PLANNING OF THE DISTRIBUTION NETWORK OGULIN USING OPTIMIZATION TOOL CADDIN

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ABSTRACT

Presented paper demonstrates challenges and solutions proposed by University of Zagreb, Faculty of Electrical Engineering and Computing in the project of planning distribution control area Karlovac, specifically city Ogulin and its outskirts. Classical approaches which include predicting future load and needed grid upgrades are supported by optimization algorithm giving solutions for future distribution grid layout. Also; possibilities of the software CADDiN, developed for this purpose at the Faculty of Electrical Engineering and Computing are presented as well as problems, approximations and solutions applied in preparation of the input data. The final result is a layout of distribution grid during the period of which will give meaningful solutions to the planner at the minimal investment cost.

INTRODUCTION

Initial requirements for planning future distribution networks, in each distribution control area, were set by the distribution system operator with the goal of creating an universal template. In this proposal there were very few deviations from the classical method: grid topology data, history load, future load predictions etc. [1]. Since the sole future load prediction is not useful unless placed spatially, some other factors need to be taken into calculation (like future load centers, future potential distribution generation sites etc). [2, 3]. Combining all these information gives a complete picture of future load distribution and with that layout of the future grid. Literature on optimizing distribution grid layout is pretty extensive but will not be listed here. Following the current trends in the world which stipulate the usage of these type of software for network planning, University of Zagreb developed its own optimization algorithm.

CADDiN (Computer Aided Design of Distribution Network) is an application for optimization and planning of distribution systems in differently structured distribution networks. The large majority of the existing planning tools are based on so called variant approach. This means a planner, based on his experience, defines possible solution for the future grid and the programming tools then analyzes, evaluates and compares proposed solutions. Optimizing distribution network, on the other hand, is a complex, non polynomial (NP hard), nonlinear problem. Finding a solution, with often conflicting goals, large number of unknown variables and significant number of technical and spatial boundaries creates a demanding optimization problem. [4]

CADDiN consists of two main components; CADDiN MapModul and CADDiN Optimization module.

CADDiN MapModul

MapModul is AutoCAD add on for drawing, editing, data retrieval and Optimization module input data generator. It is also used for post-optimization visualization and analysis.

Optimization module solves NP-hard combinatorial problem of distribution network layout. Algorithm is based on evolutionary algorithm, heuristic method which can find (sub)optimal solution in acceptable time. The algorithm output is a distribution network layout which takes into account the cost of the grid reinforcement as well as the cost of power losses and cost of power not delivered to the final consumer. So the goal function of the algorithm is minimization of all costs.

To analyze all costs it is necessary to prepare an extensive amount of data. Optimization module input data are connection cost matrix, power lines cross section vector, power lines length vector and power lines material vector (Al/Cu). Since the software supports GIS data and analyses (Geographical Information System) every distribution network is created, drawn, in AutoCAD Map with network information stored in Object Data Tables related to each element. One of the features developed in the earlier stages is an addition to AutoCAD Map which simplifies separating and selecting elements using queries based on elements features.

When determining connection cost CADDiN can distinguish and combine three types of links between substations: existing cable, ex-line route and corridor.

Existing cables are available cable connections which satisfy planning conditions in horizon year. Planning requirements are determined by planer input and are based on the type of the problem. Most common ones are age, cross section, insulation level etc.

Ex-line routes are typically existing cables which do not satisfy planning conditions. This type of connections are more expensive because the new cable has to be installed. Ex-line is a term inherited from urban cable networks but it generally indicates route where it may be cheaper to install new cable.
Corridors are theoretical lines for cable installation. They are usually central street lines.
Ex-line and corridor cost ratio is determined by the planner. Corridors are the most expensive connections and the algorithm will rarely use this kind of link. Nevertheless, they are important because they ensure solution existence.
During data preparation process for the optimization module, consumption points are spatially joined with supply points. This is not essential for the optimization module but it presents a security check to see if included area can be supplied with electrical power.

