

DONG ENERGY - TOWARDS THE INTELLIGENT UTILITY NETWORK

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ABSTRACT

In the summer 2008 DONG Energy takes a major step towards the Intelligent Utility Network by implementing an IUN solution in their MV network.

The solution - 'SmartPIT' - will determine all line load flows, transformer loads and bus voltages in the entire MV network every 10 minutes; thus providing an unprecedented amount of information about the actual network state.

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

The entire MV network may now be analysed, planned and operated on actual hour-by-hour values rather than peak estimates.

INTRODUCTION

In Denmark, as in most other countries, deregulation imposes strict limitations on electric utilities' capital and operational expenses.

Additionally, new regulations introduced 2008 include benchmarking of quality of service, based on the reliability indices SAIFI and SAIDI (System Average Interruption Frequency / Duration Index, respectively).

These 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 electrical distribution network.

First initiatives were aimed at responding faster and more efficiently to outages. This led to investments in advanced distribution automation solutions such as Discos [1].

The SmartPIT initiative was next; planned and developed in co-operation with IBM it aims at using the information provided by the automation devices in daily operation.

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. Here the IUN solution has its role and justification:

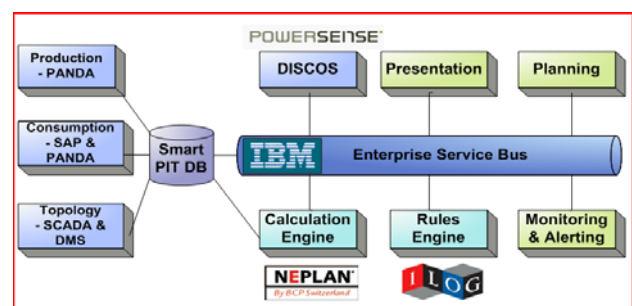


Figure 1: Solution components and overview

One complex aspect is the use of synthetic load curves to describe the behaviour of different LV customer categories.

By introducing synthetic load curves, the number of extra MV measurements required to make a reliable network state estimation may be reduced.

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
- Bus voltages
- Load currents at feeder head - in a few cases also active and reactive power
- Switching state (topology) in MV network

The information is sent to SmartPIT every 10 minutes.

Secondary substations

A key source to information about the MV network is the Discos systems from PowerSense, originally implemented for short-circuit detection and remote sectionalizer control.

The system's optical current sensors also offer on-line measurements of current, active and reactive power on MV lines and MV/LV transformers.

This information is transmitted from each Discos equipped substation to SmartPIT every 10 minutes. Communication runs via GPRS, using the IBM MQTT protocol.

Incoming measurements are then validated with a rules tool from ILog 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

In order to build an exact network model for the continuous calculations, network data are imported once every 24 hours from two sources, SAP PM and GIS:

- MV lines
- HV/MV and MV/LV transformers
- Generators
- Network structure
- Line lengths
- Substation locations

Load data

Load data are essential for making a reliable network state estimation. Load data are collected from 3 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

In Denmark, automatic meter reading is mandatory for customers with an annual consumption above 100,000 kWh.

Readings are retrieved once a day via SMS or dial-up lines and stored in the database 'PANDA'. Measurements are checked for validity and sent to SmartPIT after 72 hours.

The data contain hourly sales; i.e. kWh/h. This 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; the most usual types being wind turbines and CHP (Cogeneration Heat & Power) plants in the 100 - 5,000 kW range and wind farms in the MW range.

Production data for embedded generation is handled along

the same lines as for large customers. Data contain hourly sales; i.e. kWh/h, which is used as an estimate for the mean load in that specific hour. Different power factor estimates are used for asynchronous and synchronous generators.

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, the following information on more than 900,000 customers is retrieved once every 24 hours:

- 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

The last source of load data are MV/LV stations equipped with Discos systems. Here, both MV line and MV/LV transformer active and reactive load is pushed to SmartPIT every 10 minutes via the GPRS / MQTT interface.

Apart from enhancing the quality of the state estimation, these measurements are also used for checking and improving synthetic load curve models used on non-telemetered stations.

