OPTIMIZATION OF MV GRID BASED ON GENETIC ALGORITHM IMPLEMENTED IN "OES" CALCULATION SYSTEM

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ABSTRACT

Grid reconfiguration is one of the methods of reducing energy loses in the network. It can be realised with very small investment costs. Genetic algorithm implemented in "OeS" calculation computer program as an optimization tool is presented in this article. The program is a part of a complex network, energy and data management system.

INTRODUCTION

Vattenfall Distribution Poland (VDP) is a power distribution network operator in the southern part of Poland (Silesian Voivodeship). VDP's MV power grid encompasses the area of 4200 km^2 and includes 3063 km of overhead lines and 4883 km of cable lines. The network is supplied by 97 HV/MV substations and includes 9373 MV/LV substations. 1131000 users are supplied in total. The MV power grid is located mostly in urban-industrial area and has closed meshed structure but it is operated as a radial network. The grid's configuration was determined historically based on the power flow, voltage drops, important facilities with a double supply system or a remote control location. The determination was mostly indicative without complex system analysis.

When searching for a method of reducing transmission losses, the network operator has decided to employ a new optimisation method of distribution system reconfiguration developed at the Silesian University of Technology. The method is based on a genetic algorithm implemented in the "OeS"- network calculation computer program integrated with a GIS system. The program can be used for typical power flow and short circuit analysis as well as different optimization tasks (an example is presented in [2]). Because of the range of the calculation problem and time-consuming data processing the entire area was split into 15 regions. After performing analysis, the programme returns a list of the proposed changes to the sectionalizing switches in the network. The possibility of the changes is verified on site for each location and than the new system is implemented. The process is continued for individual regions. On average three areas are optimised each year.

OPTIMIZATION GOAL AND ALGORITHM

The optimisation of distribution points in the network includes works aimed at reducing energy losses in the MV grid through optimising their configuration without bearing larger investment expenditures. No major modifications to the network infrastructure are, therefore, anticipated (i.e. installation of new switches at a larger scale, construction of new substations, etc.).

The idea of optimization is to present a technical solution meeting specific requirements and being also the best one considering a specific criterion. The primary criterion of optimization may be in this case the costs of power and energy losses. The group of the required technical conditions (limitations existing for the optimization task) embrace:

- no overloading of the network components,
- maintaining the permitted voltage drops,
- ensuring supply for all users,
- maintaining the appropriate network structure – a radial "tree" type network.

The following detailed tasks have been formulated to implement the specific optimization tasks:

1. Creating a digital network model – preparing input data for network configuration and the technical data of the components in the format enabling optimisation calculations.
2. Estimation of grid loads.
3. Preparing calculation modules for performing optimisation calculations – calculations using the "OeS" software.
4. Determining the optimum distribution points in the cable network according to the minimum power and energy losses.
5. Preparing a list of switches in the network the position of which will change after network optimisation for the practical implementation of optimisation results.
6. Calculating the economic results of optimisation.

DIGITAL NETWORK MODEL

VDP as a system operator decided to implement a complex system for network, energy and data management. The general architecture of this system is presented in fig. 1. Basic elements of of the system are:

- SCADA – Supervisory Control And Data Acquisition
- SONET – Geographic Information System of the hole network
- SQLMS – DataBase
- ESB – Enterprise Service Bus – bus for data exchange between applications
- MZ – module for data management

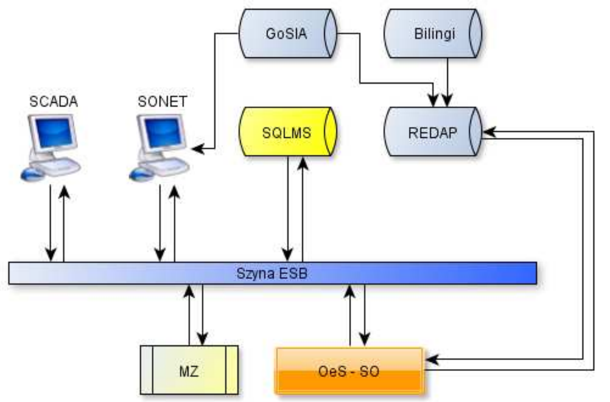

Fig. 1. Architecture of the system for network, energy and data management

- OeS – network calculation program
- GoSIA, Bilingi – data base of supplying points and energy consume
- REDAP – measurement data base

The fully integrated system is still under construction. But the program calculation OeS is able to download the network data from the GIS system SONET and database. Then the process of input data preparation for network configuration and the technical data of the components in the format enabling optimisation calculations were realised. Fragment of the modelled MV network in the program is presented in fig. 2.

