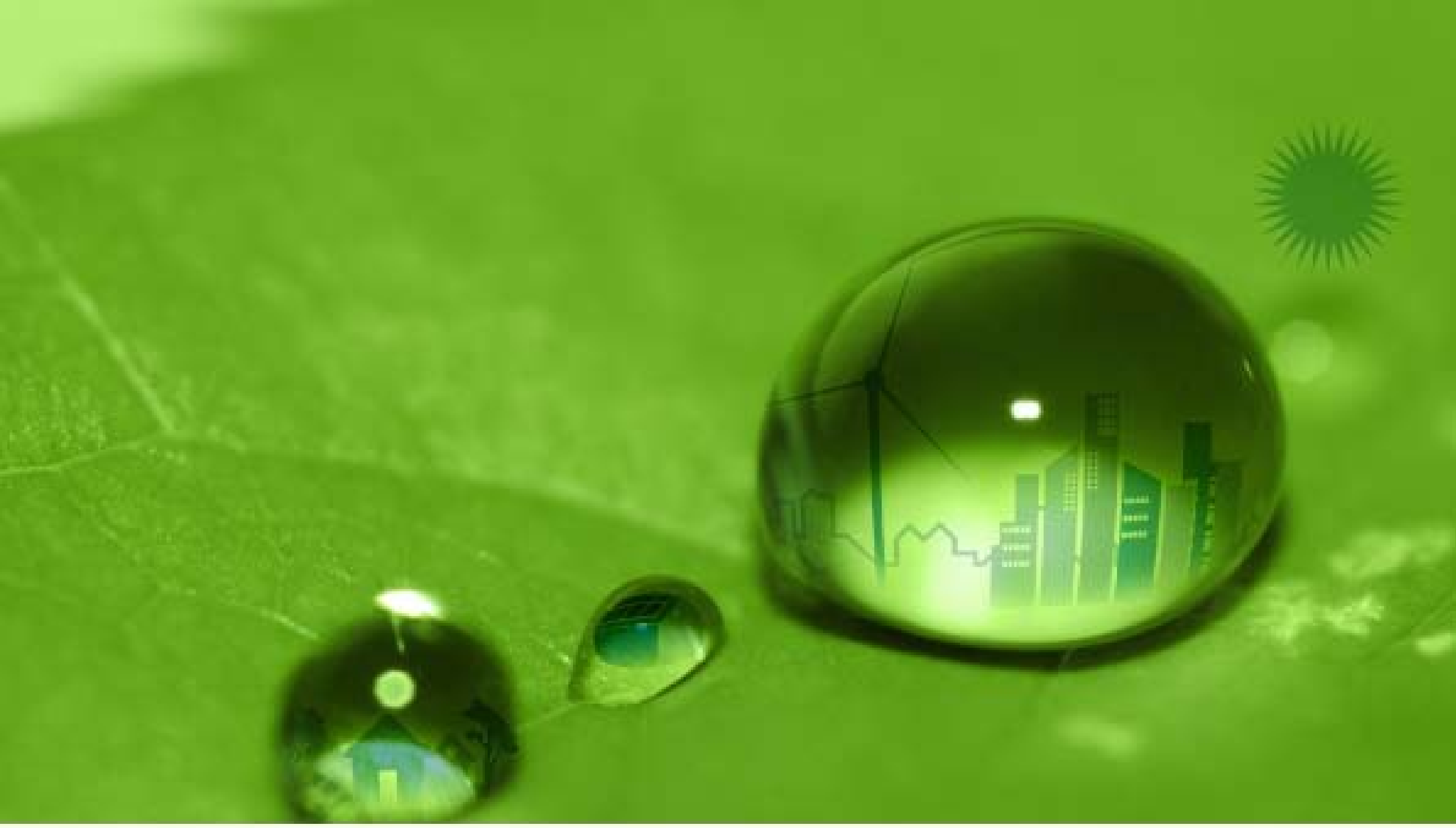

INNOVATION FOR ENERGY NETWORKS

Technical Spotlight DEMO1

Spotlight on the forecast algorithm implemented in DEMO1

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement n°268206.

