MONITORING SYSTEMS FOR SECONDARY SUBSTATIONS – A COMPARATIVE STUDY

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ABSTRACT

This paper describes and compares monitoring systems installed in six secondary substations in Stockholm. Ellevio's experience from the planning, commissioning and operating of these systems is described, as well as their functionality. Ellevio has classified monitoring of secondary substations into four functional levels. Two of the tested systems have a high monitoring level and one has a medium monitoring level. These systems have been installed in both new and existing secondary substations. Ellevio's experience is that simple systems are more suitable for retrofit, while more advanced systems are more suitable in new secondary substations. Communication over a public mobile communication network has been used successfully in all cases. Two of the systems include a connection to Ellevio's network operations centre while one system has a connection only to the supplier's own management system. All data is stored in a database for further analysis. The paper concludes with the outlook for future steps.

INTRODUCTION

Ellevio, the second largest distribution system operator (DSO) in Sweden, has installed equipment for the monitoring and communication of six secondary substations, 11/0.4 kV, in the emerging Stockholm Royal Seaport neighbourhood in Stockholm. The first of these installations was described in a paper during CIRED 2015 [1]. The other installations include equipment delivered by two other companies than the first one. So there are three different systems for monitoring of secondary substations and these will be described and compared in this paper. The paper will describe Ellevio's experiences from the planning, commissioning, and operating of these monitoring systems up to and including December 2016.

Stockholm Royal Seaport

Stockholm Royal Seaport is the largest urban development area in Sweden with 12,000 new homes and 35,000 workplaces [2]. One project goal within the project Smart Energy in Stockholm Royal Seaport is to find solutions to improve both the System Average Interruption Duration Index (SAIDI) and the Customer Average Interruption Duration Index (CAIDI) [3].

Another important goal for Ellevio is to measure and collect data from the distribution network to improve operation, maintenance, and network planning.

Main Goals

The main goals of these installations are:

- To evaluate if it is possible to improve the availability and capacity of the network by implementing systems allowing advanced monitoring of secondary substations.
- To evaluate alternative technical solutions for advanced monitoring of secondary substations.
- To evaluate mobile communication as a replacement for the signal cable network in Stockholm.

Another key purpose is to gain experience from new systems of this type in the local network.

PLANNING

Planning of these systems started in 2011 and the idea, right from the beginning, could be described as "to collect all data". The result of this is that as many relevant signals and measurements as possible are collected in the system, although it is unclear how exactly all the data shall be used and their specific value for the customer and Ellevio.

Functional Levels

Ellevio has divided the monitoring of medium voltage/low voltage (MV/LV) substations into different functional levels, see Table 1. The basic level describes the situation today in Stockholm where most equipment is locally operated with only a very basic remote communication. The *only* communication with the secondary substation is a combined sum alarm function with each of the secondary substations. A sum alarm consists of 5-15 unique alarms caused by e.g. high transformer temperature or a tripped circuit breaker. Any of these alarms triggers a sum alarm via signal cables in the ground to the feeding primary substation and from there via the SCADA system to the network operations centre. [1]

Table 1. Functional levels for monitoring.

Basic monitoring level	Low monitoring level	Medium monitoring level	High monitoring level
Operating modes: Circuit-breakers* Switch disconnectors*	Operating modes: Circuit-breakers* Switch disconnectors*	Operating modes: Circuit-breakers* Switch disconnectors*	Operating modes: Circuit-breakers Switch disconnectors
Measurements: LV*	Measurements: LV*	Measurements: LV, temperatures	Measurements: LV, temperatures, MV**, LV-feeders**
Fault indicators: Short circuit and earth faults*	Fault indicators: Short circuit and earth faults	Fault indicators: Short circuit and earth faults	Fault indicators: Short circuit and earth faults
Sum alarm	Alarms and events	Alarms and events	Alarms and events

*Manually read on site in secondary substation
**Optional

The high level monitoring describes a situation where alarms, events, faults, operating modes, and various kinds of measurements are sent to the SCADA system, the distribution management system (DMS), and the file server. The DMS system handles the network supervision and control of Ellevio's LV distribution network, while the SCADA system handles the HV and MV networks.

