REAL-TIME RESEARCH LAB IN THE SUNDOM SMART GRID PILOT

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ABSTRACT

The Sundom smart grid pilot offers a unique opportunity for evaluating new kinds of smart grid technologies. In this paper, we present how we set up a research lab to determine how protection and analysis can be executed remotely. First field tests show that remote data analysis is feasible and that remote protection requires additional research.

INTRODUCTION

In future smart grids there will be a large amount of measured data from IEDs (Intelligent Electronic Devices) and other devices which need to be communicated securely and rapidly between different devices and systems. In this paper, we present a research and demonstration environment for such future smart grids based on the Sundom smart grid pilot.

Sundom, Finland hosts the first smart grid pilot within the Innovative Cities program, which is co-funded by TEKES, the Finnish funding agency for innovation. Behind the Sundom smart grid pilot are the following partners: ABB, the electric utility company Vaasan Sähkö, the communication company Anvia, and the University of Vaasa. The aim of the Sundom smart grid pilot is to enhance the reliability of electricity supply, as well as to establish the preconditions for wind and solar power usage in the homes in the region.

To answer the upcoming new regulation requirements in a cost-efficient and future-proof way, there is a need for new technologies as well as research environments for prototypes and demonstrators. For this reason, we set up a real-time research lab connected to the Sundom pilot to evaluate and demonstrate new technologies for the smart grids. This raised the following challenges:

- How to communicate live measurement data in a fast, secure and reliable way from the substation relays to the research lab?
- How to ensure a predictable and deterministic real-time behavior of the applications executed in the research lab?

In this paper, we describe how we addressed these challenges in the Sundom smart grid pilot. We then present preliminary results from field tests during which we evaluated the communication of measurements from the smart grid to our research lab.

SUNDOM SMARTGRID PILOT

The goal of the Sundom smart grid pilot is to enhance distribution reliability and efficiency and to enable sustainable energy solutions such as wind and solar power. The Sundom smart grid is composed of one main HV/MV substation and four secondary MV/LV substations. It contains two distributed generation units: a wind turbine of 3.6 MW and photovoltaic panels of 33 kW. A single line diagram of the Sundom smart grid is shown in Figure 1.