FROM ANNUAL ENERGY 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:

$$P_{max} [kW] = A * Q [MWh] + B * \sqrt{Q}$$
 where the parameters A and B are determined statistically for each 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. Since individual peak loads do not occur simultaneously, $\sum S_{max}$ will exceed peak load measured at feeder head, $S_{measured}$ head.
6. Consequently, substation loads are downscaled by a factor $k = S_{measured} / \sum S_{max}$. k is typically 0,5-0,9.

This approach has several shortcomings:

- Usually, total number of categories is kept low for

simplicity, assuming similar behaviour of different customer types

- Parameters A and B are historical values but rarely updated, and so they do not reflect changes in e.g. load utilization time over the years
- 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
- The time variation of the actual load is not available, meaning that assets must be dimensioned to carry peak load 'for ever'

Figure 2 shows the relation between annual energy sales [MWh/year] and peak load [kW] for both a former high-level category 'Trade' (red line) and the new sub-category 'Telecommunication' (blue dots for specific customers).

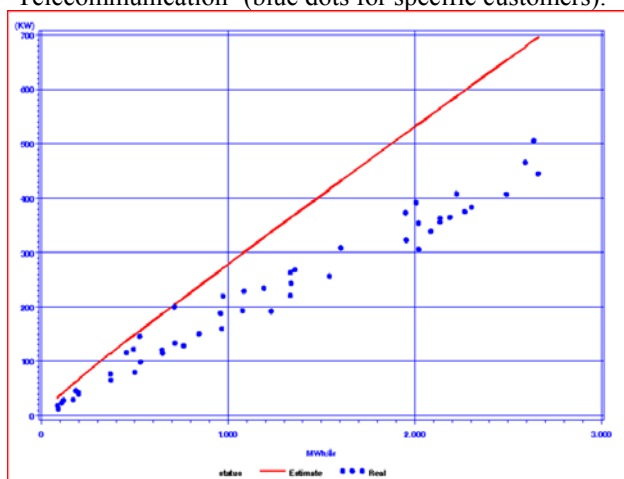


Figure 2: Relation between Q and P_{max}

Historically, utility companies have had either to build in enough network capacity to handle the uncertainties above - leading to higher investment costs - or to accept the risk of compromising network safety and power quality.

New approach

The traditional approach is prohibitive for analysing, planning and operating the individual components on basis of their actual hour-by-hour values.

The new approach works in two stages:

1. Annual energy sales per category are transformed to peak loads per category
2. Peak loads are then transformed to synthetic load curves per category

The synthetic load curves are transferred to the SmartPIT network calculation model to give substation, line and feeder loads.

From annual energy sales to peak loads P_{max}

In principle, stage 1 is similar to the traditional approach,

but has been improved on two important issues:

- The number of categories have been increased from 6 to 27, giving a much better discrimination between different load patterns
- New Velder parameters A and B have been determined for all 27 categories, using up-to-date load measurements

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

Next stage is to apply normalized synthetic load curves to each category for the different seasons of the year.

Usually, load profiles are defined by year, month, week and day profiles, giving an hourly load of:

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

In the DONG Energy implementation, 22 different seasons are used instead of weeks and months; some several weeks long, other just a few days, e.g. Christmas, to give the best possible representation. This gives an hourly load of:

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

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

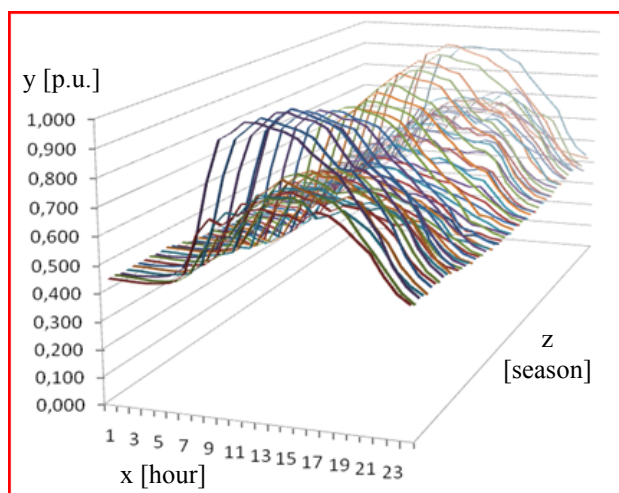


Figure 3: Synthetic load profiles for 'Bank & Insurance'

The 'high' curves represent workdays; the 'low' curves are Saturdays and Sundays. The 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.