System Architecture

Monitoring systems from three different suppliers (A, B, and C) are used to monitor the secondary substations. A robust communication solution was created with the commissioning of the system from supplier A (system A). The solution is divided into three parts: SCADA using IEC 60870-5-104 protocol, power quality data using SFTP file transfer, and system administration using remote access [1].

The system architecture of the system from supplier B (system B) differs quite a lot in architecture from systems A and C. The overlaying system is, at this stage, the supplier's own management system. The only connection with Ellevio's system is the unidirectional file transfer of measurement data from system B to the database server.

An example of the system architecture for the system from supplier C (system C) can be seen in Figure 1. There are many similarities between the architecture of systems A and C. Critical process information is continuously polled from SCADA and forwarded to DMS. Extended measurement data is file transferred to a database server and can be used for post-processing.

Monitoring Systems

Ellevio, in consultation with each supplier, has prepared a site-specific requirement specification for each installation. The requirements are based on specific conditions and preferences for each site. Each supplier has developed a technical solution which meets the relevant requirements.

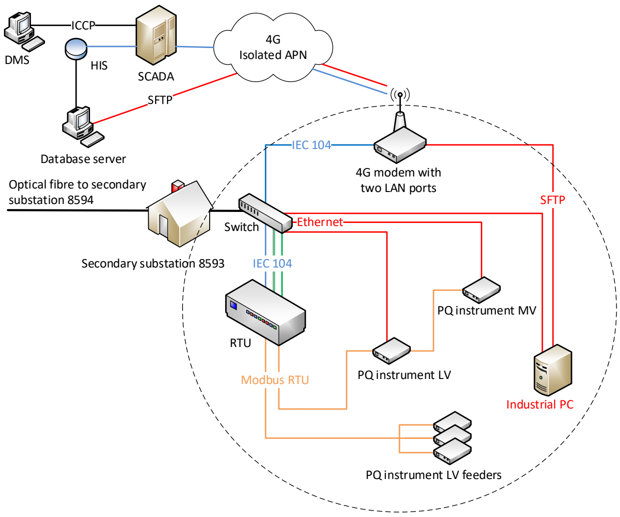

Figure 1. System architecture for system C.

The three different monitoring systems have been installed in six secondary substations. Table 2 shows an overview of the functionalities and an indicative cost for each installation. Three of the systems have been installed in new secondary substations and three have been installed in already operating secondary substations. Both systems A and C have a high monitoring level but the number of measurements varies in these systems. System B has a medium monitoring level.

In central Stockholm, the MV network is designed as a double cable network. In station 8456 the MV switchgear has four cable bays connected to the two systems. In system A, an automatic switch-over functionality for the two redundant MV systems has been developed and implemented. In station 8343 the automatic switch-over was installed already when the secondary substation was built. In both station 8593 and 8594 the MV switchgear has two cable bays, and each station is connected to a separate cable system. The LV switchgears in both stations are interconnected with three LV feeders. This allows for some degree of redundancy although not complete. Consequently, in system C an automatic switch-over functionality has been implemented for the LV side.

In case of a power outage the battery backup for systems A, B, and C are 12, 15, and 2 hours respectively. However, the backup for the mobile stations that communicate with these monitoring systems varies with each mobile operator.

Radio Planning

Radio planning in terms of mobile coverage and measurement of radio characteristics was performed at an early stage. This was essential in order to understand what network technology and mobile operator to choose and whether an externally placed antenna should be used or not.

Table 2. Monitoring, control, and communication of secondary substations.