CO - FUNDED BY THE EUROPEAN UNION

Table of content

List of figures & tables

1 Introduction and scope of the document

Type of solution				
■ Equipment / Hardware / Firmware ☐ Information system ☐ Process				
Manufacturer(s) implied (for equipment or hardware)				
TU Dortmund University				
Work Stream considered				
☐ Active Demand ☐ DER ☐ Storage ☐ Islanding ■ MV Innovation ☐ LV Innovation				
Location / Topology (with regards to distribution grid)				
☐ HV/MV Substation ☐ MV ■ MV/LV SS ☐ LV ☐ DER ☐ Meter ☐ Downstream meter ☐ Other Centralized system (calculations, information system) ☐ Other Decentralized ☐ Other :				
Thematic(s)				
■ Grid Monitoring / state estimation ☐ Active demand / DSM ☐ DER Integration / increased grid capacity ☐ Islanding ☐ Anti Islanding protection ☐ Automatic Failure Detection ☐ Remote Grid Operations ☐ Automatic Failure Management / Grid recovery ■ Automatic Grid topology reconfiguration ■ Other : power forecast				
Use Case(s)				
DEMO 1	☐ Failure Management in MV networks	■ Decentralized grid operation in MV Networks		
DEMO 2	☐Outage detection in the LV Network			
DEMO 3	☐Automatic Grid Recovery (AGR)	☐Automatic Outage Detection (AOD)	☐Secondary Substation Node (SSN)	☐Customer Engagement
DEMO 4	☐Voltage control on MV grids (with high DER penetration)	☐Anti-islanding protection on MV grids	☐MV Measurement acquisition	☐Demand response for MV Customers
DEMO 5	☐MV grid automation of failure management	☐LV grid automation of failure management	☐Management of islanding operations	
DEMO 6	☐Islanding	☐Reduction of power demand	☐Manage maximised PV production on LV network regarding constraints and flexibility programs	☐Encourage resident to adopt smarter habits according to network state
Key figures				
MV grid with ~100 secondary substations, 7 switching modules, 11 measurement modules				

2 Objective and technical requirements

2.1 Context & Objective

In order to reduce network losses it is useful to adapt the network's topology to the current loading situation. This is done by the topology reconfiguration algorithm which sends switching commands to some substations equipped with circuit breakers. On the one hand, every significant network state change should be followed by a reconfiguration process for gaining maximal loss-reducing effect. On the other hand, many switching actions result in faster wear of the switching devices. A tradeoff for less switching actions and still good loss reducing operation should be found. In order to find this balance, a network state forecast îs calculated. A network state can be represented by the residual load (see Figure 1, top), which consists of the sum of the active nodal power measurements acquired at the secondary substation level.

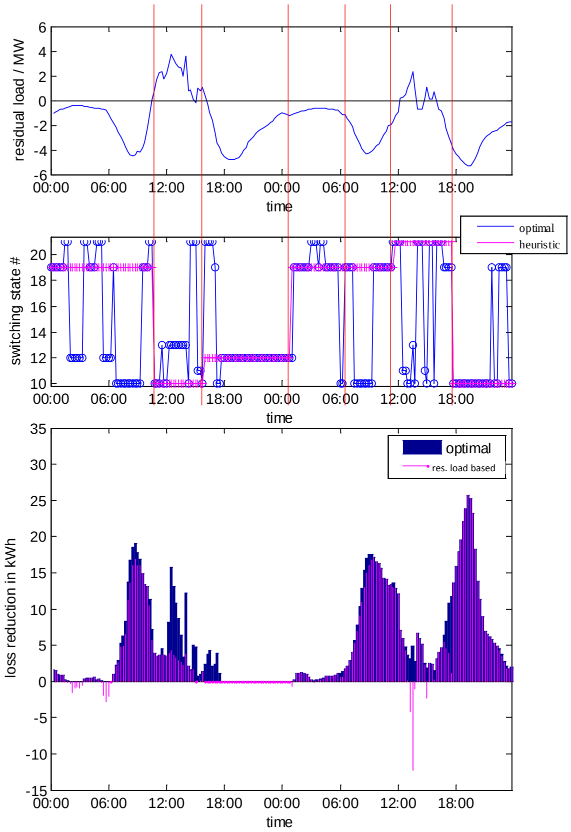

Figure 1: Forecast-based loss reduction compared with the optimal reconfiguration

As illustrated in Figure 1, the forecast-based loss reduction algorithm might not reach an optimal loss reduction (see Figure 1, bottom). Still, a high loss saving potential is expected, simultaneously minimizing switching actions (see Figure 1, middle).

2.2 Requirements

For the execution of the loss reduction algorithm at the primary substation the forecast data from all automated secondary substations need to be collected, as depicted in Figure 2.

