculation method is widely spread analytical method. It assumes that system mathematical model must include not only all possible states for elements and system in global, but also their transition from one state to another. For its application it is necessary to have mathematical model in the shape of collection of states in which elements and system can be in the different possible states of exploitation, i.e. cases of failures, reparations, and maintenances of all elements.
Processes of states transition within observed systems can be represented with mathematical model in graph shape (state space diagram), which illustrates process of state changing and which can be used for obtaining the needed differential equations.

Processes modelling for failures, reparations, and maintenances by using Markov's states request that system electrical scheme should be replaced with its graph of possible states. By using this graph, system of differential equations can be written, solved and analysed. This exact enough, but for complex system very large computation, is suitable for use only when accuracy of results is requested, when the cases of two or more time states are observed, or when it is necessary to take into consideration beginning states of some elements, that is when reliability parameters are calculated on relatively small time range.
Markov's state models method can include additional factors in distribution system reliability calculation such as: elements disconnection because of overloading or lose of stability, failure development etc. These factors easily can be taken into consideration by corresponding transitions on the state space graph, which is one of the advantages of this method.
Taking into account possible simplification and assumptions, as well as fact that in complex systems it is very difficult to get solution of different equations in general time shape, these systems usually are observed as stationary Markov's process. In that case, system of differential equations is reduced on system of linear algebraic equations, from which reliability parameters cab be easily calculated.

EXAMPLE OF RELIABILITY CALCULATION

Block scheme method and Markov's state models method are illustrated on the example of reliability parameters calculation for distribution system of town Tivat. Single line diagram of this distribution system is given on the figure 1, with all lines lengths and transformers rating. TS 110/35 kV Tivat is feeder substation for distribution systems of towns Tivat and Kotor. These two distribution system are supplied from different busbars systems 35 kV, because transformer 110/35 kV, which supplies distribution system of town Tivat, works with neutral point connection over low ohm impedance on 35 kV side, while transformer 110/35 kV, which supplies distribution system of Kotor, works with insulated neutral point on 35 kV side. TS 35/10kV Tivat is supplied through two underground cables 35 kV, which are composed of seven insulated conductors (one conductor is backup for both cables). TS 35/10 kV Racica and TS 35/10 kV Przno also belong to distribution system of town Tivat. However, these distribution substations supply only very small part of customers in comparison to TS 35/10 kV Tivat, so they will not be taken into reliability calculations.
The great part of 10 kV network in distribution system of Tivat is made as underground system, except lines Seljanovo II i Gradiosnica, which have parts with overhead no-insulated conductors.
Reliability calculation is performed with reliability parameters of the observed elements that are given in Table 1. These parameters are obtained through accessible statistically processed data of exploitation for elements in the observed distribution system.

TABLE 1 – VALUES OF RELIABILITY PARAMETERS FOR ELEMENTS IN DISTRIBUTION SYSTEM OF TOWN TIVAT

Element	Voltage	Outage rate f	Repair duration T_O	Planned outage rate f_p	Maintenance duration T_p
	(kV)	(1/year, km)	(h)	(1/year)	(h)
Breaker	110,35	0,014	35	0,3	100
Disconnector	110,35	0,0006	4	1	4
Bus	35,10	0,001	4	1	4
Cabl	35 10	0,11 0,142	0,379 0,6895	0 1	0 8
Transformer	110/35	0,25	1,0083	1	30
	35/10	0,1875	0,8575	1	15