Finally, hour-by-hour values are transformed into 10 minute values by interpolation for comparison with measurements.

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 will be modelled in this phase.

The calculation 'engine' is the planning tool NEPLAN from BCP. NEPLAN calculates loadflow using load balancing, meaning that simultaneity factors of the synthetic load curves are adjusted to meet power or current measurements.

Calculated flows and voltages are returned to SmartPIT where the 'virtual' measurements are stored alongside real measurements with a tag identifying them as virtual.

Should calculations on single feeders or primary substations fail for some reason, the system will notify the operator but continue calculations on remaining part of the network.

Off-line analysis

SmartPIT allows the network analyst to extract a NEPLAN project file containing the entire network model including loads and generators - for any point back in time.

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.

Finally, the SmartPIT database is designed to permit direct SQL queries. This is very useful for special studies of e.g. voltage profiles, asymmetric loading of lines, etc.

RESULTS AND LESSONS LEARNED

Good estimates of loads and voltages

The synthetic load curves and the calculation methodology has been validated by comparing estimated and real loads on two feeders, densely equipped with Discos units.

One benchmark was to estimate current at the head of feeder GHOA3. The figure below shows estimated and actual current [A] from 7th December 2007 to 14th January 2008:

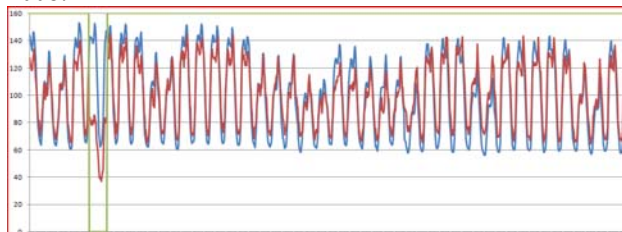


Figure 4: Calculated and measured MV feeder current

Blue and red curve is estimated and actual current; green curve shows an abnormal switching state on 11th December.

In general, the estimate proved quite fair with a MAPE

value (Mean Absolute Percentage Error) at approx. 9 %. The absolute deviations over the period are:

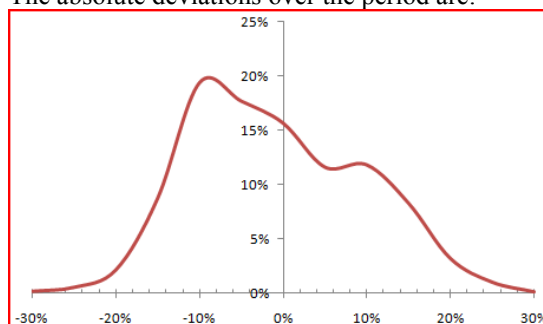


Figure 5: Error distribution curve, feeder GHOA3

Next step is to include Discos power flow measurements on feeder branches to improve these figures and make them fully sufficient for both planning and operational purposes.

Reduced need for measurements

The use of synthetic load curves permits a reliable network state estimation even with a low number of MV network measurements. This is only possible with an IUN solution to handle the large amount of data and calculations.

Challenges in data management

The tight data integration between SmartPIT and Business IT systems is a huge advantage but puts hard requirements on data actuality and topicality.

To make SmartPIT robust in an environment where network and customer data are changed daily in large numbers, appropriate default data have been defined for all data types to ensure that the continuous state estimation is not impaired.

BUSINESS PERSPECTIVES

With the information provided by the SmartPIT solution, real peak load data for individual components have become available. Capital expenditures can now be optimized and directed to the real bottlenecks of the network.

Prior to the project, the planning business processes were analysed in cooperation with IBM, since the solution adds an entirely new dimension to short and long term planning.

The business case estimated a reduction in planned network reinforcements in the range of 80 % - and a much better overview of network utilization and power quality. These results will be validated over the next year using SmartPIT.

REFERENCES

- [1] P. Vinter, H. Vikelgaard, "A novel approach to Distribution Grid Automation at Nesa A/S" *CIRED 2005*.
- [2] IBM, DONG Energy: "Making the most of the intelligent electrical grid", November 2007: <ftp://ftp.software.ibm.com/software/solutions/pdfs/DC03017-USEN-00.pdf>