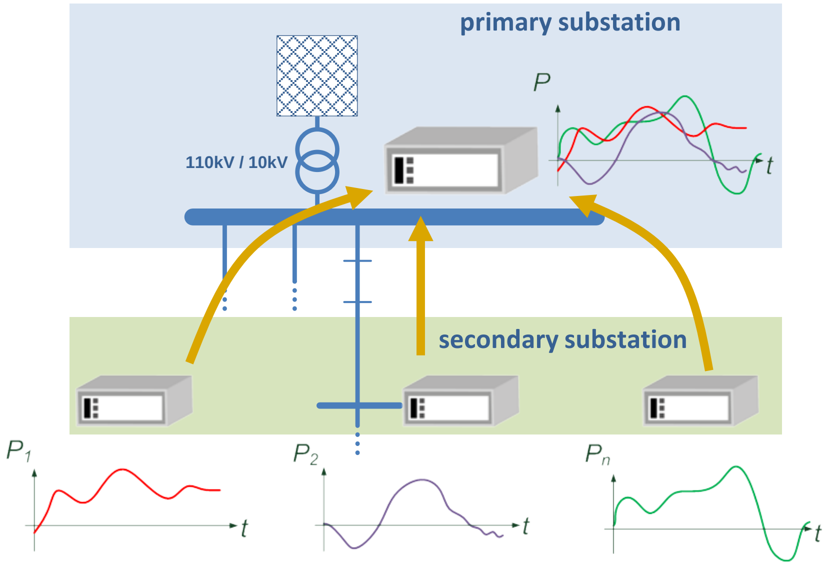

Figure 2: Architecture of the forecasting system

Therefore the reactive and active power measurements need to be collected in the secondary substations. From these measurements the 15-minutes mean values are computed. Every 15 minutes a day-ahead forecast time series is computed locally. This forecast data is forwarded to the primary substation where the forecast based loss reduction algorithm is launched.

3 Development and implementation

3.1 Overall algorithm

The overall loss reduction algorithm is based on the residual load analysis and network reconfiguration for the forecasted power time series (see Figure 3)

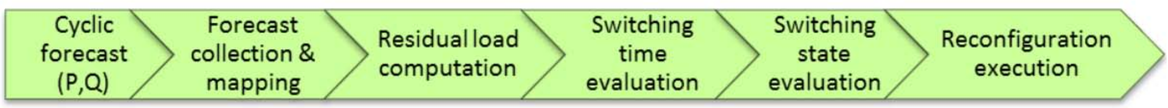

Figure 3: Loss reduction algorithm flow chart

In the first step, the forecast data is computed decentralized on the slave RTUs. This data is periodically gained by the master RTU. In this step the data from multiple measurements is mapped onto the reduced network model which is used for the network reconfiguration algorithm and consists only of 31 nodes. When the data complexity is reduced, residual load is computed.

The main idea consists in searching for appropriate points of time to perform the reconfiguration. These correspond to the points of inflexion of the residual load curve (see Figure 4)

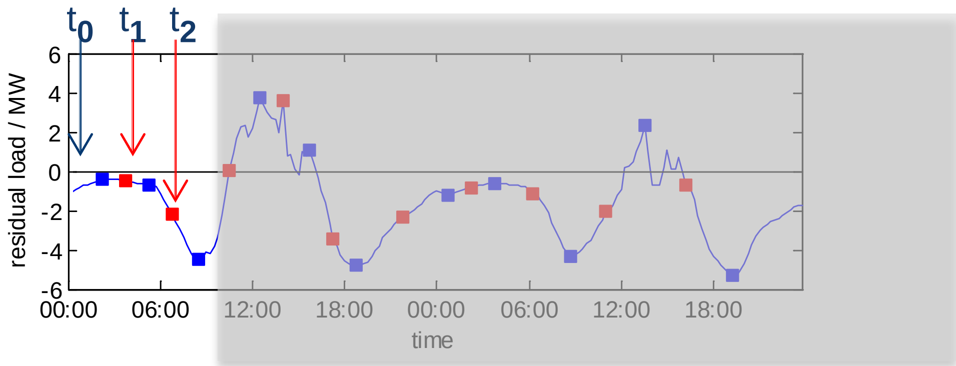

Figure 4: Exemplarily residual load curve and switching times

Being at the time t_0, the next switching interval [t_1, t_2] is evaluated. The switching state for this interval is obtained by applying a static reconfiguration algorithm. As input data for this algorithm mean power values $P_{\text{mean},[1,2]}$ and $Q_{\text{mean},[1,2]}$ are computed at the given interval. So, the target network topology supposes to reduce losses for the predicted time interval. The required switching actions are scheduled for t_1.

3.2 Used forecast method

The forecast algorithm used for the power time series prediction is based on the adopted version of the double seasonal exponential smoothing method with following properties

- Univariate method – no additional information required
- Less disk space is required
- Equidistant measuring intervals (15 minutes)
- Forecast model based on three components: level component, daily cycle, weekly cycle

This technique is well suited for the implementation on the remote terminal units (RTU), which are the basis for the secondary substation automation. In order to unburden the central RTU at the primary substation, the forecasts are carried out locally. The computed time series are then forwarder to the primary substation RTU for the central algorithm. The implementation on the RTUs is carried out by using the PLC (programmable logic controller) programming.

