A METHOD FOR OPTIMAL DEVELOPING OF URBAN MEDIUM AND LOW VOLTAGE NETWORKS

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ABSTRACT

The paper ranges with the problem of optimizing distribution networks, observing the necessity to be outlooked now so that they may optimally develop in the future; it offers to the planning engineer practical approaches for easily determining optimal developing trends for these networks. By using an appropriate model of a distribution network, an application was issued, using Visual Basic and the graphical facilities of EXCEL, to visualize the minimum of the object function of this model which represents the overall cost for a chosen strategy to develop the distribution network in a local area.

SCOPE OF THE PAPER

The meaning of economic optimum of a developing solution is that of an optimal relation between the initial investment effort and the subsequent costs during the operating period of the network (maintenance, cost of demand and energy losses, cost of failure).

During the last ten years, the development of urban and rural distribution networks in Romania was often made according to some momentary requirements of covering a local area energy demand. Thus one has attained almost provisional developing solutions for the distribution networks, which are far from the optimal planning criteria: reliable solutions, with high quality of supply and least demand and energy losses, landscape friendly, overall minimal costs.

The present approach is based upon a model of the distribution network, including the medium voltage (MV) network, the MV/LV substations and the low voltage network (LV) connected to a substation. The method is thought for simple sectioned loop and sectioned grid structures of the MV network, but it may easily be applied for other structures, such as the double branch structure. Getting started with the physical network model, a mathematical optimization model was built, having as object function the overall discounted costs (ODC) for the transit of one kVA from entering the MV network to the customer's terminals. The optimizing criterion is minimizing the object function.

THE NETWORK MODEL

The network chosen as a model is meant for calculation, formulated on a geometric model considering the uniform distribution of load, namely of the MV/LV substations. Structures including MV cable networks (feeders) connected at two different HV/MV substations, or at two different busbars of the same substation are considered. The MV/LV substations are connected to the MV feeders in a sistem "in - out" by means of cells fitted with switches or disconnector-switches. There are two MV network structures which have been modeled, namely:

- the simple sectioned loop - see Fig. 1;
- the sectioned grid structure - see Fig.2.

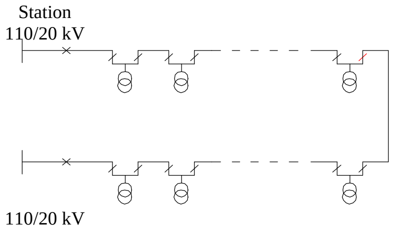

Fig.1

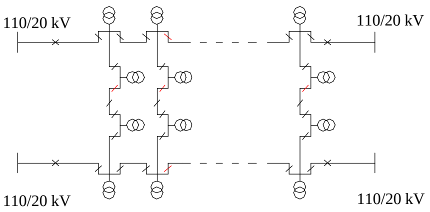

Fig.2

Each cable of the simple sectioned loop structure supplies the same total number $2n_s$ of MV/LV substations; in normal operatin the loop of each MV feeder is sectioned in two equal parts, so result two half - feeders, each connecting radially n_s substations.

The sectioned grid structures are also connecting $2n_s$ MV/LV substations as a whole on each feeder. This structure includes two main feeders or axes, connected to the bars of different HV/MV substations, similar to the simple sectioned loop, and derived feeders connected to each MV/LV substation on the main feeder through a disconnector cell, each extremity at a different axis; each derivation cable feeds the same number of identical MV/LV substations, differing from the main feeder substations only by lack of the disconnector cells. In normal operation each axis and all its derivations are sectioned in two equal radial parts, and they feed n_s MV/LV substations. The substations are uniformly placed on each main feeder and derivation; each substation is equipped with a single transformer, of the same size (power), chosen from the standard power range. All the MV feeders have equal lengths and cross sections. The LV network includes an equal number of identical cable routes outgoing from each substation.

The area load demand is considered to be uniform for the supplied zone.

