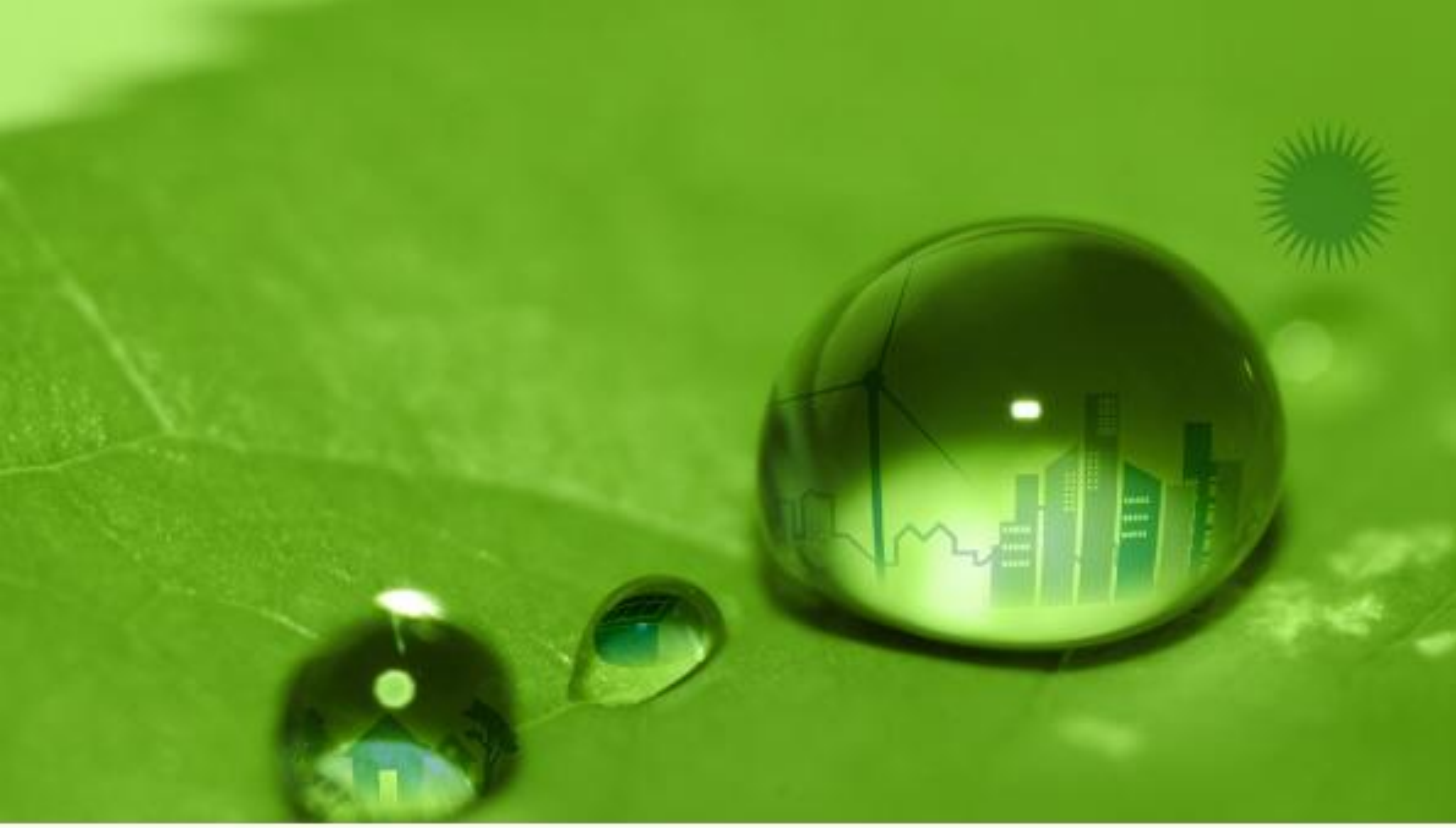

INNOVATION FOR ENERGY NETWORKS

Technical Spotlight DEMO2-2

Spotlight on Power Quality Meter Event analysis implemented in DEMO2

CO - FUNDED BY THE EUROPEAN UNION

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1 Introduction and scope of the document