4 Results

4.1 Simulation

The overall algorithm development was subdivided in the development of the forecast algorithm and the development of the forecast-based loss optimization algorithm. The implementation started with a prototype phase using MATLAB environment and then the functions developed in MATLAB have been transferred to the PLC on the RTUs.

The testing results in MATLAB showed that the mean absolute percentage error varies between <1% and 12% which is adequate. With this forecast precision it is possible to reduce significantly the number of switching actions when compared with the optimal reference, as stated in Table 1.

	Network losses	Switching actions*
static topology	100%	0
optimal reconfig.	71.3%	17814
forecast-based	79.7%	3142

*) one switching action = switch on/off

Table 1results of the loss reduction algorithm for a one year simulation

Also different technical effects of using the loss reduction algorithm can be seen. In Figure 5 an exemplarily 3-days period is illustrated. Most of the time, the forecast-based method (in red) generates network losses which are lower than for the static operation (in blue) and higher or often nearly equal to the optimal switching operation (in green). Loss reduction also influences voltage characteristics of the system – the voltage range becomes narrower. Still, due to forecast errors in seldom cases loss reduction driven switching actions lead to state violations – as it can be seen in Figure 5 at time step 9750. During this period network losses are increased.

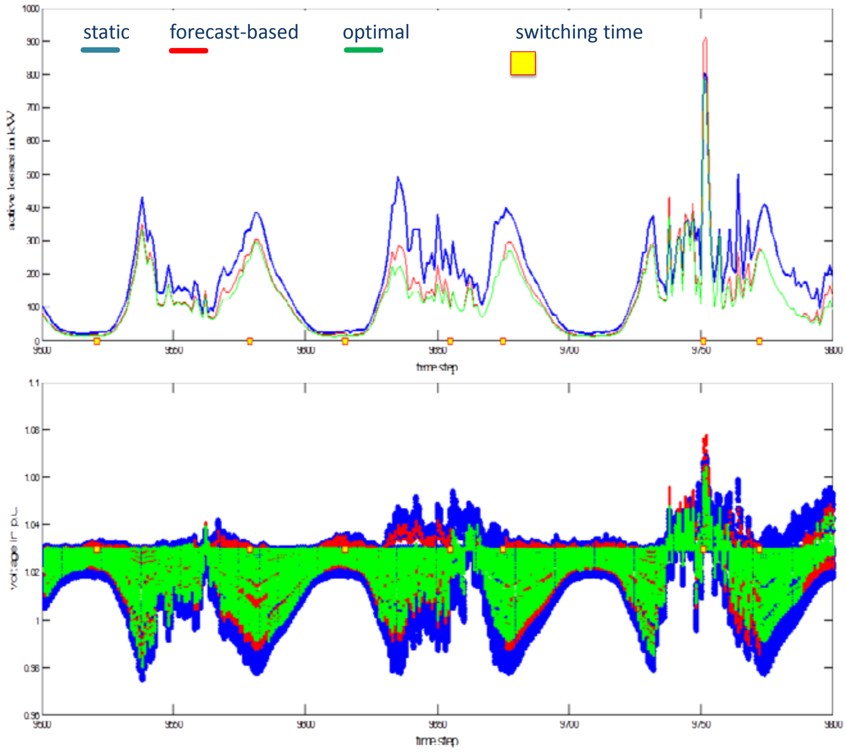

Figure 5: Loss reduction algorithm: network losses and voltages

4.2 Field Implementation, technical issues, outlook

Single software components of the overall loss reduction algorithm have been implemented on RTUs. So, the forecast precision of the PLC implemented function is identical with the prototype MATLAB implementation. Also the residual load analysis algorithm implementation succeeded.

Most difficulties occurred when implementing forecast data forwarding from the substation RTU to the master RTU unit: here the IEC 60870-5-104 communication standard is used for transmitting data between RTUs. Unfortunately this communication protocol enables only single value transmission, whereas forecast data is an array of floating point values.

A workaround was developed: to transmit single forecast values iteratively in a short time (100ms cycle). Still, the data doesn't always arrive in the right order or incomplete. The future development will be to guarantee a synchronization of forecast data between substation and the master RTU.

As to the field implementation, communication outages of the substation RTUs have to be considered – they appear at least several times a day, in some cases for periods of time over 15 minutes. This would mean, parts of the forecast would be missing. As a solution, historical data might be recorder at the master RTU unit to provide a data consistency and be able to fill missing data.