

USING CONTINUOUS STATE ESTIMATION IN GRID PLANNING

Peter VINTER
DONG Energy – Denmark
petvi@dongenergy.dk

Hans KNUDSEN
DONG Energy – Denmark
hknud@dongenergy.dk

ABSTRACT

In 2008, DONG Energy implemented an IT solution that determines all line load flows, transformer loads and bus voltages in the entire MV network every 10 minutes.

Calculations are based on a combination of on-line measurements and statistically based synthetic load curves for various load types and seasons.

The solution - 'SmartPIT' - provides an unprecedented amount of information about the network state. The entire MV network may now be analysed, planned and operated on actual hour-by-hour values rather than peak estimates.

INTRODUCTION

Marketplace and regulatory demands along with the need for future infrastructure reinvestment drove DONG Energy to look for a way to better manage and utilize the network.

The SmartPIT solution [1] collects and analyzes all information about the network available from GIS and SCADA / DMS systems, billing and AMR data and measurements from MV automation devices.

By leveraging this information, DONG Energy becomes able to make more efficient use of existing electrical infrastructure and plan more intelligently for the future [2].

The goal is to optimize future network reinforcements without compromising network safety and power quality.

SOLUTION OVERVIEW

The major challenge lies in continuously collecting large quantities of data from the MV and LV network, processing it into information and reacting to it:

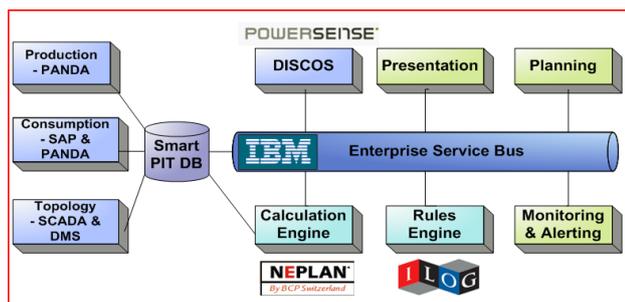


Figure 1: Solution components and overview

Current implementation focuses on handling the data and making it accessible for long-term network planning and 'off-line' analysis of specific pain points in the network.

DATA ACQUISITION FROM THE NETWORK

Primary substations

Primary substations are monitored with a traditional SCADA / DMS (Distribution Management System). Data imported into SmartPIT are:

- Bus configuration at primary substations
- Transformer and bus voltages
- Load currents measurements at feeder head - in some cases also active and reactive power
- Switching state (topology) in MV network

The information is sent to SmartPIT every 10 minutes.

Secondary substations

Key sources to MV network measurements are the Discos™ supervision devices, originally implemented for short-circuit detection and remote sectionalizer control.

The devices offer on-line measurements of current, active and reactive power on MV lines and transformers. This information is transmitted from each Discos-equipped substation to SmartPIT every 10 minutes via GPRS.

Data Validation

The tight data integration between SmartPIT and other systems is a huge advantage but puts hard requirements on data actuality and topicality in an environment where network and customer data change daily in large numbers.

To make SmartPIT robust to this, appropriate filters and default data have been defined for all network components to ensure that the continuous state estimation is not impaired.

Incoming measurements are validated with the ILog™ rules tool to protect state estimation calculations against implausible measurements. The operator is also notified so 'bad' measurements can be found and rectified.

DATA FROM BUSINESS IT SYSTEMS

Network data

Network data for the calculation model is imported every 24 hours from two sources, SAP PM and GIS, comprising:

- MV lines, lengths and cross-sections
- MV breakers and disconnectors
- HV/MV and MV/LV transformers
- Generators
- Network structure including substation locations

Load data

Load data are essential for making a reliable network state estimation. Load data are collected from 4 sources:

- Hourly energy sales, remotely read customers
- Hourly energy production, embedded generation
- Annual energy sales, small customers
- Telemetered MV/LV stations

Hourly energy sales, remotely read customers

AMR (Automatic Meter Reading) is mandatory for Danish customers consuming 100,000+ kWh / year. Readings are retrieved once a day via SMS or dial-up lines, checked for validity and sent to SmartPIT after 72 hours.

The hourly consumption, i.e. kWh/h, is used as an estimate for the mean load in that specific hour. Power factor is not measured, so an estimate is set up in SmartPIT. Hour-by-hour values are transformed into 10 minute values by interpolation for comparison with actual measurements.