Though the model network adopted has a very regular, ideal structure, it is possible, by introducing a number of parameters, to adapt it to different close to reality situations.

THE MATHEMATIC MODEL

The mathematic model used for optimizing within this method includes:

The object function. It has the following overall formula:

$$ODC = DC_{LV} + DC_S + DC_{MV} + CF \qquad (1)$$

With:

ODC = overall discounted cost of the strategy,

DC_{LV} = discounted cost for the LV network,

DCs = discounted cost for the MV/LV substation,

DC_{MV} = discounted cost for the MV network,

CF = cost of failure.

The first three terms of the object function (1) include each components of cost of investment, cost of operation, maintenance, and cost of energy and demand losses [1].

The technical conditions. 1. The condition concerning the thermic stability (TS) in normal long - term operation of the MV cable. Taking into account the maximum admissible current, calculated according to [2] for cables having 150 sq.mm. cross section AL and insulation of polyethylene, the maximum admissible power transited through the first part (from the station to the first derivation or load) of the cable will result of 5000 kVA . It results:

$$S_{m\,ad} \quad 5000 \text{ kVA} \qquad (2)$$

2.The condition concerning the maximum admissible voltage drop (VD) on the MV cable. According to [2] is calculated the expression of the voltage drop u_s of the cable supplied radially, which has to satisfy the condition:

$$u_s \quad 10\,\% \qquad (3)$$

The variables of the model are:

k_l = the loading factor, same for each transformer of the MV/LV substations, for a chosen configuration;

S_{nt}= the nominal power, same for each transformer of the MV/LV substations, for a chosen configuration;

n_s = the total number of MV/LV substations connected to a radial (half) feeder.

We also impose **the mathematical conditions**:

S_{nt} , n_s are positive integers, k_l ª [0, 1]

The main parameters by means of which the model is made closer to different real situations, are:

- the specific area load demand (s.a.l.d.), expressed in kVA/sq.km. for a zone where the distribution network will be developed; different values will be chosen according to a local load prognosis;
- the number of LV cable routes (n.c.r.) outgoing from the LV distribution bar of a substation;
- the specific length of LV network (l.s.), expressed in km./sq.km. of territory fed from the same MV/LV substation.

Beside all these, there are implicit parameters, such as the cost discount annuity a and the annual gain of the maximum load, r; the model also includes data which according to the norms may be considered fixed.

All the investment costs, costs of operation, costs of losses, costs of failure are expressed in USD, at the existing prices.

The value of the object function, ODC, is expressed in thousands USD / kVA.

SOLVING THE OPTIMIZING PROBLEM

By use of the mathematic model we end up with the final form of the object function, which is:

$$\begin{aligned} ODC = (&V_1 k_l S_{nt} + V_2 k_l^3 S_{nt}^3 + V_3 + V_4 S_{nt}^{3/4} + V_5 k_l^2 S_{nt}^{3/4} + \\ &+ V_6 n_s^{-1} + V_7 k_l^{1/2} S_{nt}^{1/2} n_s^{-1} + V_8 k_l^{1/2} S_{nt}^{1/2} + V_9 k_l^{5/2} S_{nt}^{5/2} n_s + \\ &+ V_{10} k_l^{5/2} S_{nt}^{5/2} + V_{11} k_l^{5/2} S_{nt}^{5/2} n_s^2 + V_{12} k_l^{1/2} S_{nt}^{1/2} + \\ &+ V_{13} k_l^{5/2} S_{nt}^{5/2} + V_{14} k_l S_{nt}) / (k_l S_{nt}) \end{aligned} \qquad (4)$$

restricted by:

$$V_{15} k_l S_{nt} n_s \quad 1 \qquad (5)$$

$$V_{16} k_l^{3/2} S_{nt}^{3/2} n_s (2 n_s + 2) \quad 1 \qquad (6)$$

In the expressions above the variables of the model are k_1, S_{nt}, n_s, while $V_1 \ldots V_{16}$ are coefficients depending upon the model 's parameters.