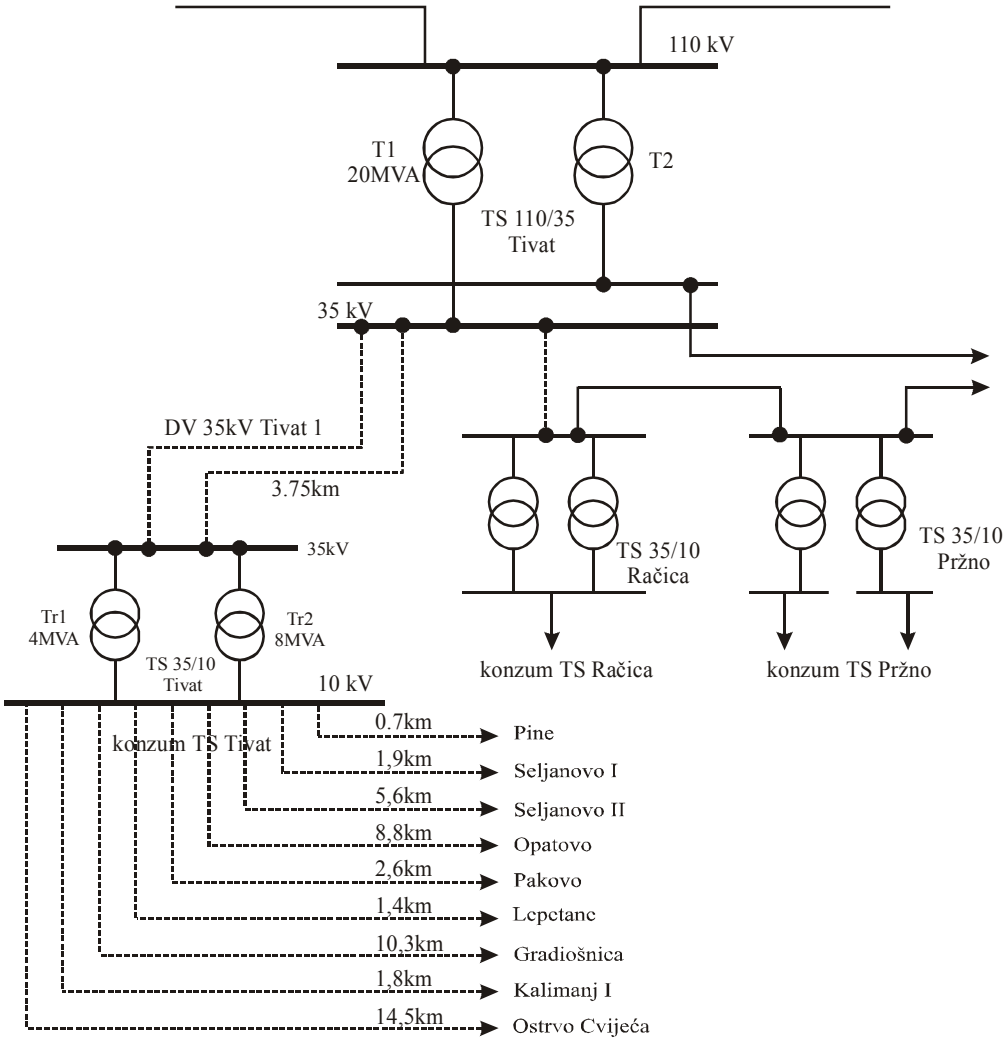

Figure 1. Single line diagram of distribution system of town Tivat

Application of block scheme method for reliability calculation

The different phases of block scheme composed for the observed distribution system are given on figure_2. Results of reliability calculation for any blocks and for entire scheme, by means of supplying one of customers connected on 10 kV lines, are given in table 2.

TABLE 2. - RESULTS OF RELIABILITY CALCULATION USING BLOCK SCHEME METHOD

Element	λ	K_O	f	T_O (h)	K_p	f_p	T_p (h)
I	0.618858	$4.963 \cdot 10^{-5}$	0.618827	0.702676	0.000456	1	4
II	0.2155	0.000143	0.215469	5.82396	0.004946	1	43.3333
III	0.2155	0.000143	0.215469	5.82396	0.004946	1	43.3333
IV	0.0921404	$1.371 \cdot 10^{-5}$	0.0921391	1.30391	0.000456	1	4
V	0.4525	0.000112	0.452449	2.17173	0.004109	1	36
VI	0.4525	0.000120	0.452446	2.32563	0.004109	1	36
VII	0.392196	0.000154	0.392136	3.45417	0.006088	1	53.3333
A	0.0464403	$2.263 \cdot 10^{-5}$	0.0464392	4.27074	0.009893	2	43.3333
B	0.204756	$1.678 \cdot 10^{-5}$	0.204753	0.718424	0.008219	2	36
Scheme	0.962195	0.0001027	0.962096	0.935759	0.011035	2	48.3333