Type of solution

☒ Equipment / Hardware / Firmware ☒ Information system ☐ Process

Manufacturer(s) implied (for equipment or hardware)

Schneider Electric

Work Stream considered

☐ Active Demand ☐ DER ☐ Storage ☐ Islanding ☐ MV Innovation ☒ LV Innovation

Location / Topology (with regards to distribution grid)

☐ HV/MV Substation ☐ MV ☒ MV/LV SS ☐ LV ☐ DER ☒ Meter ☐ Downstream meter
☒ Other Centralized system (calculations, information system) ☐ Other Decentralized ☐ Other :

Thematic(s)

☒ Grid Monitoring / state estimation ☐ Active demand / DSM ☐ DER Integration / increased grid capacity
☐ Islanding ☐ Anti Islanding protection ☐ Automatic Failure Detection ☐ Remote Grid Operations
☐ Automatic Failure Management / Grid recovery ☐ Automatic Grid topology reconfiguration ☐ Other :

Use Case(s)

DEMO 1	☐ Failure Management in MV networks	☐ Decentralized grid operation in MV Networks		
DEMO 2	☒ Outage detection in the LV Network			
DEMO 3	☐Automatic Grid Recovery (AGR)	☐Automatic Outage Detection (AOD)	☐Secondary Substation Node (SSN)	☐Customer Engagement
DEMO 4	☐Voltage control on MV grids (with high DER penetration)	☐Anti-islanding protection on MV grids	☐MV Measurement acquisition	☐Demand response for MV Customers
DEMO 5	☐MV grid automation of failure management	☐LV grid automation of failure management	☐Management of islanding operations	
DEMO 6	☐Islanding	☐Reduction of power demand	☐Manage maximised PV production on LV network regarding constraints and flexibility programs	☐Encourage resident to adopt smarter habits according to network state

Key figures

Demo2:

- ~10 600 Smart Meters connected to the demo site area
- >100 secondary substations included in the demo site area
- Secondary Substation sizes range between 2 and 17 outgoing feeders
- >300 000 power quality events generated by the meters connected to the demo site area

2 Objective and technical requirements

The objective for the project is to demonstrate a solution for improved outage and power quality management of the Low Voltage network. The solution is based on the already existing Smart Meters, which Vattenfall deployed at all customers several years ago. The deployment of Smart Meters could be seen as the first step of a Smart Grid solution. Introducing RTUs to the solution will be the second step of a Smart Grid solution, which we believe will support further business development in order to reach for the smart energy enabler platform. This technology will support the development towards more micro-scale production, smart homes electric vehicles, reduced CO2 emissions etc.

2.1 Context & Objective

Demo2 is participating in Grid4EU with the main purpose to demonstrate a possible solution for LV network monitoring, by deploying intelligent equipment in secondary substations (RTUs) and use the Smart Meters at customer premises. Information from two different sources in the same LV network circuit, will be used and combined in an integrated back office system environment. The benefit of the solution is believed to support different user needs and operating functions such as network planning, optimization, power quality analysis, field service processes etc. The combined usage of meter and RTU data is addressed in Technical Spotlight Demo2-1.

Apart from addressing the objective mentioned in the previous paragraph, Demo2 also analyzed the possibility of using only the power quality events provided by the AMM system to monitor the LV network. Although such analysis would not be as beneficial as the combined analysis of meter and RTU data for monitoring the LV network, it would still be very valuable in cases in which there were no RTUs installed. Today most of all the secondary substations are not equipped with any advanced measuring devices. This applies for Vattenfall as well as for most of the utilities despite the country. Many of the countries in Europe are in the process of deploying smart meters for most of their end customers. The present spotlight would probably be applicable to their current situation, allowing them to analyze meter events for monitoring the LV network.