Hourly energy production, embedded generation

Embedded generation is quite common in Danish MV grids; most common types are wind turbines and CHP (Cogeneration Heat & Power) plants in the 100 - 5,000 kW range and wind farms in the MW range.

Production measurements are handled along the same lines as for large customers. Different power factors are used for asynchronous and synchronous generators, however.

Annual energy sales, small customers

For customers with consumption below 100,000 kWh/year, only expected energy sales for the next year are known.

From SAP IS-U, SmartPIT retrieves information about more than 900,000 customers once every 24 hours on:

- Expected annual consumption
- Load Category
- Topological connection to network

Since neither power factor nor reactive energy is known, SmartPIT uses an estimate. Energy sales are then converted into synthetic load curves; see next paragraph.

Telemetered MV/LV stations

Important sources of data are Discos™ devices in MV/LV stations. Both MV line and transformer active and reactive power is sent to SmartPIT every 10 minutes via GPRS.

FROM ENERGY SALES TO ACTUAL LOAD

Traditional approach

Dimensioning MV feeders where the only information available is energy sales and peak load at feeder head is a well-known challenge. The traditional approach is:

1. Divide customers into different unique categories
2. Convert the annual energy sales Q per category to peak load P_{max} , using Velander's formula:

$$P_{max} [kW] = A * Q [MWh] + B * \sqrt{Q}$$
 A and B are determined statistically per category
3. Convert P_{max} to apparent peak power S_{max} , assuming a mean $\cos(\phi)$ for the load
4. Calculate sum $\sum S_{max}$ of apparent peak power for all categories and substations on feeder
5. Substation loads are scaled to feeder head load by a factor $k = S_{measured} / \sum S_{max}$. k is typically 0,5-0,9.

This approach has several shortcomings:

- Scaling will satisfy feeder peak load, but not true line and substation peak load
- In networks with embedded generation, line loads may be severely under- and overestimated
- Time variation of load is not described; assets are dimensioned to carry peak load 'for ever'
- Category number is kept low for simplicity, assuming similar behaviour of different load types
- Parameters A and B are rarely updated, and do not reflect changes in load utilization time over time

Traditionally, networks are designed with overcapacity to handle those uncertainties - leading to higher CAPEX - rather than compromising network safety and power quality.

New approach

One aspect of the SmartPIT solutions is the use of synthetic load curves to describe the time-wise behaviour of different LV customer categories [1].

From annual energy sales to peak loads P_{max}

The first stage is to transform annual energy sales per category into peak loads per category. The traditional approach has here been improved on two important issues:

- The number of categories was increased from 6 to 27, giving a much better discrimination between different load patterns
- Parameters A and B were determined for all 27 categories, using up-to-date load measurements

From peak loads P_{max} to synthetic load curves $P(t)$

Peak loads are then transformed to synthetic load curves by applying normalized synthetic load curves to each category for the different seasons of the year.

In SmartPIT, 22 individual seasons are used; some several weeks long, other just a few days, e.g. Christmas, to achieve an optimal representation. The hourly load is:

$$P(t) = P_{max} \cdot Profile_{day}(t) \cdot Profile_{season}(t) \cdot Profile_{year}(t)$$

By analyzing a large number of actual load curves per category and season, a set of synthetic curves has been defined for workdays, Saturdays and Sundays; see example:

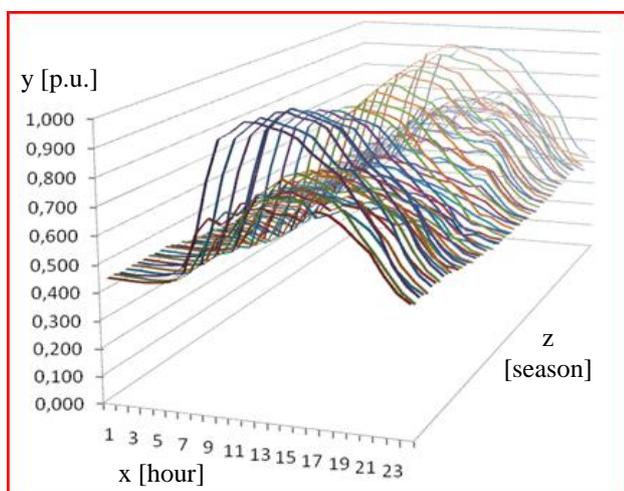


Figure 2: Synthetic load profiles for ‘Bank & Insurance’

‘High’ curves are workdays; ‘low’ curves Saturdays and Sundays. Profiles show a clear variation over hours, weekdays and seasons.