where:
K_O - unavailability factor
Kp - planned-outage factor

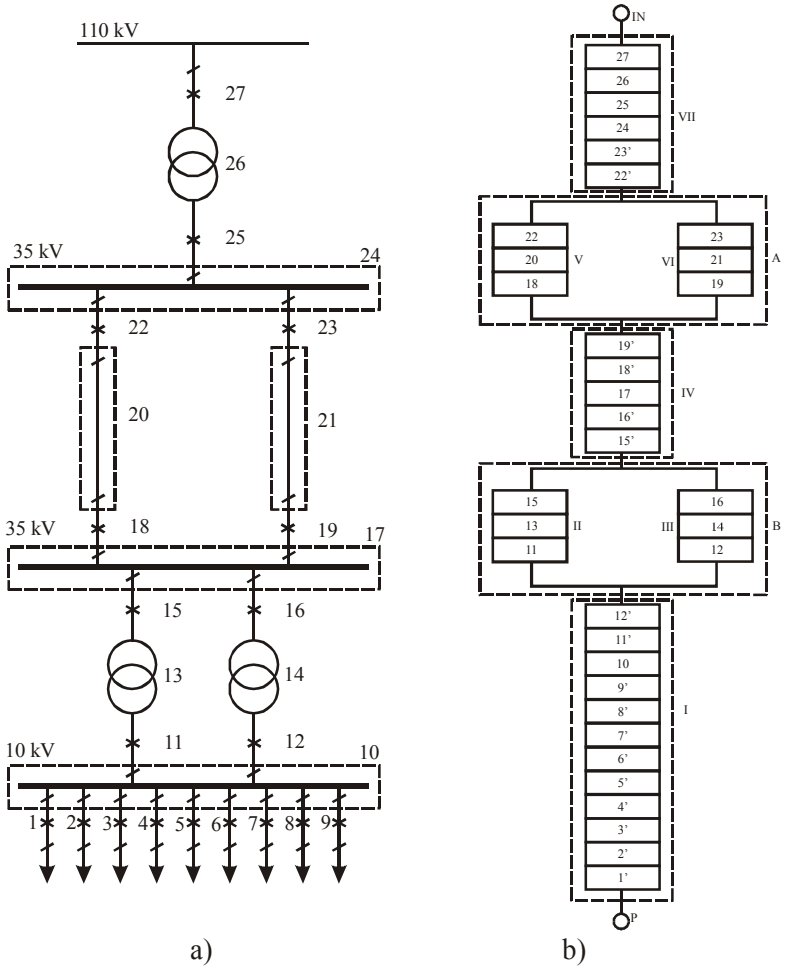

Figure 2. a) Different phases of composing of block scheme
b) Block scheme and equivalent blocks

Application of Markov's state models method

Scheme for reliability calculation using mentioned method is given on figure 3. This scheme is reduced to one element with reliability parameters for entire scheme by replacing parallel and series connections with equivalent elements as shown in figure. Results of reliability calculation for any blocks and for entire scheme, by means of supplying one of customers connected on 10 kV lines, are given in table 3.

TABLE 3. - RESULTS OF RELIABILITY CALCULATION USING MARKOV'S STATE MODELS METHOD

Element	λ	K_O	f	T_O (h)	K_p	f_p	T_p (h)
A	0,274895	0,000139	0,27486	4,43124	0,011414	1	100
B	0,436565	0,000128	0,43651	2,58411	0,011414	1	100
C	0,436565	0,000128	0,43651	2,58411	0,011414	1	100
D	0,213087	0,000115	0,21306	4,76268	0,011411	1	100
E	0,213094	0,000141	0,21306	5,82305	0,011414	1	100
F	0,822695	0,001439	0,82258	1,5332	0,011414	1	100
G	0,000112	$1,657 \cdot 10^{-8}$	0,000112	1,29205	$7,485 \cdot 10^{-8}$	0,0026	2,519
H	$5,364 \cdot 10^{-5}$	$1,604 \cdot 10^{-8}$	$5,364 \cdot 10^{-5}$	2,61987	$2,758 \cdot 10^{-6}$	0,0048	5,0243
I	0,2929	0,000147	0,29289	4,3939	0,001193	2	52,2582
J	0,813358	0,000142	0,81324	1,5332	0,011417	1	99,55
Scheme	1,08114	0,000282	1,0808	2,29	0,02302	2	68,0161

