'Internet of Things' - for substations

Installing thousands of sensors in substations in the medium voltage grid as part of a 'Smart Grid' upgrade creates organizational and technical challenges for the utilities. Data management becomes increasingly important.

In the good old days, the manager of the local power utility, knew quite well where to look for the failure if a short circuit occurred. Often he knew about the weakness of the grid in specific points or he would know where the local entrepreneurs were likely to be causing a short circuit. Many utilities need to introduce a new generation of power technicians to the operations and maintenance of the power grid, and are in parallel with this facing an ever growing decentralization of power production, and introduction of electric vehicle charging stations.

New objectives
Within the utilities, a number of quality and efficiency objectives must be fulfilled:
- Less personnel per km grid
- Less downtime
- Higher voltage quality
- Lower power losses
- Lower and pro-active maintenance

Smart Grid is the big buzzword, but at the end of the day such investments must be profitable.

Smart sensors and smart control are key components for reaching a medium voltage Smart Grid upgrade that lives up to its name.

Internet of Things
The increasing standardization based on the Internet Protocol as a foundation has in the last decade led to a host of advanced functionalities and applications for smartphones, tablets, TVs, cars and even white goods such as fridges.

At one point one of my good friends, a captain at one of the major airlines, invited me into the cockpit of an aircraft during a long distance flight. I was surprised to learn, that an iPad is the most important tool to look up route planning, aircraft data, airport data etc.

An apt comparison that can be made in this case is that the power harnessed in an aircraft is subject to dedicated mechanical and electrical control systems with extreme reliability, similar to some of the control mechanisms in use in a power grid with protection relays, breakers etc..

On top of these systems, in an aircraft, an iPad is used. It is not part of the critical control mechanisms, but it is responsible for providing the pilots with an overview of the operational state of the aircraft and its surroundings, for the pilots to act on.

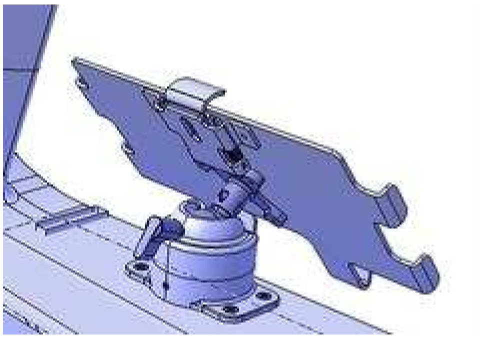

Illustration 1: Airbus provides a dedicated iPad mount for A320 Family pilots

Understanding your data sensitivity
Similar to the pilots, the operationally responsible of a utility must have data available, to understand the maintenance needs at any given time. However the data and

underlying control options are important to consider. You do not want to risk a protection breaker to rely on a long data-transmission to the control centre before activation. Reaction must be almost instantaneous and therefore autonomous. In the opposite end of reaction time, you may afford waiting for days for data about a change in the harmonic content of the power flowing through a transformer.

For billing purposes you need voltage and current measurements within strict tolerances, typically 0.1% of accuracy. For the purpose of understanding load conditions in a medium voltage power grid, the reactive power content, the total harmonic distortion (THD) and similar measures a tolerance in the area up to 10% for the underlying voltage and current measurement levels will often be sufficient. For some measurements the relative accuracy is more important than the absolute accuracy. If a voltage suddenly drops on a phase conductor, it could be important to know if the drop is 3 % but less important to know if it in absolute measures is 5% precise.

The game changers

A valuable aspect of introducing 'IoT' smart sensors into the power grid, is the configuration and feature expansion options. Remote upgrade support will ensure that further applications can be added over time, as new knowledge is gained via Smart Grid data collection. E.g, it may turn out that some transformer models exhibits a significant increase in the 7^{th} harmonic frequency content minutes or hours before a catastrophic short circuit occurs. The sensors can then be updated to create an alarm if that measurement point exceeds a given threshold.

Cost efficient measurement techniques

Small sensor devices, not relying on measurement transformers, for substation monitoring is a game changer, enabling simple retrofitting on existing infrastructure, without the need for adding transformer sections, and/or disassembly of the phase conductors, and similar costly and disruptive changes.