Station name	8456	8410 and 8371	8593 and 8594	8343
Station type	2x800 kVA	2x1000 kVA 1x1600 kVA	1x800 kVA 1x800 kVA	4x1000 kVA
Supplier/system	A	B	C	C
System cost	$$$	$$$	$$$$$	$$$$
Installation	New	Retrofit	New	Retrofit
Year	2014	2015 2016	2015 2016	2016
Monitoring level	High	Medium	High	High
Measurements	LV Temperatures MV	LV Temperatures	LV Temperatures MV LV-feeders	LV Temperatures
Automatic switch-over	MV	None	LV	MV*
Network operating system	SCADA DMS Server	Supplier's own system Server	SCADA DMS Server	SCADA DMS Server
Communication	3G and 4G (public operator)	3G and 4G (public operator)	4G (isolated APN) Optical fibre	4G (isolated APN)
Battery backup	12 h	15 h	2 h	2 h
Dimensions H x W x D (mm)	800 x 400 x 300	1000 x 560 x 580	2000 x 800 x 600	2000 x 800 x 600

*Delivered with switchgear

COMMISSIONING

Due to different conditions concerning the location and load of secondary substations there are a number of standard types of secondary substations in Stockholm. These include e.g. both site-built and prefabricated stations. New installations were performed in site-built stations while retrofit installations were performed in both types.

Thorough pre-tests were performed together with suppliers A and C before the equipment was delivered to site. Supplier B performed its own pre-tests.

The basic requirement was that all installations should be carried out without any interruption of the power distribution for our customers. In stations with two or more transformers this was not a problem since the installation could be done during the time of day with low load, so that one transformer could be de-energized. For prefabricated substation 8371 with only one transformer (1600 kVA) a mobile generator of 1100 kVA had to be used for several hours during the installation.

It turned out that the retrofit installations were more complex and took much longer time than expected both during planning and installation.

Figure 2 shows system B installed in a prefabricated station while Figure 3 shows the inside of system C installed in a site-built station.

Figure 2. System B in a prefabricated secondary substation.

Figure 3. Inside system C, showing from top industrial PC, RTU, PQ instruments, and UPS.

OPERATIONAL EXPERIENCES

Communication and Security

Public mobile communication is used for all stations, though station 8594 is connected to station 8593 using optical fibre and communicates through the 4G modem of the latter. Systems A and B have been using two different public operators and both 3G as well as 4G have been tested. For system C, Ellevio has chosen a 4G solution with an isolated Access Point Name (APN). The APN delivers a safe IP-network from the public mobile operator, meaning a network separated from the Internet and dedicated to Ellevio only.

Furthermore, the 4G-router configured with the closed APN has separated networks (VLANs) for the SCADA network and the service network (file transfer). Naturally, the IP traffic between the substation and Ellevio's central systems is encrypted.

Cyber security is an important issue and the main risks are handled by perimeter security and by continuous monitoring and hardening of the networks and devices.

Network Operations Centre

Systems A and C are connected to the SCADA system and alarms, events and measured values are continuously monitored. Both systems are also connected to the DMS. System B is connected to the supplier's own management system, where alarms, events, and measured values can be continuously monitored. Another feature with system B is a surveillance camera that is installed inside the station 8410.

The number of signals and measurement points of the different monitoring systems can be seen in Table 3.

Table 3. Number of signals and measurement points.

Station and system	No. of signals to SCADA	No. of measurement points to SCADA	No. of measurement points to server*
8456 A	19	24	53
8371 B	4**	10**	222
8410 B	18**	10**	223
8593 C	29	30	307 + 127***
8594 C	29	30	307 + 127***
8343 C	40	30	307 + 12***

*Each point has min, max, and avg values measured with 15-minute intervals
**Not to SCADA but to supplier's own management system
***Measurement points for outgoing feeders and temperatures via SCADA

Measurements

The basic reason for collecting measurements, e.g. power quality data and temperatures for later analysis is the same for all three systems. The data is measured at 15-minute intervals, stored locally and periodically sent by file transfer.

Two web interfaces are provided by suppliers A and C respectively, which enables easy access to the most interesting data. Though the two systems are similar, the web interface of system A is more advanced, for example it allows an easier change of time interval and access to more data.

