INCREASE IN POWER NETWORK OBSERVABILITY AS A DATA SOURCE TO IMPROVE THE EFFICIENCY OF THE POWER NETWORK - RESULTS OF THE PILOT SMART GRID PROJECT

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ABSTRACT

The paper focuses on an analysis and the results of the Smart Grid project, especially on new possibilities to reduce technical losses the in MV and LV networks.
Research of model MV and LV networks was designed to evaluate the possibility of increasing network efficiency, using technical calculations based on the actual data obtained from GIS, SCADA, and AMI. The calculation system, based on genetic algorithms, was used to perform optimisation calculations aimed at reconfiguring the network.
The system was devised to support the development, planning and management of the electric grid, including distributed generation, energy storage, as well as controllable receivers, and optimisation of network configuration.
The total reduction of energy losses in pilot area reached over 10%..

INTRODUCTION

In order to face the major challenges of ensuring high quality electricity supply, improving power system efficiency, and enabling new service levels to be offered to energy consumers, ENERGA-OPERATOR SA (DSO) took up a pilot Smart Grid solution project. The Hel Peninsula with its ca. 200 km of MV lines, 150 MV/LV substations, and 150 km of LV lines was selected as the pilot project area. The grid serves ca. 10,000 customers. The project was completed in 2014.
The project entailed the following major elements:
- deployment of smart meters,
- deployment of automatic control and measurement devices over the MV and LV networks,
- extension of the SCADA system to the LV network level (SCADA LV),
- automatic detection of damages in the MV network,
- automatic grid reconfiguration,
- advanced system of voltage control and regulation in the MV network,
- SCADA integration with the GIS system.

The pilot project aimed at testing the technology and solutions which can improve the efficiency of the company operations while ensuring high standards of electricity supply. The anticipated benefits included:
- reduced interruptions in power supply in the pilot area,
- reduced grid operating cost attained through automation of the grid operation in the pilot area,
- reduced network losses by 5%.

The paper focuses on new opportunities to reduce technical losses in the MV and LV networks. The research work and analyses carried out revealed that there is a substantial possibility to reduce technical losses in the LV network. The possibility arises when integrated information is employed from the AMI, GIS, and SCADA LV

SOURCES OF THE CALCULATION INPUT DATA

Employment of new technologies and IT systems has enabled substantial enhancement of grid observability, including the MV and LV networks. Grid monitoring devices installed in the network, including the AMI meters, provide the details of the power flows. The geographic information system (GIS) implemented at ENERGA-OPERATOR SA provides information on the grid model, technical data of the individual grid elements and their topology. The grid asset management system stores information on the electricity supply points. The AMI system is the source of detailed information on the electricity consumed, graded down to as little as 15 minutes. This input data comes from both the meters installed at the consumers, and the balancing meters deployed at MV/LV stations. Integration of the thus sourced data builds a new quality of the information on the actual power flows in the grid and enables reaching a new quality of the technical calculations. The integrated data enable e.g. accurate engineering analyses and calculations, which pave the way to optimising the grid operating system. This particular approach was adopted in the pilot smart grid project on the Hel Peninsula. The calculations and model studies conducted in the area led to the development of the MW and LV grid model. The input data used to develop it included e.g.:
- the data of the grid infrastructure, including its topology and mapping on the geographic diagram obtained from

the GIS system (also grid breakpoints at the LV level)
- the information on the customer assignment to the specific energy take-off points
- the measurement data from the SCADA system
- the metering data from the AMI system (from the balancing meters and the meters installed at the end consumers)
- the energy consumption data from the billing system.

CALCULATION SYSTEM

ELGrid is the system designed to support management and planning of the electric distribution network, including distributed generation, storage, and controllable receivers.

