COMPUTER PROGRAMS
FOR ARRANGEMENT OF HIGH- AND MEDIUM-VOLTAGE POWER DISTRIBUTION NETWORK

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SUMMARY

This paper presents the potentiality of computer programs for the arrangement of HV power distribution network, independently of its current configuration. The potentiality of computer programs and variants of possible network shaping are presented on the example of Belgrade prospective HV network.

Computer programs are used to obtain the middle-term plans of construction of the network on the consumption area of JP "Elektrodistribucija-Belgrade" up to the year 2000, and will be useful during the make of long-term plan documentation for the planning period up to the year 2020.

Based on "general arrangement" obtained by the computer, and bearing in mind other conditions, three variants of arrangement with minimal network length are proposed, with a total of up to 2, 4 or 6 transformer substations 110/10 kV (2x40 MVA) on connecting directions with 110 kV cables (Al 1000 mm^2).

***Key words** :computer programs, arrangement of high voltage network, arrangement of medium voltage network,*

RAČUNARSKI PROGRAMI
ZA RASPLET VISOKONAPONSKIH I SREDNJENAPONSKIH ELEKTRODISTRIBUTIVNIH MREŽA

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Kratak sadržaj :

Ovaj rad prikazuje mogućnosti računarskih programa za rasplet visokonaponskih i srednjenaponskih elektrodistributivnih mreža nezavisno od njene postojeće konfiguracije. Mogućnosti programa se prikazuju na primeru raspleta visokonaponske mreže Beograda.

Računarski programi su korišćeni kod izrade srednjoročnog planskog programa do 2000. godine, a sigurno će biti korisni i kod izrade dugoročnih pplanskih programa do i posle 2020. godine.

Na osnovu principskog raspleta, a vodeći računa i o nekim drugim uslovima, predlažu se ukupno tri varijante raspleta mreže sa ukupno 2, 4 i 6 TS 110/10kV (2x40 MVA) na pravcima sa kablovima 110 kV (Al 1000 mm2)

Ključne reči : Računarski programi, rasplet visokonaponskih mreža, rasplet srednjenaponskih mreža

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INTRODUCTION

So far, the development of the high-voltage power distribution network on the consumption area of the Public Company Electric Power Distribution Belgrade ("Elektrodistribucija Belgrade" – hereinafter referred to as: EDB) (the urban part on an area of approximately 250 km^2 and the suburban one of approximately 2300 km^2 with the maximum peak power of 1600 MW) has been very intensive and strictly defined by the conceptual documentation. Power distribution 35 kV cable networks in the urban part of the consumption area were constructed in the period from 1957 to 1975 (of a total length of around 438 km), while the construction of 110 kV cable network (approximately 35 km) started around 1970. Overhead 35 kV (approximately 450 km) and 110 kV (approximately 420 km) networks are typical for the suburban and extra-urban parts of the consumption area, although they are also present on the peripheral parts of the urban consumption area.

For the purpose of optimization of the overall techno-economic effects in construction of the high-voltage power distribution network, the computer programs have been developed for definition of a large number of variants of network development and selection of the optimal variant and the time schedule for network construction. By the computer programs, the network configuration is proposed irrespective of its current state and for a hundred-percent redundancy for incidents in case of a single outage, completely independently on each voltage level of the networks.

MAIN CHARACTERISTICS OF THE COMPUTER PROGRAMS

The computer programs were written using the program language "PASCAL" with the program package "DELPHI" and they are based on the sorting of HV/MV transformer substation distances from the directions by which VHV/HV transformer substations are connected as well as the center of gravity of the load on the consumption area; thus formed groups of HV/MV transformer substations are connected by HV lines based on the principle of testing of a large number of combinations by computer logic "BACK TRACKING". In this way, it is achieved that each of HV lines has a minimum length, with bigger or smaller chances that the total length may also be minimal – which depends on selection of various requirements, which the program user sets in the program when starting it up.

With the methodology used, 110/10 kV transformer substations are connected using 110 kV lines with the X/110 kV substations based on the principle that, by the arrangement, the lines are brought to the center of gravity of the load of the consumption area, with the arrangement zones from the center of gravity to the existing X/110 kV substations; thereby it is also enabled to "shift the center of gravity of consumption" to the point of the location of the first X/110 kV source, which is topical for construction – in view of the spatial prognosis of loads and the possibilities concerning installation of supply 400 kV lines in the consumption area. In this way, as it was demonstrated in a large number of iterations with the change of the "center of gravity of the consumption area", the increase of the total length of the network has been achieved; however, the arrangement of the network is even more acceptable.