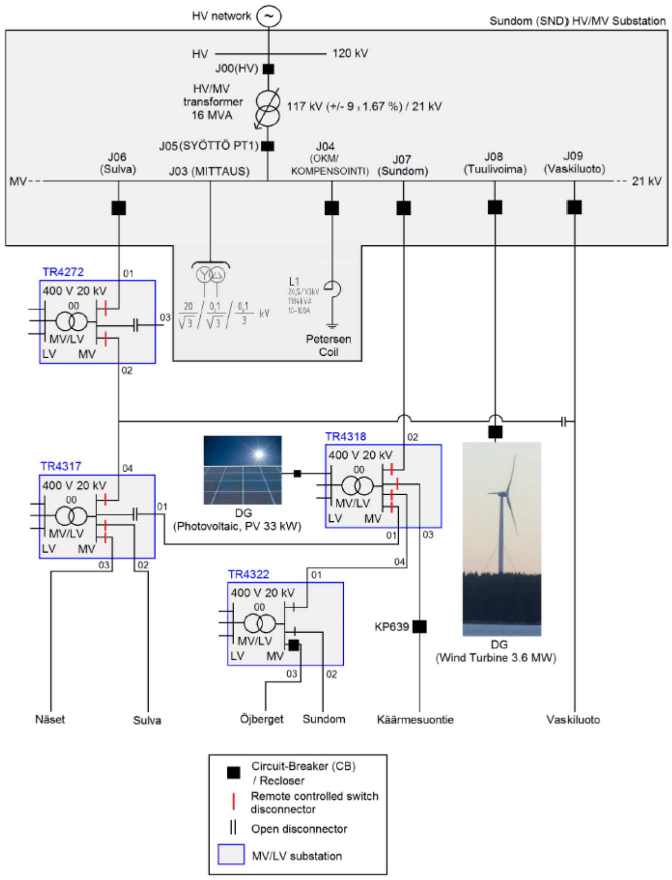

Figure 1: Sundom Smart Grid Single Line Diagram

ABB installed state-of-the-art technology for automating the network fault management of the power grid that serves the Sundom village. The driving factor for installing the technology is the upcoming amendments to Finland's Electricity Market Act. New regulations will be phased in by the year 2028. The need for a more reliable and smarter grid to meet consumer demand has led utilities to reinvest in distribution grids.

One of the most important features of the network automation technology is the intermittent earth fault detection management system, which is critical when the share of cable networks in the grid increases. This system sends its data in real time through the optical fiber network, which is located in the area surrounding the Sundom village. The data is collected at the service center of Anvia, where it will be made available to all parties involved in the project.

COMMUNICATION ARCHITECTURE

On top of the IEDs required to protect and operate the Sundom smart grids, additional IEDs have been installed in the substations in order to capture the measurements of current and voltage values and transfer them to a data center using the IEC 61850 9-2 protocol.

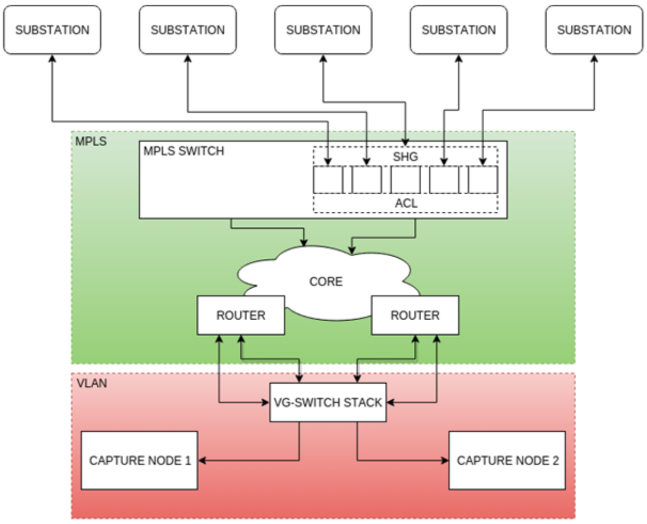

Figure 2: Communication Architecture

Figure 2 describes how the communication between substations and servers at the datacenter was implemented using MPLS (MultiProtocol Label Switching) and VLAN (Virtual LAN) switching technologies. Each substation is connected to a dedicated port in the MPLS switch isolating the communication between substations with SHG (Split Horizon Groups). All substation traffic is isolated into a single VLAN. The data is then transferred over the MPLS network into a virtual switch between datacenters. The switches are connected to storage servers in which the data is aggregated.

Incoming traffic into the substations is filtered using ACLs (Access Control Lists). These ACLs can be controlled from the servers at the datacenter. Some substations are also isolated with media converters allowing only unidirectional data flow.

Future improvements to the network architecture include redundant connection between the substations and the MPLS network.

REAL-TIME RESEARCH LAB

In this section we present the software architecture of our real-time research lab. The first subsection describes how the measurement data is captured and stored in the ANVIA Data Center. The second part describes the environment in which we run the control and protection algorithms that we want to evaluate using the live measurement data from the smart grid.

Capture and Storage of Measurement Data

A redundant capture and storage system was implemented for this research lab so that the grid activity could be analyzed asynchronously. The system records all Layer 2 traffic from the grid's network, compresses the data, and stores it on replicated block storage. The main requirement for the system is to capture all Ethernet traffic without filtering of modifying the data in any way.

