USING SMART GRID SURVEILLANCE^{TM} TO DETECT AND LOCALIZE FAILURES IN THE OVERHEAD MEDIUM VOLTAGE GRID

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ABSTRACT

The paper describes how Exeri AB has applied the classic OODA loop to Smart Grids, making it possible to not only know the status of the grid at all times but also to get decision support in when, where and how to respond to problems. The product Smart Grids Surveillance^{TM} has been deployed by Skellefteå Kraft AB, where it is currently monitoring a grid that has earlier been prone to problems.

INTRODUCTION

The term "Smart Grid" or "Intelligent Grid" has been around for many years. The progress to achieve a Smart Grid is however slow, and one reason is that it seems hard to reach a common definition of the term itself.

To Exeri AB, with a background in military systems, sensor networks and telecom management, a Smart Grid must be a power grid with the capability to autonomously monitor, decide and act upon different kinds of changes, internal or external. To complete the definition, it should even be able to optimize the grid itself. The final goal of introducing a Smart Grid is thus to go from a completely manual approach to monitor and control of the grid, to simply supervising an automated process.

THE OODA LOOP

The Grid management process can be compared to the classic OODA loop, first described by John Boyd (see reference [1]) in 1976 and since then applied to a number of disciplines like commercial operations and learning processes.

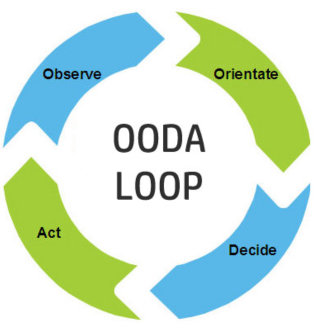

Figure 1: Illustration of the OODA loop

The loop consists of four phases, Observe-Orient-Decide-Act. Today, all these phases are done more or less manually. Observation is partly done by sensors and SCADA systems, but the information given by these is far from complete enough to form a possibility to actually Orient the user to what is happening in the grid – you might say it gives clues but no conclusions. Orientation is thus a completely manual task, as is Decision and Acting on problems/resolutions.

By making the steps of the OODA loop automated, the loop itself becomes much faster, saving a huge amount of time (and thus money) for the grid operators.

AUTOMATION OF THE LOOP

To take the first steps towards automation, Exeri AB attempts to technically implement the OODA loop steps Observe, Orient and Decide, to reach what may be called a Decision Support System.

To start with ***Observation***, it has been found that it is impossible to observe the whole power grid through a few specific points, like single sensors placed at a couple of positions or by using feeding measurements. A description of some of the problems and limitations may be found in reference [2].

One of the most monitored networks today is the Telecom network, where each and every component has a level of intelligence in itself. This is of course an impossible feat in a power grid. To really add monitoring capability for the complete grid, we need an intelligent distributed sensor network, that covers the grid in a way that makes it possible to actually know what is happening there. To summarize, it is not enough to know what happens in a single point, but to be able to draw conclusions it must be known what happens in the grid itself, as it consists of many parts that are completely dependent of each other.

The main challenge is to find and localize erroneous events in a complex and branched grid. Fault currents will vary heavily depending on fault type, on where in the grid the fault occurs, on the grid topology and on currently connected load. Knowing the direction of a fault current using single sensors are thus not enough, instead information from a number of points is needed to be able to draw the correct conclusions.

There are several challenges to get information enough.

- The number of sensors needed to monitor the grid, as sensors simply cannot be put everywhere.
- Exactly where to put them to make sure that it its possible to draw conclusions, and optimize detection/positioning capability
- The level of inbuilt intelligence in the sensors

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That such intelligent sensors can be placed and provisioned with a reliable way to accurately detect and classify faults that occur was verified in field tests together with Skellefteå Kraft AB during the fall of 2017.

To be able to utilize the information from the intelligent agents it needs to be distributed. The communication has to be completely stable and redundant, available at all times and working in all conditions. It also has to be secure, not only encrypted but also integrity secured so no one can tamper with the information. Unfortunately, many power grids, especially in rural areas, go through areas where current communication infrastructure is non-reliable or even non-existant.