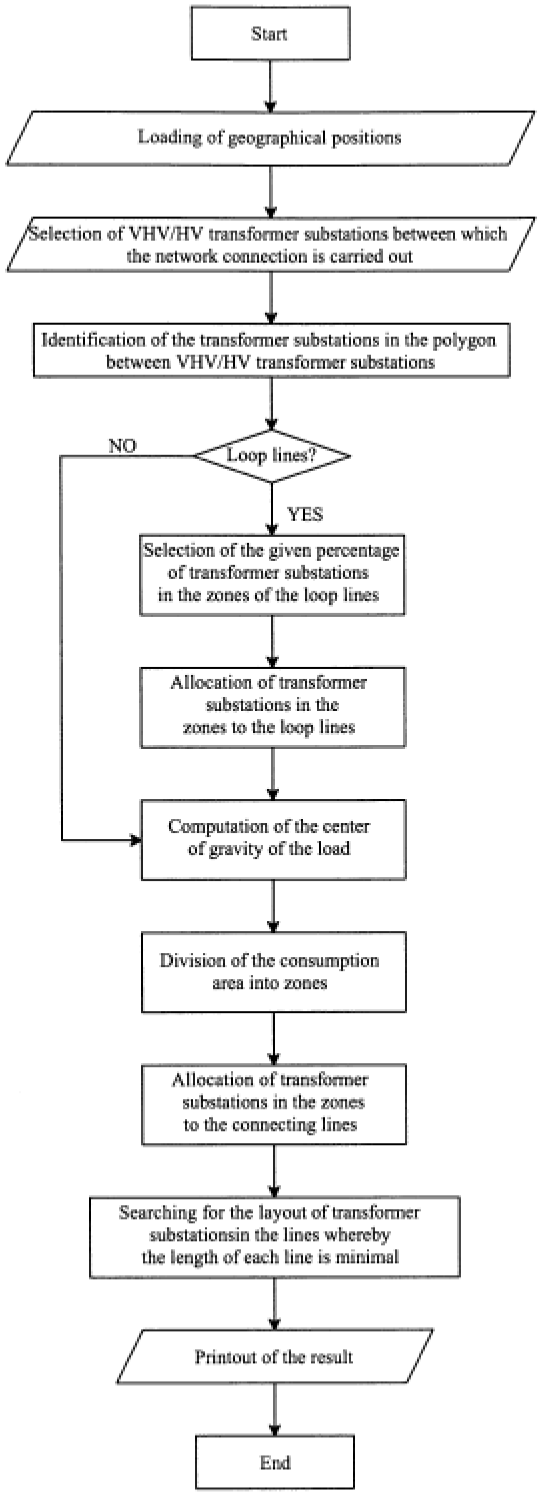
The enclosed diagrams, which present a few variants of the prospective 110 kV network in the consumption area of EDB, show the lengths of the overall network (as the indicators for the planners) as well as the total operating time of the computer program (as the indicators of efficiency of the program and the methodology applied).

Full insight in the efficiency of the applied methodology can be gained based on the fact that a minimum length of 110 kV network with four VHV/HV transformer substations and thirty HV/MV transformer substations can be arrived at by searching of a total of n! = 30!

combinations, for which modern computers require the operating time in excess of 15 billion years at commercial operating frequencies of PC-computers of the order of 1000 MHz (from the "Big Bang" to the present day). By various other methodologies as well as by this one (the comparison of which is not the topic of this paper), the computer program eliminates unnecessary combinations on engineering principles and leads to approximately "the shortest network" within a very acceptable time period.