Minimizing of the object function may be achieved for instance using mathematics by means of the method of geometric programming. We present here a more practical way of solving this problem, by use of charts or tables to represent the dependence of ODC upon the model' s variables. For each structure of MV and LV distribution network, through a specific program we obtain series of charts, according to all ranges of rated power for the transformers in the substations or series of charts according to different values of the loading factors of the transformers. On each chart, the program will indicate a point MIN for the minimal value of ODC on that chart depending upon the number n_s of MV/LV substations on the MV feeder, and the points TS and VD corresponding to a maximum n_s for which the technical conditions are observed. The planner may choose a structure of distribution network which is economically and technically optimal, that means the overall discounted cost (ODC) of the solution is minimal, while the technical conditions are observed. It is also possible to present tabular results, indicating the number of substations corresponding to the minimum of ODC, comparative for the two structures of the MV network and for different number of LV cable routes connected to the LV distribution bar of each substation.

The program includes many modules, corresponding to the four terms of the object function (1) and to the restrictions.

As a first stage primary data bases are constructed, including, for one of the MV structures and for a value of the specific area load demand, the values of the object function for different values of LV cable routes number and for different values of the three variables, observing the mathematical and technical conditions. The data from the primary data base are arranged, as a second stage, in a different way, according to the plotting of the charts corresponding to all values of nominal powers and load coefficients of the substations transformers.

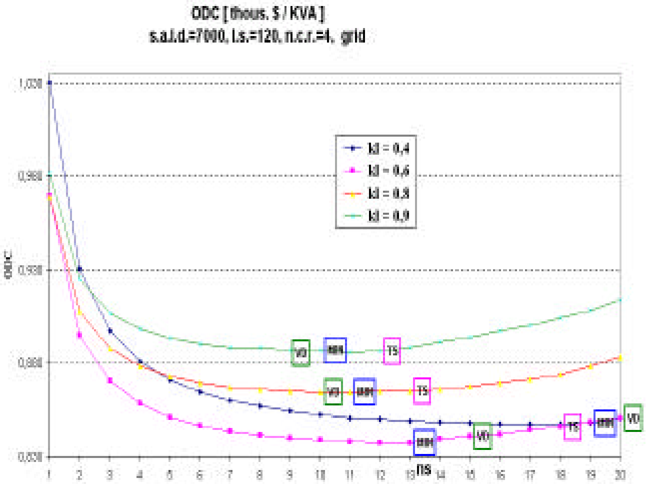

Fig.3

The application also includes a command sheet, for selecting: the structure of the MV network, the value of the specific area load demand (s.a.l.d.) the number of LV cable routes (n.c.r.), option for displaying charts or for displaying a table of minima of ODC for all examined variants.

The charts presented in Fig. 3 illustrate the way the optimal number of MV/LV substations connected to a MV cable, corresponding to a grid structure, in an area with a specific load demand of 7000 kVA/sq.km. when the substations are equipped with 400 kVA transformers may be estimated.

CONCLUSIONS

The method we proposed in this paper permits, under given consumption conditions, including specific area load demand, density of LV network, time of use of maximum load, annual gain of load, a.s.o. to estimate the solutions conducting to the the minimal cost of transiting one kVA through a MV and LV network.

The optimal solutions are mainly characterized by:

- optimal rated power of the transformers in the MV/LV substations,
- optimal load factor of the transformers in the MV/LV substations,
- optimal number, economically and technically, of MV/LV substations to be connected to the same MV cable.

By simple estimate we end up with the optimal values for:

- MV feeder lengths,
- the number of MV/LV substations from a certain area,
- the maximal loads transited through a feeder,
- the number of LV cable routes outgoing from a substation.

The graphic or tabular solutions are easy enough and convenient for the user.

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[2] Buhuº, P., Comãnescu, Gh.- 3RE-I 164/1986- Study concerning the optimal solutions for developing electrical distribution networks -Norm of the Ministery of Energy, 1986, pp.36-37; 54-55