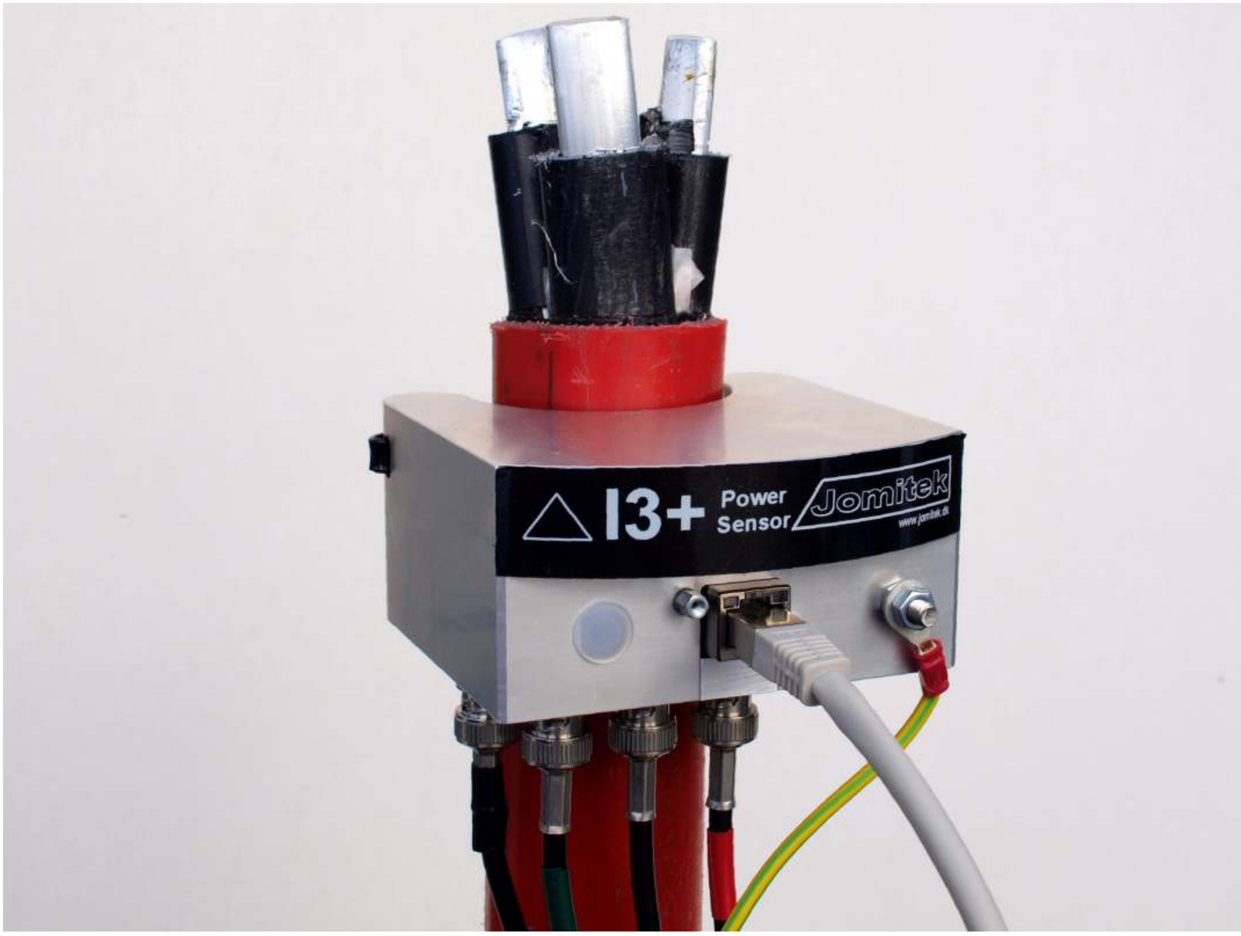

Illustration 2: IP based Smart Grid power sensor -

It should not come as a surprise, that initial comments and arguments in this text, is meant as an introduction of the new I3 series of power sensors. The development has been ongoing since 2011, and a major utility in Holland has been a pilot customers since early 2013. By May 2016 the sensors will be released for general sales, and during the spring of 2016 additional pilot customers are invited.

The sensors basics

The basic measurement methods utilized by the I3 sensor is to measure voltage capacitively and current using small semiconductor sensors inside the sensor box. Details about the measurement principles, can be found in the articles 'The impossible 3-phase measurement', and 'Medium voltage measurements'.

The absolute accuracy for current and voltage measurements, with no on-site calibration, is typically better than 3% for currents, and 1-10% for the voltage measurement, depending on the physical configuration. With calibration, measurements better than 1% can be achieved.

Normally there is no reason to perform on-site calibration, meaning that installation is a matter of minutes. Strap the sensor to the cable to be measured. Attach the voltage inputs. Attach grounding and the Ethernet cable and the device is up and running.

Power to the device is supplied by Power over Ethernet (PoE) from the Ethernet switch used, or alternatively a 12-48VDC supply can be used on the same Ethernet wire.