CADDiN Optimization modul

CADDiN Optimization module is a Multiple Vehicle Routing Problem algorithm (MVRP) adjusted to electrical network infrastructure. Algorithm is not limited with the number of feeding or consumption substations. It allows the user to select whether the network will form a closed loop (so called ring) or station to station formation.
Supply station type can be feeder, connection support point, inter support point (Figure 1)

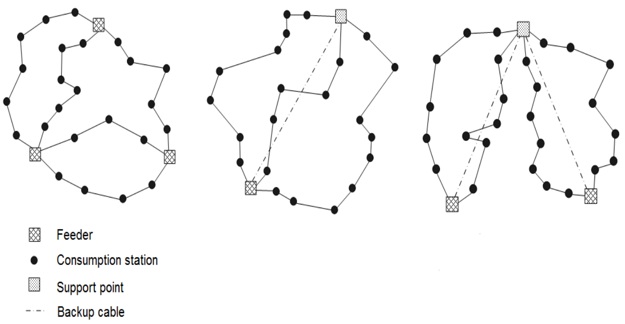

Figure 1 - Types of supply station and potential layouts

The output of the optimization module a consumption substation connection order is gained, as well as total cost presented as a Net Present Value (NPV) so different solutions can be compared. [5]
Solution visualization is conducted in MapModule based on data generated for optimization module and locally stored data in the drawing (e.g. topology). Map Module can show new power lines that need to be build, power lines that need to be replaced or reinforced, used ex-line routes and corridors. In case the concept of ex-line corridors is additionally expended, like in the presented case, it is necessary to create custom queries.

PLANNING OF THE DISTRIBUTION NETWORK OGULIN

City Ogulin is situated in the mountain part of Croatia and because of its geographically isolated location it has only one feeding station. Geographical layout of the entire distribution grid is determined by the terrain configuration. In Figure 2 it can be easily noticed that, besides population concentration in the city, only two long radial lines supply the whole area.
Radial lines present a problem for the algorithm searching optimal solution. Radial line needs to "come back" to supply point. In this case forcing those two radial lines would just cause problems to the algorithm, creating unacceptable solutions. For this reason this radial lines are replaced with consumption stations presenting total load on them. These stations are called "Radial 1" and "Radial 2".

Figure 2 - Layout overview

"Radial 1" makes an approximation on 15 consumption stations while "Radial 2" approximates 5 consumption stations.
This approximation means that these stations will not have the possibility of two way supply after the model of substitute station, but do have it up to the approximation point. Since that part of the distribution network does not have a larger loads, this approximation does not cause a problem.
Layout of the existing distribution grid is shown in Figure 3. Distribution network taken into consideration is composed of 60 consumption stations. When urban plans for the next 20 years were taken into consideration, it has been established 11 new stations are planned to be built. In Figure 3 blue lines show existing cable connections, red is for existing overhead lines and orange presents ex-lines reserved in the existing urban plans
The existing distribution network layout is the result of "as needed" upgrades. This means that problems for new power lines were solved "for the next day", not taking into account

keeping the plain structure of the distribution grid. Originally there were two main power lines, leading towards the radial lines. This main lines were geographically connected into a loop topology around the city Ogulin. New consumer demanded new power lines to be built and those were placed as sections towards down town. As seen from the Figure 3 cable network exists only in the main core of the city Ogulin, while the rest of the area has overhead radial grid.

Data acquisition and Optimization module input data generation are adjusted for urban distribution networks with predominantly station to station cable network. Rural networks, on the other hand, have one main, master, line with laterals. The main problem in the optimization of urban network that has some characteristics of rural network is how to prepare data and obtain results which will give meaningful solutions to the planner.