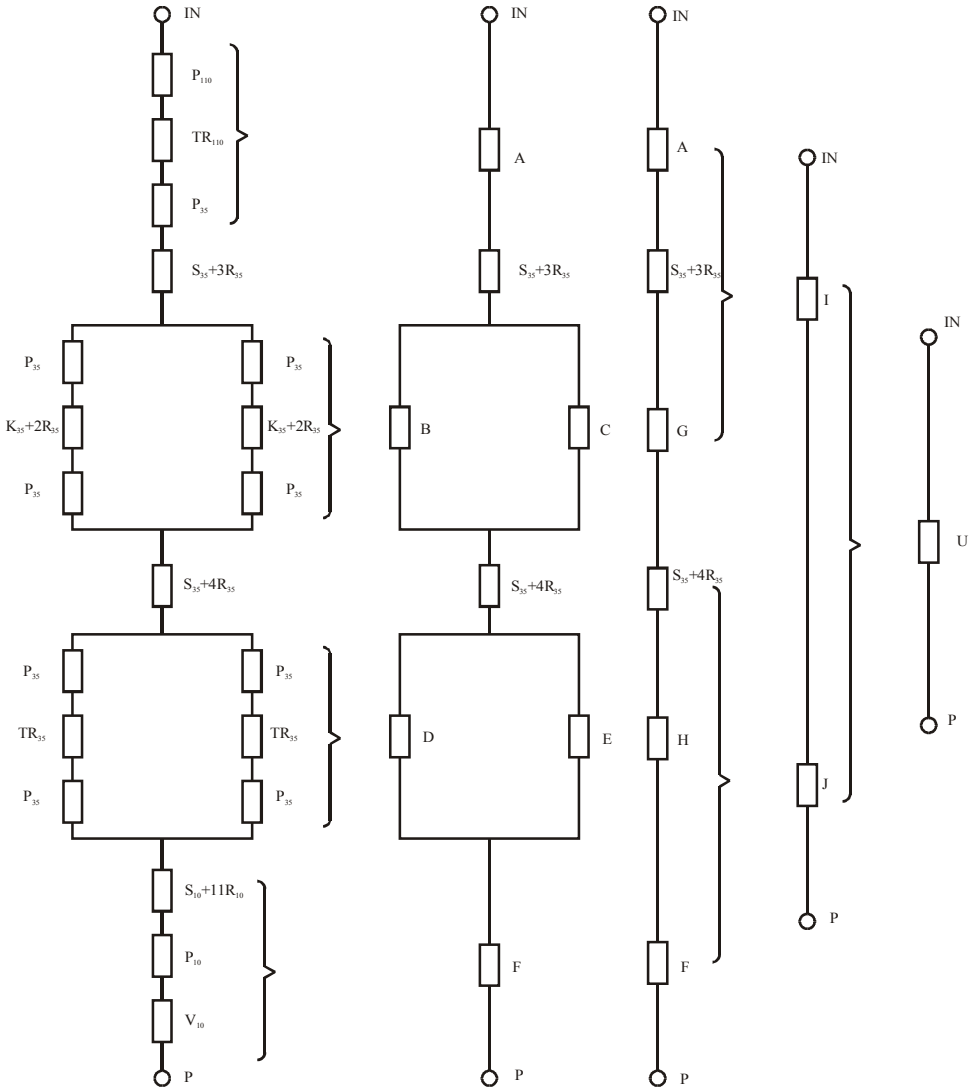

Figure 3. Scheme for reliability calculations using Markov's state models method

ANALYSIS OF THE OBTAINED RESULTS

By using obtained results for reliability parameters of observed distribution system and analysing application procedure of used methods, it is possible to note:

1. Because of different ways of their composing it cannot be completely excused comparation of the results for reliability parameters of single blocks.
2. First difference between reliability parameters for entire scheme, which are obtained using mentioned methods, is appeared because of different parameters calculations of planned maintenance.