National holidays are handled separately. Usually having load patterns similar to Saturdays or Sundays, individual days in any season may be defined as a Saturday or Sunday.

NETWORK MODEL AND CALCULATIONS

Continuous network state estimation

From the information imported to SmartPIT, a full network model, including loads and generators is built. Approx. 7,000 secondary substations are currently modelled.

The calculation ‘engine’ in SmartPIT is the network planning tool NEPLAN™ from BCP. Every 10 minutes, NEPLAN™ makes a state estimation of the entire MV grid, taking all available data in account.

Loadflow calculations are done using load balancing, meaning that simultaneity factors of the synthetic load curves are adjusted to meet power or current measurements

in primary or secondary substations upstream the feeder.

Calculated flows and voltages are returned to SmartPIT where the ‘virtual’ measurements are stored in parallel with real measurements with a tag identifying them as virtual.

Off-line analysis in NEPLAN™

SmartPIT allows the network planner to extract a NEPLAN™ project file containing the entire network. Options when extracting project file are:

Date and time	[Any point back in time]
Switching state	[Normal, Actual]
Measurements	[Discos, SCADA, both]
AMR data	[Included, Excluded]
Production data	[Zero, Actual, Maximum]
Purpose of analysis	[Loadflow, Short Circuit]

This is a very powerful feature for medium and long-term network planning, since specific point points in the network can be identified and analyzed in detail.

Special studies using SQL queries

SmartPIT is also designed to support SQL queries. This is very useful for special studies of e.g. voltage and load profiles, etc. as will be demonstrated in the next section.

STUDIES AND RESULTS

To demonstrate the capabilities of SmartPIT, some analysis examples will be given, using a MV feeder ‘GHO A4’.

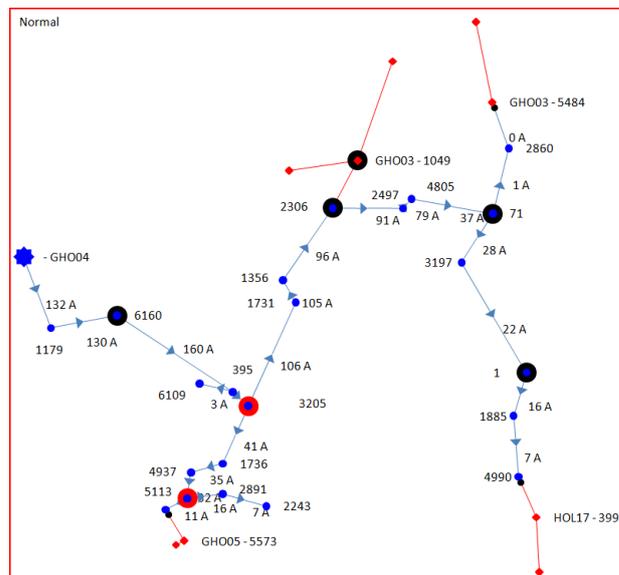


Figure 3: Sample feeder overview ‘GHO A4’

Feeder overview is built automatically every 10 minutes by SmartPIT using SAP / GIS data. Primary substation / feeder head is in left side of figure. Large circles show Discos™ units; red lines are tie connections to other MV feeders.

Primary substation representation including measurements is also generated every 10 minutes (only 5 bays shown):

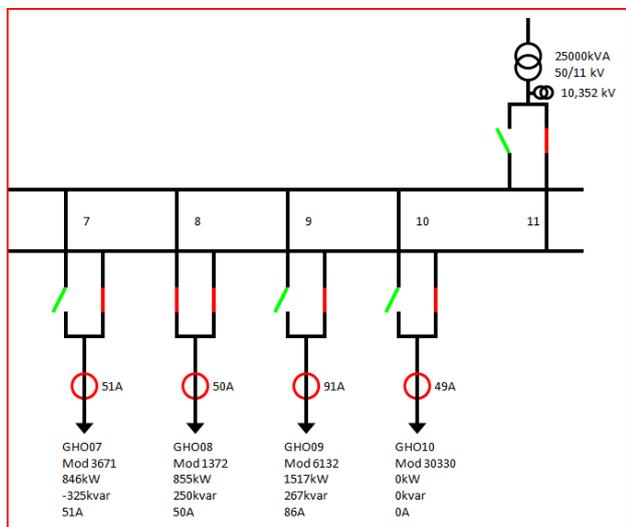


Figure 4: Primary station 'GHO' overview

Below is shown secondary substation 6160 (2nd station on the feeder). Discos measurements (red rings) and two CHP generators running at near full load are shown. Since production exceeds load, net transformer load is negative.