Measurement output

Based on the current and voltage measurements, all other parameters are calculated inside the sensor, like:

- Active Power
- Reactive Power
- Apparent Power
- Power direction
- Phase specific directional short circuit alarm
- Phase specific directional earth fault alarm
- Phase specific frequency analysis of voltage
- Phase specific frequency analysis of current

All such measures are communicated via the Ethernet interface.

The Ethernet interface

The connection to the sensor for both power and communication is the Ethernet connector.

The web interface

All web browsers in general use are supported, e.g. Chrome, IE, Firefox and Safari, by the web interface providing a simple overview of the configuration and measurement status of an I3 sensor.

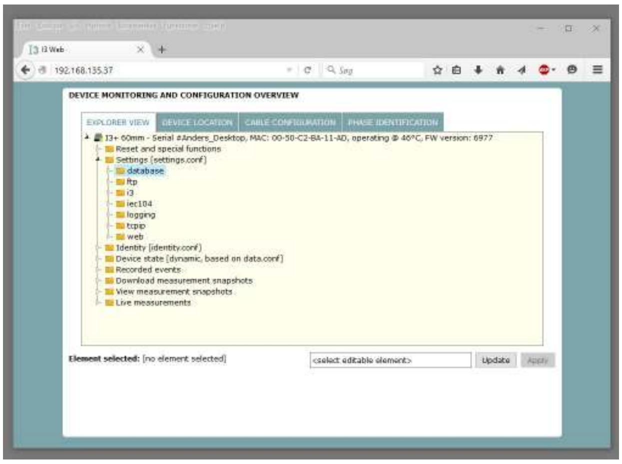

Illustration 3: Web interface of a sensor

The web interface can be used to modify the settings of the devices and it can be used to see events recorded as well as live measurements.

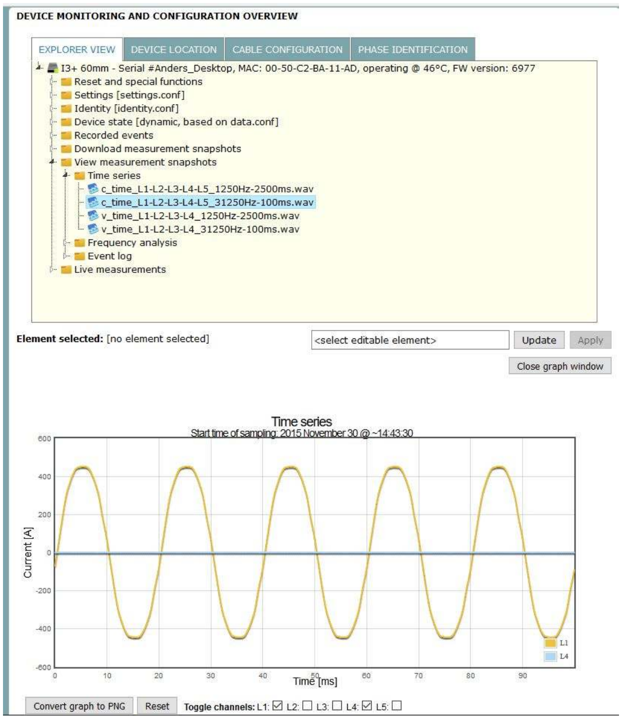

Illustration 4: Snapshot of a current

Architecture of the interfaces
The web browser is limited in that it enables configuration of only the single device, whereas mass configuration, or reconfiguration, is not efficient using a web browser.

For mass configuration purposes, extraction of detailed log data (wave files), as well as software updates, a file transfer system is provided. Initially using FTP, later to be expanded with a secure file transfer protocol option. All sensor settings can be edited via simple Lua configuration scripts, allowing sensor specific settings to be kept or overwritten depending on the needs.

Lua scripts also control the program flow and configuration for other protocol interfaces e.g. the IEC 61870-104 protocol, which is the default for SCADA interfacing.

In general you can change most of the behavior of the device without the need of software upgrades. Changes in the configuration files are sufficient.

Split responsibility of installations and use
The personnel that installs the sensor just have to strap the sensor to the cable, attach the connectors and maybe change the IP address of the device to fit into the substation network (if DHCP is not used).

Now that the sensor is up and running and attached via a secure connection, the IT department may take over the remaining configuration responsibility and transfer any device specific setting if any changes to the factory default is wanted. This could e.g. be in the form of coordinate and address information, and a description of which cable the sensor is installed on.

When the setup is completed, it can be included as part of the normal supervision of the network. It could be either directly integrated into the existing SCADA system or - at least initially - it could be for specialized analysis of the grid conditions and for network planning.

The future
Based on I3 sensor data the utility will gain a grid health management system that runs in parallel with, or as part of, the SCADA system and presents actionable information on the grid conditions for both reactive and proactive maintenance.