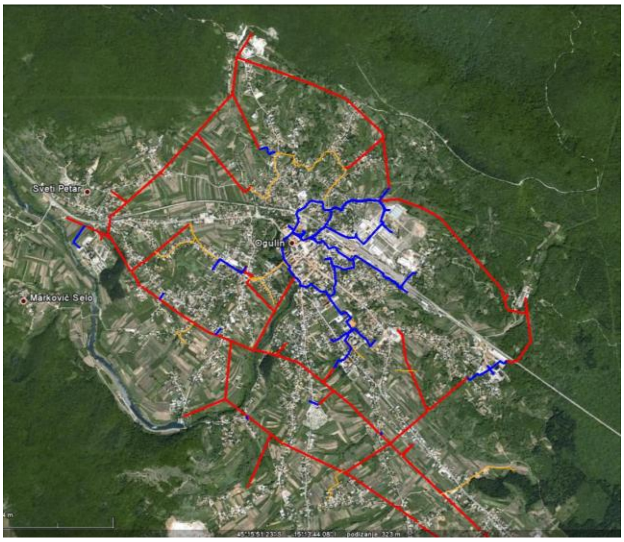

Figure 3 - Existing layout

As mentioned before CADDiN distinguishes three types of links. In should be noticed that there are two different correlations between existing lines and ex-lines. Existing lines can be interpreted only as exclusively cable line or also as potential ex-lines. Similar relationship is valid for ex-lines and corridors. This correlations are depended on the planners interpretation of input data. In presented case existing lines can be interpreted in both ways.

Net present value calculations are conducted in AutoCAD Map and it is possible to use AutoLISP Expressions as a useful tool for more realistic presentation of costs. All line objects have a associated appropriate AutoCAD Object Data table (local database in drawing) which contains additional coefficient which is used in AutoLISP Expressions for calculating connection cost. This enables the planner to prefer one line over the other.

Table 1 - Ex-line types

Ex-line type	Reduction coefficient	Ex-line/corridor
Existing cable	0,9	0,81
Existing overhead line	1,0	0,9
Ex-line obtained from urban plans	0,95	0,855

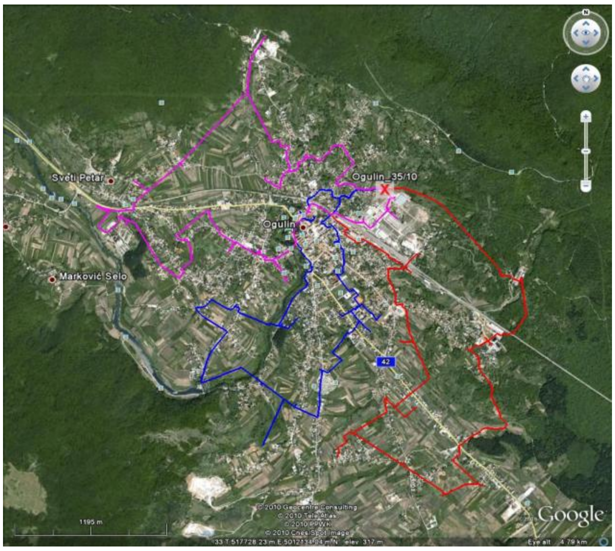

Figure 4 - Proposed solution

Often it is a case of old city cores which cannot be altered and new cables cannot be placed there, despite existing lines. This was also the case in city Ogulin.

Usage of the aforementioned coefficient makes it possible to recognize three cost classes. These can be seen in Table 1. The basic idea is to replace the existing overhead lines with cable network. This explains the small cost difference between different ex-line types. Assumption is made that ex-line is 10% cheaper than the corridor because of the pre existence of the needed documentation.

Feeding station Ogulin currently has six outgoing lines so the general idea was to create three loop structures. This resulted in a solution presented in Figure 4. Comparing the obtained solution with the starting layout shown in Figure 3, it can be noticed that existing lines have been used maximally and that ex-lines defined in urban plans are preferred to those of overhead ex- lines.

The algorithm also calculates optimal separation point and determines it according to minimal power losses. Optimal separated point in the loop structure was set just before the radial lines. This resulted with similar supply solution to the one of the existing concept but this time keeping plain layout structure. Also it satisfies the demand of supplying future consumption stations.

CONCLUSION

Traditional planning methods most often gave satisfactory results to the network operator. Since long term planning period is, and was, usually 20 years a general idea on load growth and potential future investments was considered to be sufficient. Modern planning methods introduced spatial load forecasting and gave a better picture of what distribution network might look like in a longer period. Introduction of distributed generation demanded adjustment of these methods. The paper presents practical possibilities an optimization tool developed within power systems department at Faculty of electrical engineering and computing has in planning a real distribution grid. Very briefly practical problems have been presented without deeper analysis of the software structure itself. This can be found in reference papers. The results have shown that optimization tools can be a powerful tool for planning future distribution network, helping the planner making decisions on future layout and investments in its gird.

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