To go forward to the ***Orientation*** phase, the system must reach an understanding of what and where things are happening, e.g. where faults occur.
This means that the system must be self-aware of its topology including branches, feeds and all kinds of included network elements. The major challenge here is to use this information in combination with the information from the distributed intelligent sensors. As the grids behaviour will vary depending on connected loads, alternative feeds and maintenance work, the system has to be self-learning and adaptable to compensate for normal variations. By doing this correctly, faults can be localized and even classified. Intermittent faults may also be detected and pinpointed, even if they are temporarily cleared by an automatic reset.

To increase automation in the ***Decide*** Phase, the information gathered and the conclusions made needs to be presented as Decision Support for the grid operator. Here, knowing how the dependencies within the grid topology affect the whole of its operation is imperative. By knowing this, not only the position of a fault may be presented directly on a real-time Situation Picture, but also how to quickest isolate the fault may be pointed out.

For the moment, Exeri AB has not made any efforts to implement the ***Act*** phase. In the future, the possibilities are however enormous. Automatic remote control of breakers and redirection of feeds in the grid are quite plausible, even if this of course has challenges of its own.

CURRENT IMPLEMENTATION – SMART GRID SURVEILLANCE™

Today, Exeri AB has implemented the system Smart Grid Surveillance™, or SGS. The system is currently constructed for Medium Voltage Overhead lines, as they are prone to faults and often present in areas where established communications is scarce or unreliable. The system is designed to detect and position the following faults:

- Short Circuits (Phase-2-phase and Phase-2-ground)
- Missing Phase
- Whether a line is out of its normal position on top of a pole
- Leaning or broken pole
- Broken or contaminated insulator
- Current leaking through pole

SGS contains two kinds of intelligent Line Agents that are mounted directly on the poles in the grid, about 1,5 meter below the wires. These measure the fields and their variations, and use AI algorithms to separate normal and abnormal behaviour. To make sure that the line agents are not destroyed by lightning or grid faults, they are galvanically separated from the lines themselves, and run on batteries for 10 years. All the line agents are completely self-calibrating, meaning that they need no specific settings or configuration to be able to do their job. The software can be upgraded remotely, meaning that after mounting the line agents, they will operate without any maintenance.

The two kinds of line agents are QiC (Quick Coverage) which are placed at crosspoints, endpoints and by net elements like net stations and breakers, and ToCo (Total Control), which are placed in every single pole and thus not only gives a much higher resolution in positioning, but also can find more types of faults. The two kinds of agents may be mixed freely in the grid to fulfil the coverage and resolution wanted depending on topology, vegetation and closeness to roads.

Figure 2: QiC mounted on pole

Further, the SGS system includes communication relay points, or ExComs as they are called. They communicate by radio with the line agents, and are placed in key points to reach as many of the agents as possible, creating a meshed network with in-built redundancy. This means that if an ExCom is out of order for some reason, the others will automatically take over its duties. The ExCom is connected to the distribution side of the grid for power supply, but also has batteries to be able to convey alarms containing the cause of the problem when the power has been automatically shut off.

Figure 3: ExCom mounted on pole

The final part of SGS is the ICCU, the Information Collection and Conclusion Unit. It exchanges information with the ExComs (and thus with the line agents), analyses this together with its knowledge of the grid topology and its internal dependencies, using AI algorithms. This results in finalized alarms that are presented to the user in a Situation Picture, a map of the area where problems are presented in real-time at their localized position. With this knowledge, it is also easy to add presentation of lines that are unnecessarily affected by the problem and where power may be restored by isolating the fault, and how this isolation is done most efficiently.

PROJECT WITH SKELLEFTEÅ KRAFT AB

Skellefteå Kraft AB was highly interested in SGS already at an early stage. They helped Exeri AB in doing field tests by giving the company access to a live part of their grid during the fall 2017, inflicting a number of common fault types into the grid. During these tests, all the SGS error detection functionalities were verified. Since then, Skellefteå Kraft AB have bought a full-scale system for a part of their grid, which has been delivered and deployed during the fall of 2018.
The system has been installed in heavily forested and hilly country without existing communication. It contains 140 line agents and 4 ExComs.