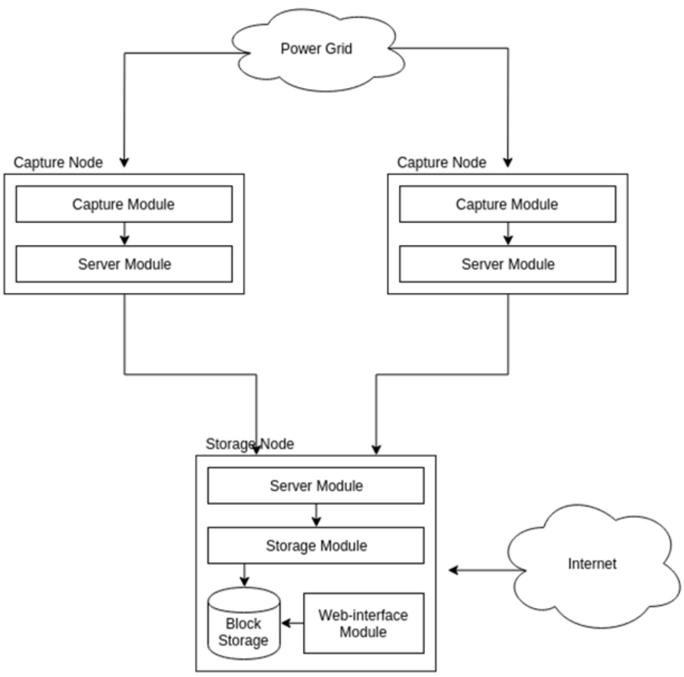

Figure 3: Measurement capture and storage system

Figure 3 describes the architecture of our measurement capture and storage system. The system consists of three physical server nodes and four software modules. The Ethernet streams are captured using two physical servers running the capture module in Docker containers. The captured streams are identical on both nodes to provide redundancy. The data is then transferred over a TCP/IP connection to the storage server, which removes duplicates from the two streams, stores the data on disk in PCAP format, and compresses it. The data can be retrieved from the storage though a REST API or web-interface, which provides functionality to filter packets by time and by MAC address. Filtered packets can also be converted into the Comtrade format.

Future improvements for the system would be dividing the data stream at the capture nodes by source IEDs so that the load could be distributed better on the storage side. The storage architecture could also be improved by implementing a redundant multi-node storage system to provide better I/O and redundancy.

Runtime Architecture

Smart grid applications are run using the Future Automation Software Architecture (FASA) [1] middleware developed at ABB Corporate Research. The FASA framework guarantees a predictable, deterministic and real-time execution of the tested applications.

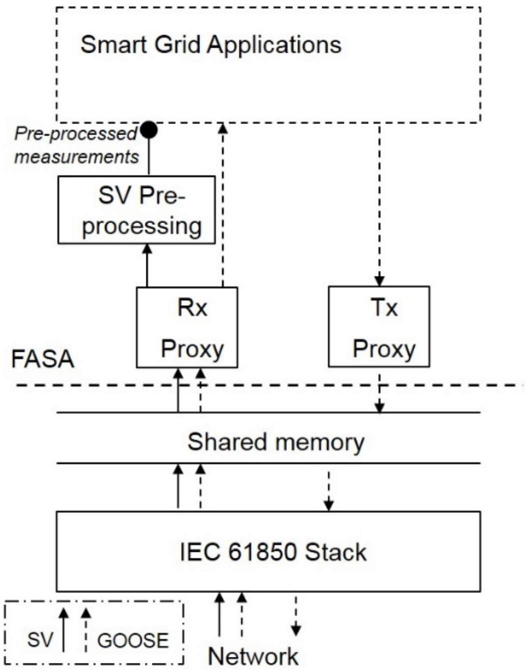

Figure 4: Data flow of the 61850 traffic

Figure 4 describes our setup. Protection and control applications for the smart grid are run using FASA while the IEC 61850 communication stack runs on a different dedicated core as described in [4]. SV and GOOSE frames are captured and decoded by the stack, which stores them in ring buffer structures in shared memory. On the FASA side, Reception (Rx) and Transmission (Tx) blocks access the shared memory to read the incoming Sample Value (SV) and GOOSE traffic and write outgoing GOOSE traffic. As part of the Sundom set-up, we integrated a preprocessing library, which performs common operations required for substation automation on the current and voltage values e.g., Fourier transform, RMS, or peak-to-peak.

