LOSS-OPTIMIZED MANAGEMENT IN LOW-VOLTAGE GRIDS BASED ON AN INCENTIVE SIGNAL

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ABSTRACT

This paper describes a loss-optimized management algorithm and the implementation of this algorithm in an energy management for low-voltage grids. Such an energy management is based on a management structure which consists of two parts of management. The communication between these two parts is implemented by an incentive signal. The paper includes the construction of this incentive signal and gives some results.

1. INTRODUCTION

The requirements for low-voltage grids have increased in recent years. This is based on the growth of renewable supplies and the increasing e-mobility. As a matter of fact the low-voltage grids break the limits of utilization or voltage drop in some regions of Germany's south. Therefore the grid operator needs a solution for this challenge. An option is the usage of an energy management which is based on different storage systems and distributed power supplies.

Such a smart grid which is considered in this research work is divided in two management parts. One part is a smart house with different storage systems, power supplies and a house management. The other part constitutes the management system in the low-voltage grid between some of these smart houses. The communication between these two management systems is implemented by an incentive signal. This incentive signal uses a loss-optimization to supply each consumer, so the energy management is based on power flow simulation.

2. POWER FLOW SIMULATION

The simulated low-voltage grid is based on a real existing grid in Germany. This grid is an urban grid which supplies a lot of households in a small area. The simulation disregards a standardized load curve for the households assuming that the houses are intelligent. Such smart houses can decide on their own if they gather energy for the grid or supply into the grid. For this reason the load-scenario of the houses is defined by chance.

The program for the power flow simulation is done with the tool MATPOWER, which is a static calculation program. It simulates only one infinite moment of the power flow. To simulate a scenario and see how it has developed over an amount of time the program uses iterative calculations. The grid calculation program ELEKTRA can be used as well, but it has some relevant disadvantages. MATPOWER works in the workspace of MATLAB therefore the calculated results can be used for other calculations without any intermediate steps. MATPOWER uses changing parameters instantly whereas ELEKTRA needs a restart after parameters in the time series have changed. Time series in ELEKTRA have to be stored in extern files which have to be loaded over a database connection. ELEKTRA only update this connection when the whole program is restarted. This is why MATPOWER is the provided tool for optimal power flow simulation. The tool was developed for high-voltage-grid power flow simulation which is why the results where referenced to ELEKTRA.

To realize a loss optimized power flow the loss-optimized management algorithm (LOMA) has been developed (see below). LOMA simulates the power flow of each bus separately, which is another reason to use MATPOWER. LOMA is used because 75 % of the losses in the power supply system are caused in the low-voltage grid. [1]

3. INCENTIVE SIGNAL

The aim is to affect consumers and suppliers in such a way that they supply each other. Every household gets an incentive signal which shows how it should modify its current behaviour. The households are regarded as buses in a grid.

$$\kappa = \alpha \cdot \left(-\frac{P_{load,act}}{P_{load,max}}\right) + \beta \cdot \left(\frac{1}{x} - \operatorname{sign}(P_{loss,act}) \cdot \left(\frac{P_{loss,act}}{P_{loss,max}}\right)^2\right) + \cdots$$
$$\gamma \cdot \operatorname{sign}(P_{mv}) \cdot \left(\frac{P_{mv}}{P_{mv,max}}\right)^2 + \delta \cdot \left(-\frac{P_{load,total}}{P_{load,max}}\right)$$

$P_{load,act}$ - current energy load condition of one bus
$P_{load,max}$ - maximal possible load in the grid
$P_{loss,act}$ - current losses, caused by one bus
$P_{loss,max}$ - maximal dissipation loss in the whole grid
P_{mv} - current supplying of the medium-voltage power grid
$P_{mv,max}$ - maximal possible supplying of the medium-voltage power grid
$P_{load,total}$ - iterative computed total load in a grid at one bus

The variables α, β, γ and δ are weighting factors and x can be used to change the maximum of accepted losses. To interpret the signal a normalisation with the major possible value κ can be adopt is necessary. The incentive signal equates to a signed percentage how to consum or supply. For example a negative κ effects a decrement of consumption, a changeover from consumption to supply or an increment of supply according to the current behaviour of the bus (consumer, supplier, inactive). A positive κ effects the converse. Since the second and the third parts are squared the signum function to save the signature of P_{mv} and $P_{loss,max}$ is used. The data, $P_{loss,max}$and $P_{mv,max}$ are characteristics of the electrical network and have to be determined.