Explanation of the block diagram:

1. Loading of the geographical positions of transformer substations
   Geographical positions of transformer substations are loaded from the file obtained from the data base formed using AutoCad program.
2. Selection of VHV/HV transformer substations between which the network connection is carried out
   The user selects the transformer substations between which the network connection is carried out using the mouse.
3. Identification of transformer substations in the polygon between VHV/HV transformer substations. For each HV/MV transformer substation, it is checked whether it belongs to the polygon, which is formed by VHV/HV transformer substations.
4. Loop lines?
   Does the user want any loop lines?
5. Selection of the given percentage of transformer substations in the zones of the loop lines.
   If the user wants that certain percentage of HV/MV transformer substations is distributed to the loop lines, HV/MV transformer substations are pinpointed, which are closest to VHV/HV ones, into separate zones of the loop lines.
6. Allocation of the transformer substations in the zones to the loop lines.
   Minimization of the length of the loop lines is carried out.
7. Computation of the center of gravity of the load.
   The coordinates of the center of gravity of the load are computed.
8. Division of the consumption area into zones.
   The polygon, which is made by VHV/HV transformer substations, is divided into triangles, the apexes of which are – the center of gravity of the load and the adjacent apexes of the polygon. HV/MV transformer substations, which are located within those triangles will be allocated to the lines, which connect the adjacent apexes of the polygon, or the adjacent source transformer substations.
9. Allocation of transformer substations in the zones to the lines.
   The first *n* number of HV/MV transformer substations, which are closest to the straight line, which connects the neighboring VHV/HV transformer substations are allocated to the first line, the next n ones to the next line, etc., whereby attention is paid to the even



distribution of HV/MV transformer substations to the lines.

10. Searching for the layout of transformer substations in lines whereby the length of each of the lines is minimal.
    All permutations of the positions of transformer substations in the given line are searched for and the one is selected in which the length of the line is minimal. The procedure is repeated for each line within the consumption area. HV/MV transformer substations may be, optionally, transferred from one line into another line, whereby the entire procedure is repeated several times, which provides for somewhat better results, but the process is significantly slowed down.
11. Printout of the result.
    The result is displayed on the screen, and it can also be printed out or saved in a file.

COMPUTER-BASED ARRANGEMENT OF THE PROSPECTIVE 110 kV NETWORK OF BELGRADE

The paper presents some possible combinations of the arrangement of the prospective 110 kV network of Belgrade with a total of four 400(220)/110 kV transformer substations and twenty nine 110/10 kV transformer substations. Thereby it was assumed that all VHV/HV transformer substations are of a power from 300 MVA to 1000 MVA and HV/MV transformer substations of a power of 2x40 MVA. The prospective HV/MV transformer substations include the existing 110/10 kV transformer substations in the urban part of the consumption area and the prospective 110/10 kV transformer substations that should be interpolated between the existing 35/10 kV transformer substations.

Arrangement of 110 kV network was made according to the principles, which were defined in the conceptual documents for the network construction from 1977 and 1986. According to the conceptual documents from 1977 and subsequent studies, the prospective 110/10 kV (2x40 MVA) transformer substations are connected by cable 110 kV lines whereby on one connecting or loop line, there are two 110/10 kV transformer substations. According to the conceptual documents from 1986, a total of four 110/10 kV transformer substations are supplied by the connecting lines of a capacity of around 150 MVA (Al 1000 mm^2) whereby the first two transformer substations are connected with VHV/HV transformer substations by "double lines" – for the purpose of minimizing the total length of the network (then in these transformer substations double busbars are required in 110 kV switchgear).

For thus distant prospective of 110 kV network in the urban consumption area, the computer proposes the configuration the total length of which very much depends on the total number of 110/10 kV transformer substations on the connecting directions. Namely, the length of exclusively connecting network with two 110/10 kV transformer substations on one connecting line (direction) is bigger by approximately 20% compared to the case where up to four 110/10 kV transformer substations are supplied with one connecting line (whereby the first sections of 110 kV lines are with two 110 kV cables); also, if one 110 kV line power supplies maximum four 110/10 kV transformer substations on the connecting direction, then the length of the network is bigger by approximately 25% of the total length of exclusively connecting 110 kV network, which power supplies maximum six 110/10 kV transformer substations on the connecting direction between 400(220)/110 kV transformer substations (whereby the first two 110/10 kV transformer substations are each connected by "double 110 kV lines on the connecting direction").