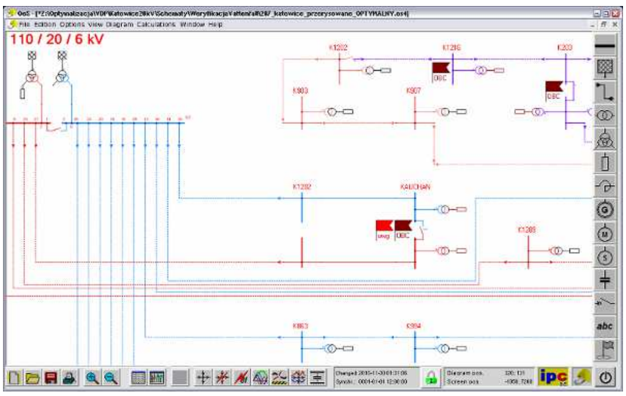

Fig. 2. The main window of the OeS program with the fragment of the modelled MV network

LOADS ESTIMATION

The permanent metering of load currents in distribution grids exists to a relatively small extent. It usually exists for HV/MV substations only – and this not fully. It thus becomes especially important to identify such loads correctly for individual network components. For the determination of the loads in MV grid nodes statistical users load models were implemented. The models are based on the loads variability tests for representative users performed in 20 distribution enterprises in the one year period. A catalogue of characteristics for electricity users was prepared as a result of the tests. The catalogue includes daily load profiles (average loads from measurements results) and certain synthetic measures of a statistical evaluation (minimum and maximum values, standard deviations). Daily load profiles are determined for different user groups in the characteristic periods, including:

- graphs for users at certain voltage levels,
- graphs for tariff groups,
- graphs for the groups of users separated from individual tariff groups, differentiated with regard to annual energy consumption and consumption degree for contracted power;
- urban and rural households were additionally differentiated
- group of municipal and household users
- users supplied with single and triple phase.

Daily load graphs are given in relative values (as percentage energy consumption in a given hour referenced to daily energy). The absolute values correspond to the typical representative users in a given group having average annual energy consumption in this user group. An example of the daily curve is presented in fig. 3. Having a particular characteristic daily load curve in summer and winter (determined directly from the catalogue) and knowing yearly energy distribution, daily graphs in any month and day can be identified through interpolation.

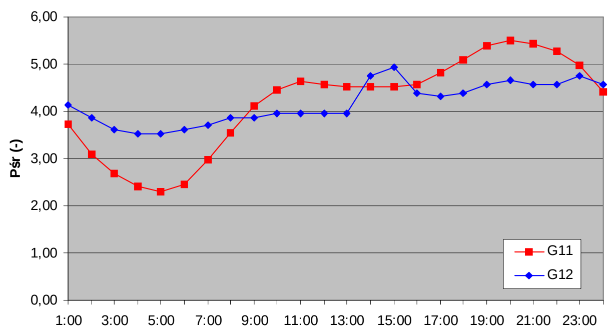

Fig. 3: Characteristic of relative loads for working winter days for the G tariff group (domestic customers)

Using presented models load curves in every node of the MV network are calculated by adding single customers supplying from particular MV/LV substations. Knowing loads the power flow calculation can be performed. The procedure can be verified by comparison of calculation results and available measurement in chosen grid branches (i.e. in supplying HV/MV substation). It should be emphasised that the comparison of measurements for transformers loads at HV/MV substation and the loads modelled based on the customers data indicates a very good consistency of total power and energy for the entire network. An example is shown in fig. 4.

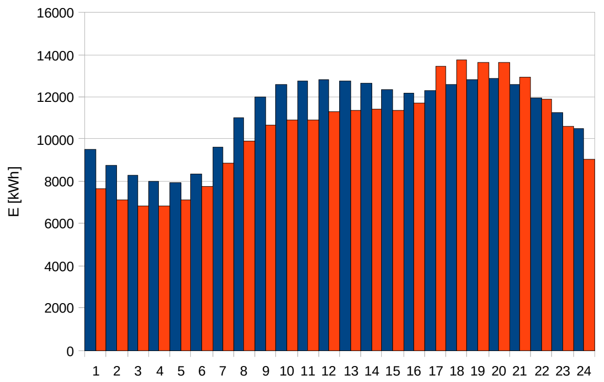

Fig. 4: Comparison between measured and calculated daily load chart for 20 kV winding of transformer in chosen HV/MV substation for a working winter day

GENETIC ALGORITHM USED FOR OPTYMIZATION

The main idea of genetic algorithms is adopting natural selection mechanisms existing in the nature of the genetic process for different calculation methods, e.g. in optimisation concepts. Usually, genetic algorithms do not ensure finding the global optimum. As the algorithms use the principle of so-called "soft selection", i.e. accepting, in subsequent steps, the solutions also worse than the ones used so far, escape from the trap of local optimums and finding the global optimum is highly probable though. It is one of the key advantages of such algorithms. Another important feature is their versatility. Various problems can be solved using them, with only minor changes to the algorithm structure itself. Some examples are presented in [1,3,4,5].