Before the incentive signal can be computed $P_{loss,act}$ and $P_{load,total}$ have to be calculated by a LOMA, see fig.1. At first the algorithm detects all suppliers (orange circle). The junctions 1041 and 3119 are inactive. To find the least losses causing bus a power flow calculation for all nearest buses follows (in this case 1042, 2041, 1010 and 2027). The one with the lowest result is chosen. This process is repeated until all buses are in an ascending order of produced losses. $P_{loss,act}$ for one knot is the difference between the losses it caused and the losses of the previous bus in the precedence. $P_{loss,act}$ for the first bus in the order is the difference between its losses and a reference value determined by a power flow calculation with all suppliers. The same procedure has to pass with interchanged positions of consumers and suppliers in the algorithm. The calculation of $P_{load,total}$ is different for consumer and supplier. Regarding a consumer it is the summation of $P_{load,act}$ of all suppliers and the consumption of all consumers ahead. In case of a supplier $P_{load,total}$ is built by the summation of $P_{load,act}$ of all consumers and analogously the supply of previous buses in the order. The motivation of the usage of the LOMA is to control consumers and suppliers to reduce the losses. In this manner consumption results close to the suppliers and supply close to the consumers.

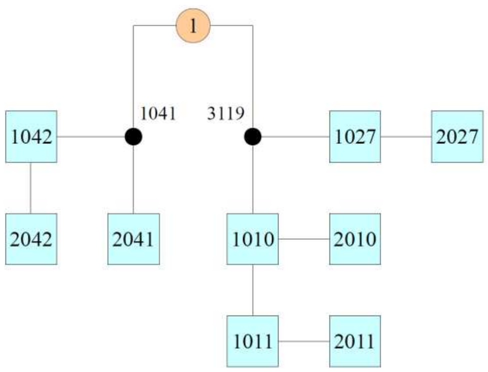

Fig. 1 – Example grid for the loss-optimisation-algorithm

4. RESULTS

Simulating the grid in the defined scenario, the results show that the LOMA is working correctly. The following diagrams were gathered in a scenario by keeping the middle-voltage-supply constant at a value of zero. The scenario contains more low-voltage-suppliers than consuming buses the overall load is negative. The incentive signal has to inform the consuming buses to increase their consumption and the suppliers to decrease the supplied power. But also the losses have to reduce so the incentive signal has to deliver the buses with the right information so that “bad-buses” get the signal to supply lesser, or consuming a less amount of power.

Figure 2 shows that the overall load converges to zero as well. The same result was gathered when is above zero so converges every time to the values of. The ideal scenario when $P_{overall} = P_{mv}$ is reached. The incentive signal, calculated by the management-algorithm does this closely and the load converges to P_{mv}.

LOMA should also reduce the losses in the low-voltage grid. The results (figure 3) show that the losses decrease as long as the buses are reacting to the signal. The transformer-losses were reduced to the non-load losses and the losses in the grid are reduced about 30 %.

The algorithm works in the whole grid, but also the single buses must be controlled to seen if the algorithm works exactly and the load does not oscillate at every bus.

The following diagrams explain how the management operates at single buses. Figure 4 shows the incentive signal for some picked buses and the curves in figure 5 reproduce the changing load of these buses.