ELGrid is the decision support system based on solutions which have been the tested in scientific and industrial research. The system uses data exchange interfaces compliant with the CIM standard, which gives computational modules access to a highly diverse spectrum of information (e.g. GIS, Billing, AMR, SCADA). The most detailed power grid data can be derived from the GIS systems. ELGrid is equipped with the functionality of performing concurrent calculations. The computer network further enables separate performance of multiple computing tasks on different computers. The distributed architecture ensures high scalability.

Here are the main functions of the system:

1.Estimation of the yearly peak loads of the distribution network elements.

2.Calculation of the power-flows,

3.Network reconfiguration optimization.

4.Optimisation of voltage levels.

ELGrid further offers the following additional forecasting functions:

1.Forecast of the energy production at renewable energy sources – ultra short- and short-term.

2.Forecast of the energy demand – ultrashort-, short- and medium-term

3.Forecast of the long-term energy demand.

The power flow can be determined:
- for a specific moment of time,
- for the maximum network load in the indicated period,
- for the minimum network load in the indicated period,

The implemented method of attaining the optimal network reconfiguration takes into account the distributed generation in the analysed segment of the power network. The payback time serves as the criterial function. This enables limiting the investments, i.e. limiting the total costs of specific investment solutions.

The method implemented in the ELGrid system is based on a genetic algorithm. An individual, representing a potential solution to the problem, is designed as a data structure. A set of individuals forms a population. The simplest way to represent the above is to devise the individual in the form of a binary string representing a point in the solution space. Determined too, is the adaptation function (corresponding to the objective function) for each individual in the population and for the entire population.

The process of searching for the optimum starts with the set of points (population) in the solution space. The task of identifying the optimal grid reconfiguration is defined as follows: determine the optimal cut-off locations in the MV and LV distribution networks so as to minimise the total cost of power and electricity losses in the specific optimisation period in recognition of the existing constraints. The set of constraints is divided into two groups: reliability constraints and technical constraints

It was assumed that the cost of losses would refer to the power flow at the peak load. Then, the cut-off points are set for a sufficiently long optimisation period T.

There are two AG algorithms based the optimisation modes:
- AGB, capex-less mode – it is possible to limit the changes to the connector states in the analysed grid
- AGI, capex mode – the possible changes affect the states of the connectors and the states of the power line sections.

The grid reconfiguration costs included:
- the average cost of a change in the state of a remotely controlled connector
- the average cost of a change in the state of a manually controlled connector
- the average cost of a new switch installation in the MV network
- the average cost of a new switch installation in the LV network.

The AG gene structure ensures compliance with the reliability conditions. Individual gene items represent the numbers of open switches in the loops. After the completion of the crossover and mutation operations the compliance with reliability requirements is checked and the gene properly adjusted so that the reliability requirements are satisfied. Technical constraints are not taken into account, however two criteria remain valid: that of the voltage (maintaining the required voltage levels), and arc transmission capacities (grid sections). More weight is allocated to the arc flow capacity overruns, as most voltage excesses over the permissible limits can be controlled through transformer tap adjustment.

Each network arc is assigned the attribute of "the degree of state change", which can take the following values:
- easy - for connector arcs, indicating the remote control possibility in place
- difficult - for connector arcs, indicating the need to change the switch state manually
- investment - for non-connector arcs, indicating the possibility to install the connector at one end of the arc
- impossible - for nodes, indicating no possibility to switch at the point, or for non-connector arcs – no possibility to install a new connector.

The following data set was used for calculations and verification of the results:

1.Data on electricity consumption from remote electricity meters
2.Data on electricity consumption from electricity meters for outdoor lightning
3.Data on electricity consumption from the billing system for customers having no remote electricity meters
4.Updated network mapping in the form of SHP files.
5.Connector states from the SCADA system
6.Completed schemes of the LV load connections.