Table I – Lengths of exclusively connecting 110 kV network as a function of variants of the network construction

		Total length of the connecting network
2	- - 0 - - 0 - -	142 %
3	= = 0 - - 0 - - 0 - -	136 %
4	= = 0 - - 0 - - 0 - - 0 = =	125 %
5	= = 0 = = 0 - - 0 - - 0 - - 0 = =	115 %
6	= = 0 = = 0 - - 0 - - 0 - - 0 = = 0 = =	100 %

However, with the desired share of the loop lines relative to the connecting ones, these ratios may be significantly different – which depends on the geographical layout of VHV/HV transformer substations and HV/MV transformer substations, or on the surface load density in the observed macro and micro areas.

Figures 1 to 3 show three variants of possible arrangement of the prospective 110 kV network on the consumption area of EDB - between X/110 kV Belgrade XX (401), Belgrade

XVII (404), Belgrade III (403) and Belgrade V (405) transformer substations; thereby one 110 kV line power supplies two 110/10 kV transformer substations (Fig. 1), or one "direction" powers maximum four 110/10 kV transformer substations (Fig. 2), and maximum six 110/10 kV transformer substations (Fig. 3). Thereby the total length of 110 kV network has been optimized by the desired ratio between the connecting and the loop lines. On the above Figures, the center of gravity of the consumption area is "shifted" from the natural location to a new location in the vicinity of the confluence of the Sava River in the Danube River, between 401 and 405 transformer substations, whereby 110 kV network has got an even more acceptable arrangement.

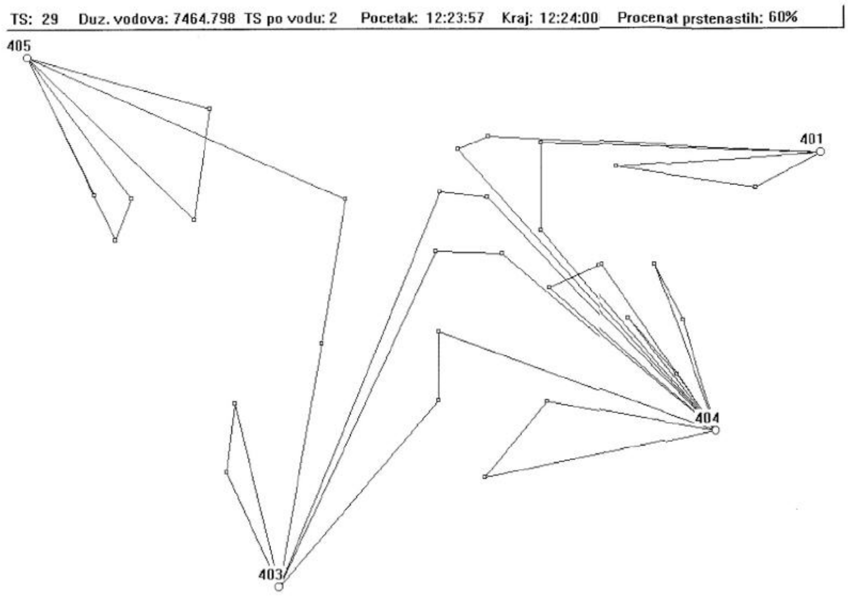


Fig. 1 - Arrangement of 110 kV network with maximum two 110/10 kV transformer substations on the connecting and loop lines between X/110 kV 401, 404, 403 and 405 transformer substations