The goal for this project was

- to be able to present a Situation Picture of the grid, with real time update of the status
- to detect, classify and localize any faults that occur in the grid
- to generate alarms based on these detections and make them available in the Control Room and by mobile device to the repair crew
- to identify and present the closest breaker to the detected fault to quickly isolate the problem

Figure 4: Presentation of current grid status in Situation Picture, line agents visible. The map shows an area about 30 km square.

RESULTS SO FAR

The network of line agents installed are running smoothly, all agents are connected and reporting their status. The communication network is also functioning well, after a few reconfigurations concerning reallocation of time slots and adaptions to changing modulation. The conveying and presentation of alarms have also been verified.

It has been verified that the loss of a single (or even multiple) Line Agent will not affect the performance of the system as a whole. The AI will automatically adapt to the lost points, even if the resolution in fault localization decreases accordingly. Neither will a lost ExCom communication device affect the system in any way.

So far, it has been verified that the system can pinpoint the exact parts of the grid that are out of power, making it possible to e.g. know when a planned work along the line has actually started.

A few weeks ago, there was a short circuit fault in the monitored grid. Due to an attempt to minimize energy consumption in our line agents, the internal parameters had been adjusted a bit too low to be able to signal the fault detection at that specific time. Since then, the parameters have been adjusted to a higher level (still energy efficient enough to make the batteries last), and using information that was collected by the line agents at the time of the short circuit, it has been concluded that the system would have been able to both detect and localize this fault at the time if better parameter settings had been used.

Information is still being collected to completely finalize the algorithms for detection/precise positioning of these faults, as well as Missing Phase. Hopefully the coming winter and spring will give SGS opportunity to locate and position a number of faults, making it possible to verify that the complete system works as anticipated. We hope to complete this report with further results at a later date.

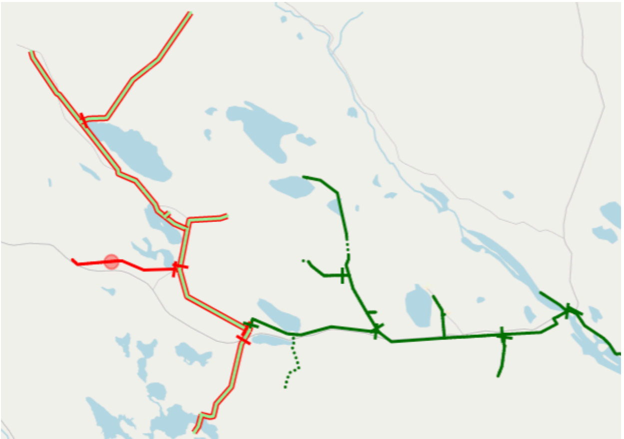

Figure 5: A fault has occurred. The solid red line indicates a line without power. The red line surrounded by green indicates a line where power can be restored by isolating the fault. The red dot is the fault position.

FUTURE DEVELOPMENT

Using the SGS as a platform it is possible to implement even more complex detection and positioning using input from the line agents. The system with its in-built AI create possibilities to do multivariate analysis and make advanced conclusions. One of the future possibilities is for example detection and positioning of overloaded or snow-burdened grid lines.

The AI may also with time collect information enough from the grid to be able to suggest proactive maintenance in specific areas (or even specific poles) to be able to avoid future problems.

The technology itself may be adapted to other grid types than overhead medium voltage. There are possibilities both in high voltage grids and for underground cables.

SUMMARY

Exeri AB has applied its extensive experience from sensor networks, military systems and telecom management onto a completely new way to monitor and supervise the power grid.
Starting with medium voltage overhead lines, the system Smart Grid Surveillance^{TM} uses intelligent Line Agents that create a meshed communication network together with specific communication devices. Information gathered is analyzed by advanced self-learning AI algorithms and presented to the user in a Situation Picture, making it easy to see and understand the status of the grid at a single glance.

The system is currently being verified in a part of Skellefteå Kraft ABs grid, where we are optimizing the algorithms to make sure the fault detection/positioning works as intended.

REFERENCES

[1] Boyd, John R, 1976. Destruction and Creation. U.S. Army Command and General Staff College.
[2] Koreneva, E, 2017. Evaluation of Practical Experience of Fault Indicator Performance in Medium Voltage Networks, Proceedings CIRED Conference, Glasgow, UK.