CHALLENGES IN SMART DISTRIBUTION GRIDS

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ABSTRACT

In this paper we show that by down-scaling the fully-blown Substation Control and Protection system as is currently used at transmission level to the limited number of interface signals and especially to the low price level of the distribution area in the grid, without sacrificing telecontrol and protection functions, a medium voltage distribution grid operated like a transmission grid is plausible. The substantial reduction of customer interruptions / minutes lost and the extended lifetime of the assets should allow for the relative modest investment.

INTRODUCTION

One of the future challenges that grid operators have to overcome in their network is the upcoming penetration of a changing mix of distributed energy resources of which a substantial part will be intermitting. Further to this, they challenge an increasing demand for a reliable distribution network, with a decrease of planned or unplanned outages, customer minutes lost and interruptions as well as improvement in power quality and life extension of network assets. In order to solve such challenges the network operators have to gain in depth knowledge of their networks and deploy preventive and recovery-measures for managing the outages.

NETWORK INFORMATION

Gaining in-depth knowledge of the distribution network requires information collection, communication and control throughout the system, from generation to transmission and distribution to end-users. For transmission level these requirements already exist. Unfortunately this is not the case for distribution level and forms a challenge as such.

In order to deploy outage prevention and recovery measures at the distribution level, advanced communication with fast reaction times is required as well as the anticipation of customer demand and network capacity limitations.

Voltage instability, resulting from hidden load caused by the introduction of electric vehicles, heat pumps and decentralized generation, requires dynamic voltage control. These control algorithms operate by performing energy measurements with predictive load flow analysis and transformer tap change control in real-time. The energy matching function typically requires data communication latencies in the order of milliseconds.

The use of intelligent meters, which communicate over narrowband Power Line Carrier (PLC) or wireless, may assist in gathering the data required for energy matching or load shedding but metering data cannot always be used by the network operator due to legal restrictions.

Requirements on power quality are rapidly increasing. The optimal location to measure and influence power quality lies as close to the customer as possible. Unfortunately there are no measurements taken and no communication to these locations. Again intelligent meters can fulfil this requirement to some extend but country specific legal restriction might limit the use of intelligent meter data for network management applications. Hence attempts for power quality regulation at distribution level will require voltage control devices, possible local storage devices of which the investments should not be under estimated.

Health-prediction and the estimation of remaining lifetime of the primary assets, which is essential for asset investment optimization also requires continuous monitoring of asset states.

In case it was not possible to prevent an outage, deployment of automatic power restoration is inevitable. These measures aim at the reduction of customer minutes lost and possibly the number of customer interruptions. The challenge involved is the realization of automated fault localization and fault isolation using telecontrol where the aim is to reduce the number of customers involved in the outage to a bare minimum.

COST DILEMMA

The dilemma one faces while placing measurement, control and protection equipment in MV/LV substations (ring main unit, RMU) is the cost of the equipment and installation, with the additional drawback of a possible outage to mount safely. A secondary challenge is the deployment of affordable communication to assets that have a very long life.

COMMUNICATION

To complicate the situation even more, management systems that can cope with the control of the large amount of data coming from all potential substations have not shown a great scale of flexibility and easy adaptability. This implies that without a conceptual change, functions such as energy matching, load shedding and wide area protection are not realizable in real-time.

The available public-communication networks do not meet the latency requirement and have often no redundancy. New emerging technologies such as power line carrier over medium voltage networks may be suitable but are currently not used widely and the time latency will remain a problem during disturbance and short circuit situations.

In densely populated countries and big cities fibre optic cabling to all substations can solve the communication challenge. In the Netherlands there is a strong drive to realize this in due course. Fibre optic backbones for all kind of services are in diverse planning stages. Telecom service providers of specialized facility companies offer 'black' fibre connections for exclusive usages to the applicant. Bandwidth and time latencies are becoming a non-issue.