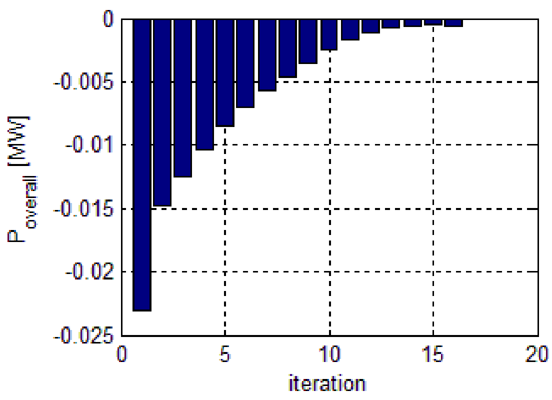

Fig. 2 – Variation of overall load based on LOMA

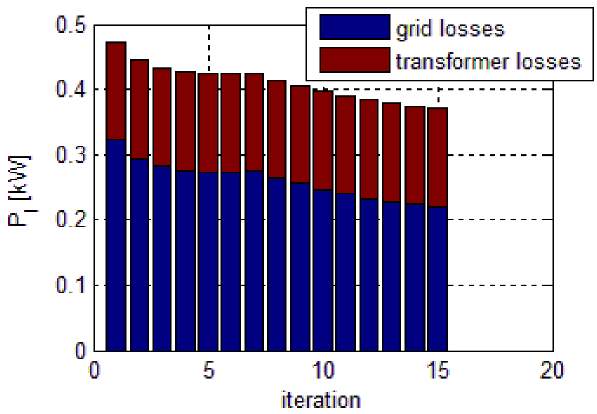

Fig. 3 – Variation of overall losses based on LOMA

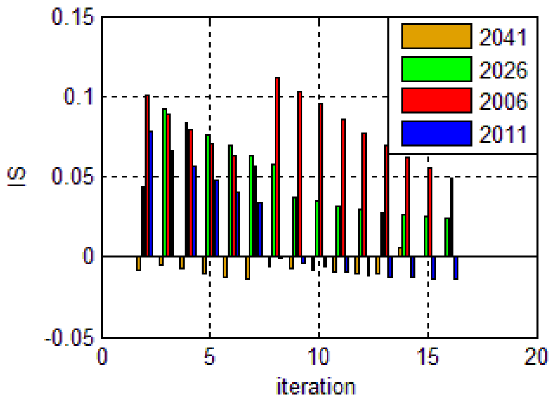

Fig. 4 – Course of incentive signal at picked buses

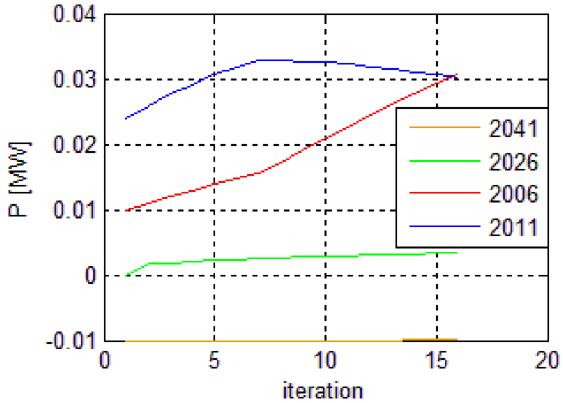

Fig. 5 – Course of load at picked buses

It can bee seen that the buses react to the incentive signal. The load increases when the signal is positive or the supplied energy decreases. The higher the signal is the higher is the increase of the load. Bus “2026” gets a high signal at the first iteration, so the load rises fast. After this step the incentive signal decreases at each iteration, so the load increases a lot slower than before. At the iteration step 14 the incentive signal of the bus “2041” changes from negative to positive and the bus reacts by decreasing the supplied energy.

If the incentive signal is negative, the load has to decrease like the bus “2011” does from the 8th iteration.

5. CONCLUSIONS

The results show the usage of an incentive signal. It is possible to regulate the power flow in low-voltage grids with such an incentive signal. The next step is to test this management system in different load situations and simulate a non-reaction of the smart houses.

REFERENCES

[1] *Teuscher, J.; Götz, A.; Schufft, W.*: Verlustoptimiertes Energiemanagement in Niederspannungsnetzen, Tagungsband VDE-Kongress 2010, VDEW Verlag, 2010, ISBN 978-3-8007-3304-0

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