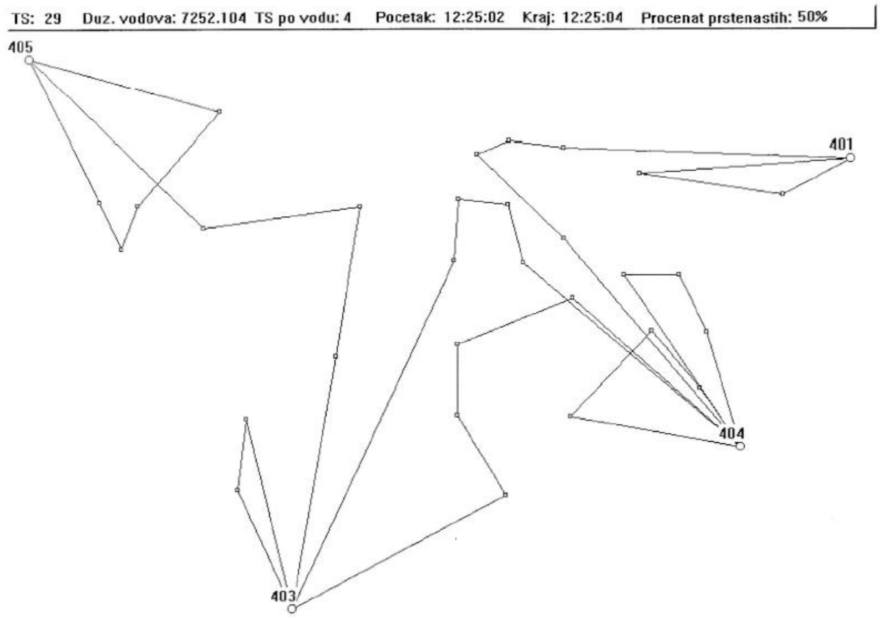


Fig. 2 – Arrangement of 110 kV network with maximum four 110/10 W transformer substations on the connecting and loop lines between X/110 kV 401, 404, 403 and 405 transformer substations (the first sections of the lines are with two cables)

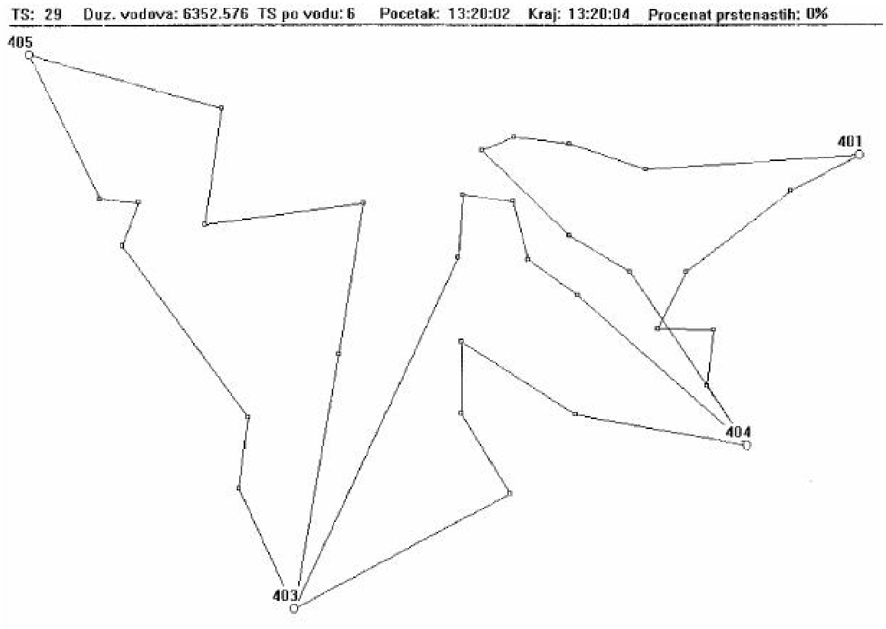


Fig. 3 – Arrangement of exclusively connecting 110 kV network with maximum six 110/10 kV transformer substations on the connecting directions between X/110 kV 401, 404, 403 and 405 transformer substations (the first two sections of the lines each are with two cables)c

As shown on the Figures 1, 2, and 3, it is obvious that the existing layout of 400(220)/110 kV transformer substations and 110/10 kV transformer substations implies very stable directions for the connecting 110 kV lines between all transformer substations, which enables defining of the routes for the connecting directions and the total number of cables in them, and "taking care" of them in prospective network construction.

However, the third variant can be even more acceptable, not only for the purpose of minimizing the total length of the network, but also because of the fact that the time schedule of 110 kV network construction up to 2020 requires the old and new 110 kV networks to be mutually supplemented and backed, with the redundancies for double outages (the safety principle »n - 2«), naturally, if the connecting directions are also supplemented with intermediate connections (between lines):

CONCLUSION

The potentiality of computer programs for the arrangement of the high-voltage power distribution network under the conditions of the prospective cable 110 kV network on the consumption area of EDB for the case of a hundred percent redundancy for a single, possibly double outage have been presented. The computer programs enable fast, precise, and objective comparison of a large number of variants of the prospective network, and selection of the optimal, generally accepted variant for the consumption area of EDB will certainly be the subject of studies of a long-term development not only in EDB

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