SMART WAY OF THINKING

In order to solve the future challenges we have to migrate from a centralized way of thinking to a decentralized way and implement distributed control, protection and management solutions that continue to function even when parts of the grid become electrically islanded. The ultimate goal is to prevent outages or islanding of parts of the grid by extreme fast short circuit detection and switching, but 100% reliability does not exist. Smooth degradation in case of any failure with proven backup functions, as last level of defence, is the starting point of the visionary breakthrough we envision to develop.

The cost/benefit evaluations to install intelligence in all RMUs depend on many issues. The Distribution System Operator (DSO) can only influence a few of them. In the future, the value of non-availability of the electrical supply system might be valued completely different than nowadays. The dependability of electrical energy will increase for sure with the energy transition in mind. To increase the availability and reliability of the network at acceptable cost different solutions are required. The academic world is studying on new concepts that can bring us further in managing the supply system in a stable and automated manner. To implement the new control models in distribution systems we have to cater for low cost open computer systems that measures all process values and is able to control primary plant where applicable. The control and protection schemes will change over time depending on the social perception of the behaviour of the electrical supply system, i.e. the software executing the automation schemes requires easy modification and open system architecture. Remote change management is essential as well as profound cyber security measures to guarantee the highest level of system reliability. All of this within a low cost implementation framework is a challenge that can be overcome by going for mass production products. Mass production products automatically introduce the problem of their often short economic life. We have to merge the long life requirement and the low cost advantages of mass production products into applicable solutions for substation automation. The modularity of the product and the inter-module compatibility is key to the future success. Separation of the items with different lifetime is one of the key elements. The interface with the process is meant to have a very long life ($\geq$ 25y), while the processing and communication equipment and its (sub) components are obtained from mass production product assemblies.

The unique idea behind the SASensor concept is the separation between physical devices (hardware) and functionality (software) on the one hand and fast ageing components (computers) and the long unalterable interface with the primary process (process interface modules) on the other hand.

This double separation within the system architecture makes it possible to adapt installations to the ever-increasing demands of the grid, simply through software upgrades and/or computer performance improvements. Therefore, the value of the present investment is guaranteed for decades.

PROPOSED SYSTEM ARCHITECTURE

Within this concept a three-layer segmentation is recognized:

1. Process signal converters
2. Digitization of the converted process signals and commands
3. Computer(s), external and internal communication facilities

The hardware architecture is based on the following building blocks:

1. Converters
2. Interface Modules
3. Communication and Control Units

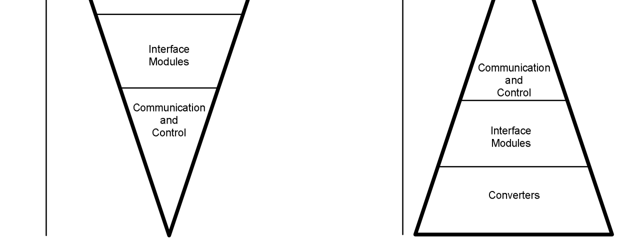

Figure 1: Hardware module segmentation

By design, the system is optimized and tuned to the low price level of the distribution area in the grid (see figure 1). In order to achieve this and down-scale the fully-blown substation control and protection system as is currently used at transmission level a number of issues must be considered:

- System Modularity
- Building Blocks
- Limited Number of Signals
- Hardware Cost Reduction
- Hardware / Software Co-Design and Partitioning

Amongst these, we must consider issues in the design and modularity of the building block:

- Mounting Principles (Top-hat rail, if possible)
- Communication Connectors (RJ45, ST fibre)
- Module-to-Module Communication
- Long Life Umbilical Cables to Terminals
- Housing in Compatible Size Patterns
- Power Supply Principles (Mains, Battery)
- Isolation and Safety Requirements