Figure 4 shows the web interface delivered by supplier C and is used to access power quality data from both system C and B. One can see the voltage's total harmonic distortion (THD_U) for all three phases for a number of days in station 8343. The measurements have a maximum distortion of about 2 %, well below the 8 % limit according to standard SS-EN 50160.

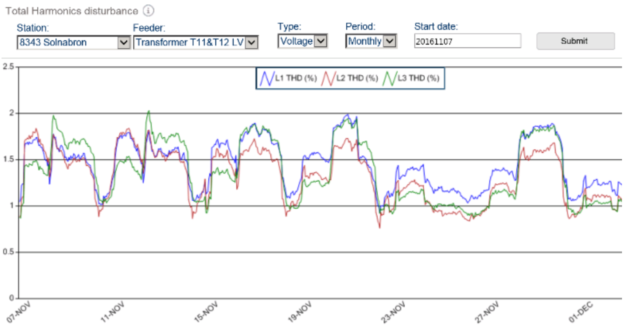

Figure 4. Web interface showing THD_U for L_1, L_2, and L_3 between 7 November and 1 December 2016.

For station 8410 there are several single measurement points that are well above the 8 % limit for THD_U and for station 8371 the active power (P) is unreasonably high for single measurement points. At present, it is difficult to interpret certain irregularities in the measurement data of System B, but troubleshooting is in progress.

Some power quality parameters are measured on the LV-feeders in stations 8593 and 8594, see Figure 5. Due to technical limitations of the instrument all that data is collected through SCADA communication instead of file transfer. The data is aggregated as 15-minute values by the historical database function (HIS) of the SCADA system.

When comparing the power between MV, LV, and the summarized power of all LV-feeders for station 8593, it became clear that the LV measurements were incorrect and an installation fault was discovered. The problem was that the clamps had not been removed from the LV current transformers. This also occurred when system A was installed previously, but at that time with another supplier and contractor.

Figure 5. Current transformers on all outgoing feeders in station 8593.

CONCLUSIONS

Three different monitoring systems A, B, and C have been installed and deployed in six secondary substations. Mobile communication is also up and running. For systems A and C there is a connection to Ellevio's network operations centre, while system B instead has a connection to the supplier's own management system. Some of Ellevio's important conclusions so far are:

- The functional level will vary depending on type of secondary substation. This implies that a limited number of different monitoring and communication systems will be used in Stockholm.
- Our experience is that the retrofitting of equipment is complex. Consequently, it makes sense for as simple systems as possible to be installed in existing secondary substations. Basic or low monitoring levels are preferable but in some cases medium level monitoring may also be appropriate.
- In new secondary substations, more advanced systems can be used if there is a need for medium or high monitoring levels.
- By measuring power quality data in secondary substations, faults have been detected in the system which had been difficult to detect without measurements and these can then easily be corrected.
- It is of great importance to prioritize the data which it is most important to receive in order to optimize the solution for both monitoring and power quality analysis [1]. Time resolution is also important and our experience is that 15-minute intervals is a good compromise between quality and quantity.
- Ellevio also wishes to point out that this new technology places new demands on the staff's competence levels in areas such as planning, commissioning, RTU, communication, SCADA/DMS and, last but not least, analysis.
- System A is a technically mature and flexible system suited for secondary substations. System B has great potential even if it today is not fully adapted for secondary substations. System C is a technologically advanced system, but the cost is currently too high.

OUTLOOK

Ellevio will continue to evaluate the monitoring systems described here and others during the coming years. Ellevio would like to better understand how much these systems can improve the availability and capacity of the network. The continued evaluation will also be used for developing standard solutions for the future.

The next step is to retrofit monitoring equipment in sixteen secondary substations in Stockholm. The monitoring level for these systems will be basic, low, and medium; compare with Table 1. The selection of equipment and installation methods for these sixteen stations is, to a high degree, based on the experiences from the above described systems A, B, and C. The idea is to try out systems which meet Ellevio's most urgent needs at different levels. More stripped-down equipment will hopefully also make the completed projects simpler, faster, and lower in cost.

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