Certain selected concepts need to be defined before starting to construct a genetic algorithm. The concepts include a gen, chromosome, population. A single chromosome defines here a certain single, specific variant of a problem solution. A so-called fitness function is used to evaluate single chromosomes within a population. It is an actual function, constructed most often in such a way that the greater the value is achieved by it, the better fitting is particular chromosome, i.e. it brings the algorithm closer towards achieving the objective function optimum. The following genetic representation of an issue of optimal distribution network reconfiguration has been adopted. A single gene contains information on a single switch. The length of chromosome determines the number of switches installed in the network. Each chromosome contains information on the condition of all switches installed in the network, therefore defines a specific network configuration. The fitness function is defined as follows:

$$F = \beta \cdot \left(\frac{1}{\Delta E}\right)^{\alpha} - f_{K}^{\alpha}$$

ΔE –the value of the defined criterion function,
α, β – constants decisive for fitness function selectivity.
The variable f_K corresponds to a penalty function used in many optimisation methods and causes this function to be zeroed in case of an inappropriate (i.e. not radial) network configuration.

Selecting the appropriate genetic parameters of an algorithm is essential for its effectiveness. The inappropriately chosen algorithm parameters are leading to the considerably extended time of calculations or even make it impossible to perform.

The genetic algorithm parameters include:

- population density,
- mutation frequency
- fitness function selectivity,
- generation density of new populations (being a condition for ending the algorithm).

Table 1. gives an example of the correctly selected parameters of the algorithm.

Table 1. Selected parameters of the genetic algorithm

Population	Selectivity α	Selectivity β
100 - 200	2 - 3	10^{11}
Mutation probability	Genes mutated in chromosome	Crossing probability
0.3 – 0.8	2 - 3	0.9 – 1.0

A condition for ending the algorithm is determined arbitrarily. It is done by observing a criterion function. If the further generation of new populations do not improve markedly the criterion function values, it can be considered that the process has achieved good proximity to the global optimum and the work of the algorithm can be ended. The appropriate number of generations for new populations is selected this way. Fig. 5 presents a curve of variations in the criterion function values during the optimization process.

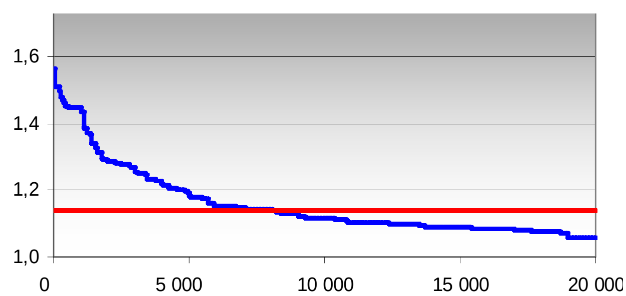

Fig. 5: The progress of variations in the criterion function values (energy loses in relative values)

The required time of calculations for reaching the optimum was more than ten hours. Considering that such type of optimisation task is solved relatively rarely, the time was considered acceptable. Parallel computer system architecture was additionally used to diminish the probability of the algorithm being stuck in the local minimum and to shorten the time of calculations (or to increase the possible number of algorithm iterations). The genetic algorithm was implemented in the dispersed asynchronous structure which enabled to start the algorithm in multiple calculation units with various input parameters.

OPTIMIZATION RESULTS

The optimal distribution grid reconfiguration has been determined for the winter working day, and losses have been evaluated based on a yearly simulation of network operation including daily, monthly, working and holiday load variability. It should be noted that, in networks with complex structure (such as municipal networks) localization of the sectionalizing switches usually deviates from the optimum. This causes increased energy losses in the network as well as excessive voltage drops, the uneven loads of network elements (possible overloads). Table 2 shows the achieved reduction of energy loses after optimization.

Table 2. Reduction of energy loses after optimization of the sectionalization points in MV network in chosen regions

Number of MV/LV substations	Length of MV lines [km]	Reduction of energy loses [%]	Reduction of energy loses [MWh/a]
620	500	16	710
780	550	4	135
480	625	12	1100
495	655	8	165
595	480	7.5	130
1135	945	9	245
450	450	0	0

CONCLUSIONS

Presented in the paper complex network, energy and data management system allows much better determination of parameters of the network. One of them is identification of power flow and energy loses. The aggregate economic outcomes of optimisation allow to conclude that it is substantiated to take actions aimed at network optimization.

It should be underlined that percentage losses in the network are relatively small (usually below 1%). But the annual costs of losses in the MV network are lowered with small implementation costs (including, most of all, the costs of the analysis). The grid reconfiguration practically does not require any investments in elements of the network.

The analyses performed reveal that optimisation allows to reduce energy losses in the network by different level depending on the network state in particular area. Optimisation considers the necessity to leave some switches as open, for instance due to the requirements concerning a supply reliability standard for selected users. There are usually relatively many such switches in the network.

Implemented genetic algorithm as optimization tool can be positively assessed because of its versatility and ease of application. With relatively small modification the same algorithm can be used for different network problems, different criterion of optimization etc.

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