The first applications being ported are earth fault protection applications. The goal is to evaluate the latencies and reliability for remote protection applications. In the future, we plan to prototype active network management applications for the smart grids using this real-time research lab. Also, we plan to evaluate in a live smart grid the advanced features of FASA, in particular fault tolerance [2] and dynamic software updates [3].

FIELD TESTS

The functionality of the research laboratory infrastructure was evaluated during field tests on 1.-3.12.2015. A series of 58 different kinds of earth fault and short circuit tests were created with a specific fault trailer. The duration of the faults was selected to be shorter than the operate time of the protection algorithms so no interruptions for end customers were caused during the tests. The primary interest during the tests was to evaluate the performance and accuracy of new protection algorithms, but also at the same time the performance of the communication infrastructure was evaluated.

The IEC 61850 standard provides requirements to the communication link reliability, which especially in the context of IEC61850-9-2 process bus are very strict. In IEC 61850-9-2 LE, which is supported by the ABB IED REF615, 4000 Ethernet frames are sent from each IED (one frame per sample measurement). If two consecutive frames are lost, the stream is considered invalid for protection purposes. Individual missing frames are still accepted and compensated by the protection system.

Results

Figure 5 shows the results from the data gathered during field tests from the primary substation.

The longest period of missing frames in a sequence was 33 samples, corresponding to a gap of 8.3 ms. On average 0.11 % of the frames were lost. The communication from the secondary substations was not as reliable as from the primary substation. From secondary substations on average 0.73 % of the packets were lost, and the longest sequence was 189 packages lost in a sequence, corresponding to a gap of 47 ms without communication.

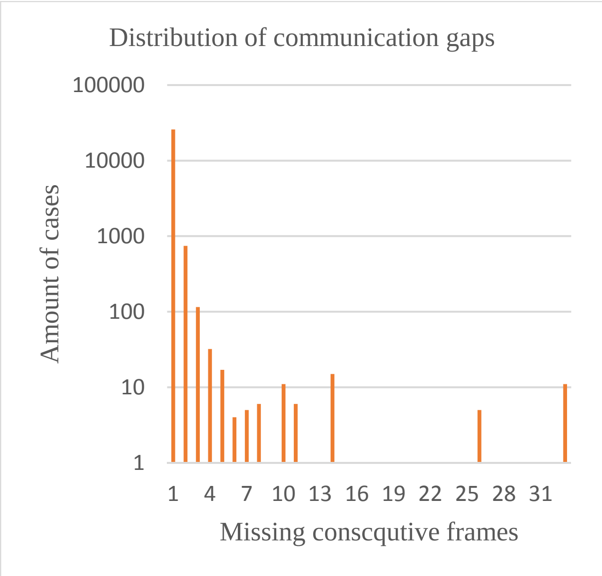

Figure 5: Distribution of communication gaps during field tests

These results indicate that the link was good enough for a real-time research lab and for providing data for further research. But the link reliability was not good enough for (remote) protection purposes because frequent communication outages lasting several milliseconds would not be acceptable for protection applications. After the field tests the communication solution has been improved and latest tests show a decrease in packet loss, further field tests are still needed for confirming this.

CONCLUSIONS

The Sundom smart grid pilot is a unique opportunity to use live measurement data to prototype novel protection and control application for smart grids. We have conducted a first set of experimentation to validate the reliability of the communication link. The measurements have shown that the reliability of the communication architecture was not good enough yet for remote protection applications, but it is however reliable enough for a real-time research lab purposes.

As future work, we plan to work on improving the reliability of the communication link to make remote protection applications possible. We also plan to use this real-time research lab to experiment with active network management solutions such as islanding detection.

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