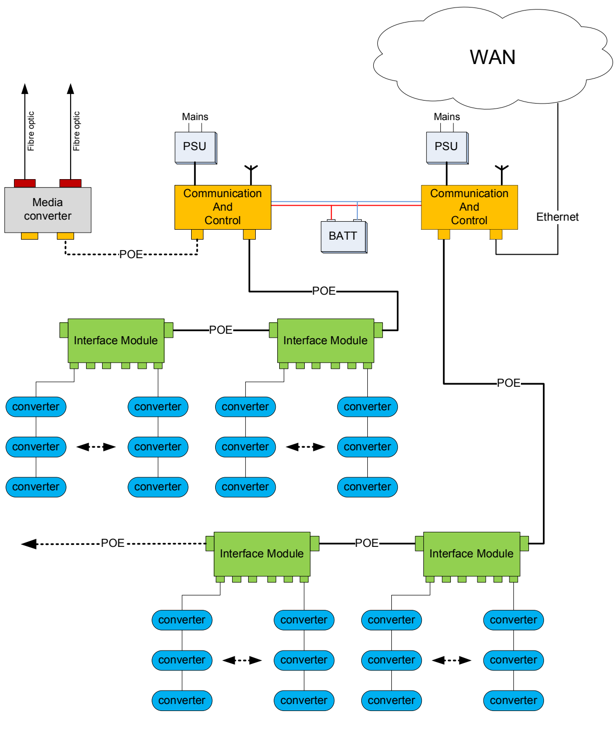

Figure 2: Proposed Architecture

Power over Ethernet

Using Power over Ethernet (PoE) as a communication medium and at the same time the power source for the Interface Modules and Control Units, the costs of additional power supply units to power individual modules is reduced.

Converters

At present the system recognizes voltage and current converters in a variety of modules as well as temperature, light and humidity converters for the measurement of environmental conditions. Each converter is suited for a specific measurement environment and the issues relating to that environment. For example, it is not always possible to insert current converters on all existing cables without creating an outage. Hence current clamp converters could be a solution to such a situation. Flexible Rogoswki coil converters on the other hand could easily be applied in dense cable environments where it is not possible to fit a clamp converter and they are also much more suited for high current measurements. Also measurement at medium voltage cables has different challenges than measurement at low voltage cables due to the implied safety issues. Knowing this it would be wise to place the domain specific solutions at dedicated converters and allow the conversion process to take place at generic modules. The price of the converter in this design is proportional to the complexity of the domain specific solution.

Interface Modules

Interface Modules have less domain specific requirements. Their function is to digitize the Converter's analogue signals, time-tag those digitized signals and communicate their values to the Control Units for processing. Time-tagging of the digitized signals allows for time-coherency between distributed Converters and/or Interface Modules.

The analogue signal interface between the interface-modules and the converter units is standard STP with RJ45 connectors. This ensures a generic interface with a long lifetime and low cost price.

Interface Modules can be chained through 1Gbit Power over Ethernet (PoE) communication links. This allows for system scalability and redundancy without the need of additional switches.

Communication and Control Units

The communication and control units process the digitized signals and implement the required system applications. The following items summarize their functions:

- Power Sourcing to Interface Modules
- External Communication
- Processing of Digitized Samples and Realization of Grid Software Applications
- Power and Battery Management

The communication and control units are by design scalable and they are responsible for power management and communication even during outages.

Communication Converters and Switches

Communication converters allow PoE signals to be converted to fibre optic and visa versa. This is especially important if it is not allowed to connect copper wires to the measurement areas due to safety and EMC reasons.