TECHNICAL CALCULATIONS

The smart grid pilot project on the Hel Peninsula involved a number of analyses of the solutions implemented.
One of the areas falling in the scope of the study consisted in verification of the potential for reducing the technical network losses by way of optimising the grid operation system without any extra capital expenditure on network development. The aim of the research here was to identify the measurable degree of reducing the technical losses in the MV and LV networks. The study was carried out in two stages, in the years 2013-2014. The 2013 works consisted in assessing the attainable effects of optimization of the entire MV and LV networks. Stage two, conducted in 2014, came down to studying a selected section of the LV network. In both variants, the analyses were carried out in the season of peak energy consumption, which for the Hel Peninsula falls in the summer. The seasonal nature of the peak consumption is due to the summer resort nature of the studied geographical area.

Stage I

In the year 2013, model studies of the MV and LV networks were conducted for the whole Hel Peninsula. The studies were performer for the period of 1 June – 31 July, and comprised over 5500 electricity supply points. The area was fed from 80 secondary substations. The power distribution was identified and the calculations performed for the maximum power recorded at the supply point feeding the area. The AMI infrastructure did not cover the entire study area. It was also necessary to resort to the data available from the billing system. The calculations were carried out for the investment-free variant – no new connectors were proposed for installation.

Table No. 1. The optimisation calculation results

Item	Unit	Value
Energy losses at the outset	[kWh]	280276
Energy losses at the close	[kWh]	254616
Energy loss reduction	[kWh]	25660
Number of switches	[pcs.]	213
Loss reduction upon optimisation	[%]	9.2

The technical calculations performed identified the attainable loss reduction at 9% for the combined MV and LV networks. This would require introducing 213 switches in the grid operating mode over the whole Hel Peninsula.

Stage II

Stage II of the study focused entirely on analysing the options available for reducing the technical losses in the LV network. To that aim, an area covered by a separate LV network was selected. The area comprised a single locality with its extensive cable network. The grid supplies power to about 1500 electricity consumers in the area. The studies were conducted in the year 2014 over the peak load period in the summer season. The selected area offered higher quality of input data to the calculation system. The works in that stage were arranged into 3 sub-stages:

- preparation of the input data,
- calculation of the technical losses based on the data covering the month of July, and introduction of optimisation switches in the grid
- recalculation of the technical losses and energy balancing (the month of August), plus analysis of the calculation results and their comparison with the energy balancing results.

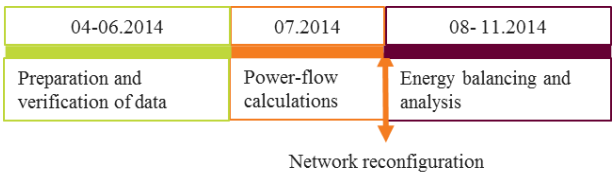

Fig. 1. The scope of stage II

Verification, in the first sub-stage, comprised the network model, including the network splitting points. The exercise involved verification of the correct customer assignment to their grid-connection points, and completeness of the measurement data. This was aimed at obtaining high quality input to the calculation model. Further works involved calculation of the power distribution in the network and the level of the technical losses to arrive at the optimal network operation system. Improvement of the network operation required 17 switches at sub-stage two. Review technical calculations were performed at sub-stage three.

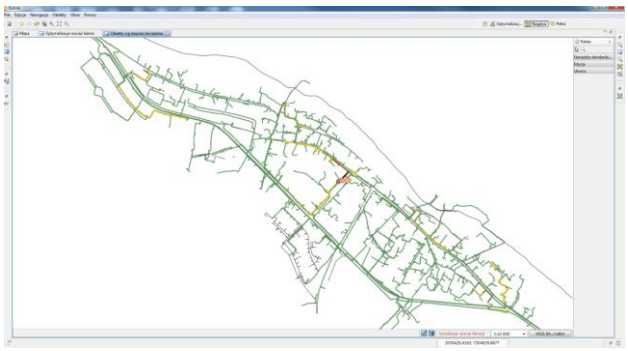

Fig. 2. Network model from the system of technical calculations. Different colors indicate levels of load cable lines

The calculation results revealed a decrease in the technical losses by 16 %. For details of the calculation results, see table 2.