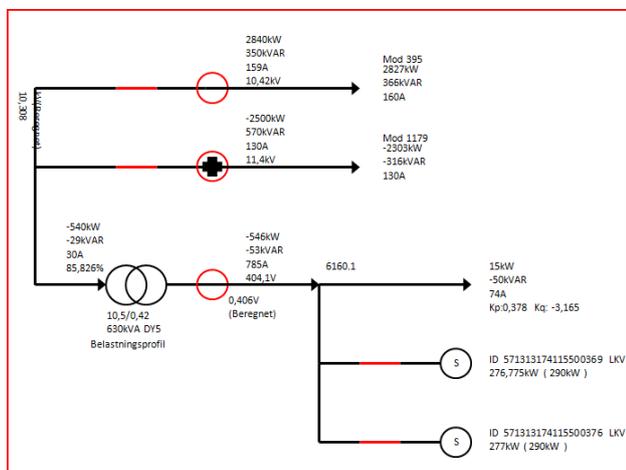


Figure 5: Secondary station '6160' overview

Load and voltage profiles

When analysing specific load or voltage variation problems, SmartPIT offers a load and voltage profile for each feeder:

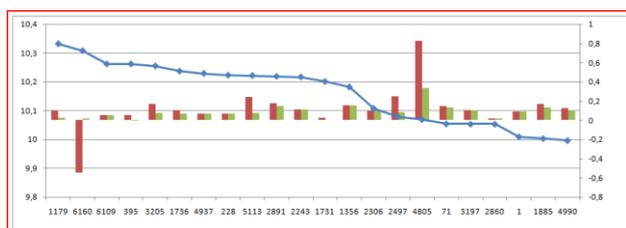


Figure 6: Load and voltage profile, sorted by voltage

Blue line shows MV voltage, dropping from 10.33 kV to 10.00 kV. Red bars are load values from AMR (note CHP generation at 2nd station 6160); green are synthetic loads.

Spare line or transformer capacity

For load analysis of lines or transformers, historic loading and switching state is crucial. SmartPIT gives access to both measured and 'virtual' historical values for all components.

Below is shown relative load of the MV/LV transformer in secondary station '4805' over a weekend and 5 workdays. Spare capacity is seen to be at least 50 %:

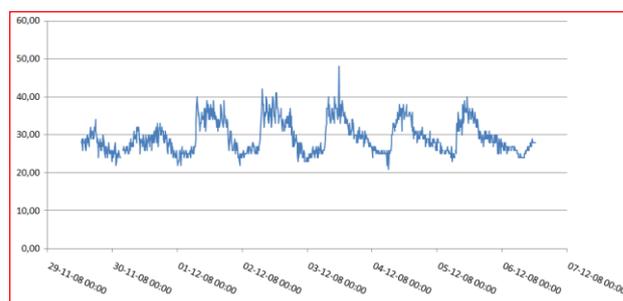


Figure 7: Relative load of MV/LV transformer in '4805'

In contrast to MV/LV transformers, spare capacity of MV lines cannot easily be deduced directly from load curves but require a contingency analysis.

The reason is that MV lines are dimensioned with respect to a peak-load back-up situation. If this combination has not occurred in the past, it is not a part of the historical data.

One possible solution is to perform a contingency analysis every 10 minutes and store the prospective loading of each component. However, this would be very time consuming, so simplified contingency methods are being investigated.

BUSINESS PERSPECTIVES

With the information provided by SmartPIT, real peak load data for individual components have become available. CAPEX may now be spent at the real network bottlenecks.

Business case studies have estimated a significant reduction in planned network reinforcements and a much better overview of network utilization and power quality. These results will be validated over the next years using SmartPIT.

REFERENCES

[1] P. Vinter, 2008, "DONG Energy - towards the intelligent utility network", *Proceedings, CIRÉD Seminar June 2008: "SmartGrids for Distribution"*
 [2] IBM, DONG Energy: "Making the most of the intelligent electrical grid", November 2007: [ftp://ftp.software.ibm.com/software/solutions/pdfs/OD_C03017-USEN-00.pdf](http://ftp.software.ibm.com/software/solutions/pdfs/OD_C03017-USEN-00.pdf)