- Reliability calculation using block scheme method for series connection of elements or blocks is performed with mean values of parameters that desribe states of failures and planned maintenance.
- Values of reliability parameters using Markov's state models method significantly depend on available possibilities for planned maintenance. There will be large difference between values for different situations by means of planned maintenance. From that reason, in reliability calculations it is necessary to use model, which corresponds with available possibilities for maintenance (1).

3. By means of application procedure for mentioned methods it can be observe that block scheme method allows relatively simplified way for determination of reliability parameters for customer power supply. This method is based on replacement of power supply electrical scheme for observed network

node with block scheme that is composed of series and parallely connected elements and for which is very easy to calculate reliability parameters.
Application of Markov's state model requests knowledge about not only all of possible states for elements and system in global, but also their transitions from one state to another. In the cases of large and complex systems with increase number of their elements, number of possible states also increases. This causes that number of differential (or linear algebraic, in the case of stationary Markov's process) also increases, which makes their solution and analysis very difficult and time consuming. From that reason, application of Markov's states models method is suitable only by using computer's programs.

Suggestions for increase of reliability in distribution system of town Tivat

By using analysis of obtained results for reliability parameters of distribution system of town Tivat and taking into consideration its equipment states and work conditions, it can be noticed that the customer power supply in this distribution system is on relatively satisfactory level. The main reason for this is relatively small frequency of failures that are happened in 10 kV network, because it is with its great part realized as underground system.
However, with detailed and individually analysis of work conditions for some system elements it is possible to notice the ways for further improvment of reliability level and decreasing of power interruption durations.
Namely, geographic and climate characteristics that exist in environment of observed distribution system are first on list which should be taken into consideration in order to analyse no-voltage states and reasons for them. Within these characteristics, the most important ones that have significant influence on elements reliability are: seaside surrounding (which has influence on high value of humidity and salinity), very high ceraunical level and craggy ground (which has influence on very high value of earthing resistance).
These work's conditions have dominant influence on very large number of failures on those 10 kV cabled-lines that have parts with overhead no-insulated conductors (Seljanovo II i Gradiosnica). Replacement of these critical parts with semi-insulated Al-Fe conductors would be solution for this problem.
Working regime of transformers within TS 110/35 kV Tivat also has a large influence on power reliability level in this distribution system. Reasons for this are different ways of their neutral points connections and procedure that is necessary to be done in cases when is needed that these two transformers work as parallel elements (because there exists only disconnector on the impedance for neutral point earthing for one transformer). From these reasons, very large numbers of short-time interruptions (temporary) of power supply are present in this distribution substation. For solution of this problem, firstly it is necessary to consider conditions of touch voltage risk and step voltage risk. After that, depending on of the obtained results, it is necessary to review possibilities and ways of optimal grounding of other transformer.
Regular maintanance of existing equipment and using new achievements such as remote monitoring and control would further improve reliability level in observed system by means of reducing of power interruption duration and failures frequency.

CONCLUSION

Reliable energy supply is one of the most important demands that are requested from customers. This demand should be fulfilled by power system in global, as well as by its subsystems and components which are performing customer supply.
In the literature there are several methods for reliability analysis of power systems components (generators, substations, lines etc.), as well as for power system in global.
These methods are different by means of established assumptions, possibilities to take into consideration different influences and states and complexity of application. The most frequent used methods are: method of Markov's state models, method of Monte Carlo simulation, method of block-scheme, method of failure tree etc.
In the paper, programs written in MATLAB, which enable calculations an analysis of reliability parameters for distribution systems, have been made on the basis of mathematical models of Markov's state models method and block-scheme method. Application of these programs and

comparison of their possibilities and characteristics are illustrated on the example of reliability parameters calculation for concrete distribution system of town Tivat. By using derived programs and accessible statistically processed data of exploitation of these elements in this distribution system, the most often used characteristic reliability parameters have been calculated.
By using obtained results, comparison of observed methods and analysis of reliability parameters for distribution system of town Tivat have been done. Using detailed and individually analysis of work conditions for some system elements, possibilities and suggestions for further increase of distribution system reliability level have been sugessted.

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