Table No. 2. The optimisation calculation results(stage II)

Item	Unit	Value
Energy losses at the outset	[kWh]	20 375
Energy losses at the close	[kWh]	17 075
Energy loss reduction	[kWh]	3 300
Number of switches	[pcs.]	17
Loss reduction upon optimisation	**[%]**	**16**

An attempt was also taken to verify the calculations based on the energy balance gauged by the meters at the MV/LV transformer stations and those installed at the end-users. Assuming that the actual loss reduction stands at 16%, the decrease translates to an about 1% change in the energy balance. However, tracking such a minute balance difference is very difficult, hence the above calculation may not be error-free because, e.g.:

- not all customers had AMI systems installed. About 10% of the population had no AMI system. Energy readings were successfully obtained for half the population in the study period, thus enabling the determination of the average daily energy consumption.
- the Energy take-off varied for the months covered in the study (July and August), which translated to a varied loss level.

In order to notice the balance difference, 10 subsequent days in each month was selected so that the power consumed by the customers would be similar.

Energy balancing was only performed for the peak load (loss, depending on I2) hours. In the summer season, the peak time is very long for the specific area under study. The adopted hours were: 9:00 to 23:00.

The calculations performer for the above-described conditions revealed a shift in the Energy balance by 1.5% over the peak load time.

CONCLUSIONS

Using the existing data, in particular: AMI and the digital GIS network model offers a new way of enhancing the operating efficiency of the power grid and optimising the operation system. The goal can be attained using the calculation systems based on the actual grid model and information on the actual power consumption at individual grid nodes. The technical calculations revealed that the potential opportunity to reduce grid losses is particularly high in the LV city networks.

However, verification of the calculation results by comparing the balance difference is not easy because of varying power consumption in the test periods, the quality of the data at hand, the potential existence of illegal power take-off, or consumers temporarily connected to the grid. Noting a loss change of 10-15% (energy balance change below 1%) requires a very accurate and complete set of data covering the study area.

The AMI and GIS data of the area are now sufficient at ENERGA-OPERATOR SA to conduct optimisation calculations. Nevertheless, in urban areas of highly complex and dynamic network structure, the quality of the data is not yet sufficient to perform energy balancing with the view of verifying the optimisation results. Even though the AMI system is in place, there are certain limitations which cause that the determined balance value may still be scarred with an error margin.

The calculations carried out using the MV and LV network model, based on the AMI measurement data evidenced that an opportunity to reduce technical loss does exist. Studies on the grid model revealed that for the peak load time, i.e. in the summer season, technical losses could be reduced by 9% in the MV and LV networks taken together. The reduction due to the network system optimisation attempt for the LV network alone (in the grid peak load period) was calculated at 16%.

The barriers hindering implementation of the calculation systems which would enable optimisation of the connection system and monitoring of the LV network operation are as follows:

- the necessary AMI system would need to cover the entire LV network optimisation area (this should be taken into account when planning AMI implementations for entire closed urban areas),
- the required accurate model of the MV and LV networks would need to be developed in the IT system of the GIS class,
- the power take-off points (PPEs) would need to be integrated in the grid model in the GIS system,
- the LV network layer would need to be represented in the SCADA/NMS system to enable monitoring of the grid operation (including the LV network).

Nevertheless, one should anticipate that the distributors will be obtaining and managing increasingly more accurate data of their grid systems (MV and LV network models) and very high quality information from the measuring systems (AMI). This data will enable implementation of additional functionalities, including systems that will make it possible to optimize the MV and LV network operation systems and forecasting the loads. The pilot works indicate there is a high potential for optimising the grid operation system in this respect. Implementation of the calculation systems will yield further benefits, to name e.g.:

- better utilisation of the transmission capacities of the existing networks (facilitation of the connection process, optimisation of the grid expansion investments)
- possibility to implement new functionalities in the DMS system area
- possibility to forecast the network loads and taking preventive measures in case of overloads or incorrect voltage parameters.