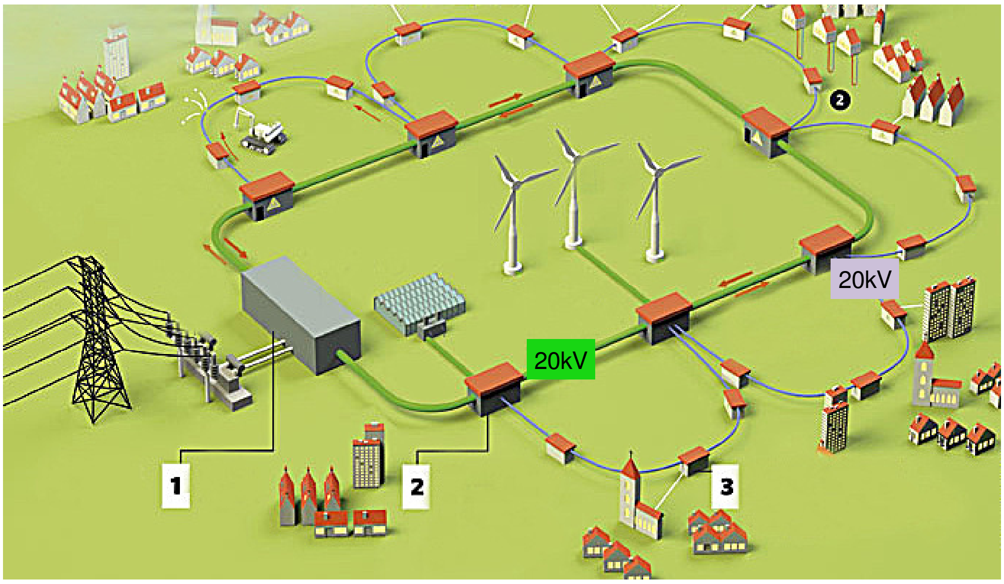

Figure 3: Intelligent network capacity upgrade

Ensuring correct functionality of the converters and modules in harsh environments is a separate design challenge that is solved by intelligent isolation and earthing schemes.

APPLICATIONS

The power transmission capacity of the parts of the distribution grid will require upgrading in future to cater to the load and generation demands of electric vehicles, heat pumps, distributed energy resources, etc. Introducing higher capacity backbone ring structures of 20kV (green as depicted in Figure 3) on top of the existing 10kV ring network will shorten the existing 10kV loops and therefore the capacity of the shorter loops. At the intersecting points of the 20kV and 10kV network new intelligent substations (2) are required. The 20kV ring is continuously operated in 'ring-mode' with 2 sided in-feeds from the main primary substation (1). The introduction of this intelligent network concept requires a new control and protection scheme throughout the ring and primary substation. In the future intelligence can be placed in the RMUs (3) in the shorted 10kV rings as well.

Fault clearing without outage

It would be nice to clear a fault in such a fast manner that effectively no customer interruption occurs and all decentralized generation remains online. In the Netherlands this means that due to regulations a fault should be cleared ≤ 150ms, otherwise, the DG will be disconnected from the grid. The realization of such an automation and protection scheme will require a serious investment. Besides the wide area protection scheme it requires circuit breakers in all RMU's and reliable communication throughout a distribution ring. Unfortunately the costs are easier to predict than the benefits. In the previously described 20kV rings a new concept of control and protection will be tested in the following years in a Dutch pilot network of Alliander.

Fault clearing with outage

If an outage occurred in a MV-ring automatic restoration, or so-called 'self healing', is a promising technology to minimise customer minutes lost. Switching possibilities and intelligence in the RMUs is a prerequisite, but in this situation not all RMUs require full-blown circuit breakers. Since there is an outage it is sufficient to apply load switches. This helps to achieve a positive business case.

CONCLUSIONS

Development of domain specific hardware for RMUs enables the application of transmission level functionality, and more, in the low cost environment of distribution grids. Open system architecture secures that future functional requirements can be added at limited costs. Segmentation in the hardware architecture ensures that lifetime issues are manageable in a practical manner without sacrificing easy installation and simplicity.

REFERENCES

[1] I. Xyngi, M. Popov, 2010, "IEC61850 overview – where protection meets communication", *DPSP conference Manchester 2010*

[2] F. Baldinger, T. Jansen, M. van Riet, F. Volberda, 2010, "Nobody knows the future of Smart Grids, therefore separate the essentials in the secondary system", *DPSP Conference Manchester 2010*

[3] I. Xyngi, M. Popov, 2009, "Power Distribution Protection Scheme Enhanced with Communication", *IEEE PES/IAS Conference on Sustainable Alternative Energy, 2009, Valencia, Spain*.

[4] F. Baldinger, T. Jansen, M van Riet, F. Volberda, F. van Erp, M. Dorgelo, W.M. van Buijtenen, 2008, " Advanced secondary technology to evoke the power of simplicity", *DPSP Conference Glasgow 2008*.

[5] S. van Loon, F.Volberda, F.Baldinger, M. van Riet, 2009, "Challenge of managing organizational changes, necessary for new substation automation systems", *CIRED Prague 2009*.