Demo2 has included some 10 600 Smart Meters connected to 100+ Data Concentrators. Together with the communication infrastructure and integrations with the AMM collecting system, this forms the Smart Metering Infrastructure. The Smart meters are collecting measurement values (meter readings per hour) and power quality events. Events are divided into general and real time events. General events are collected once a day and real time events are collected as soon as possible after occurrence. Real time events are defined to be of more importance for power quality monitoring and quality of supply to the customers.

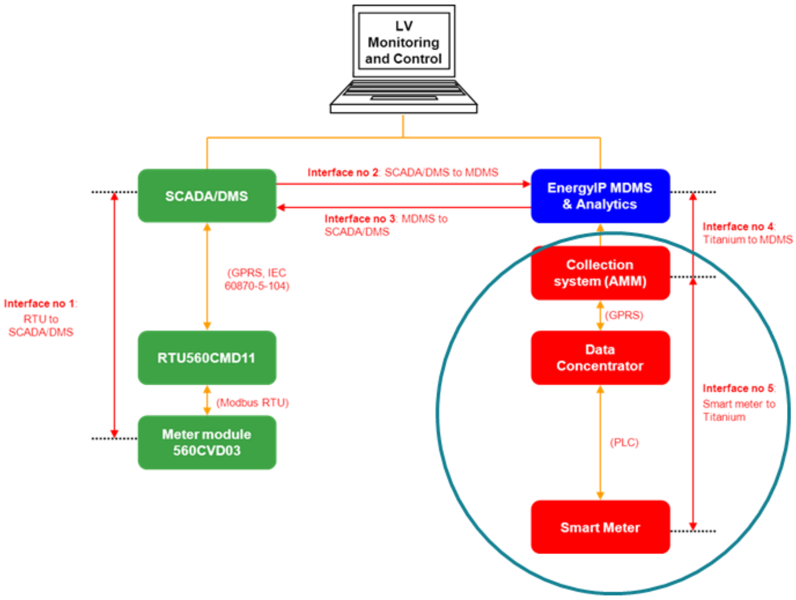

Figure 1. Global Demo2 architecture, highlighting the systems considered in this spotlight (right side of the figure).

The previous figure shows the overall architecture that has been set up for Demo2 project. As it has already been mentioned, only the right-hand side of the architecture will be used for the objectives addressed in the current spotlight (i.e., the AMM system, including smart meters, data concentrators and AMM collecting system). The smart meters communicate through the 400 V network, using Power Line Carrier (PLC) technique with data concentrators (DC). The DC is collecting metering data from the meters being installed on the same power line structure as the DC. The DC is in turn connected to the overlying collection system via GPRS. The data traffic uses common standards (OSGP) and passes the telecom operator Sierra Wireless communication platform and servers before being exported to the AMM Collecting system (Titanium) server through VPN integration.

The technical solution has the potential to be used in multiple ways and support different purposes. Note that only the methodology of analysis meter events will be described in this document. That methodology should be later on implemented in one of the available back-end systems at Vattenfall.

2.2 Requirements

The only requirement for performing the above mentioned analysis is that smart meters are deployed and are reporting power quality events to the AMM collecting system.

If the analysis are to be made based on historical data, no speed requirements would apply for the events being sent to the AMM collecting system. On the other hand, if real-time monitoring on the LV network was to be performed, power quality events of interest should be sent to the AMM collecting system as soon as registered by the meters / concentrators.

3 Development and implementation

The methodology that has been carried out for monitoring the LV network based on power quality events from smart meters is the following one:

- First, a selection of power quality events of interest for monitoring the LV network was made. As the AMM system is able to produce a wide selection of events, it was necessary to only focus in the most relevant ones at the first stage.
- Then, all those events were collected for the period that covered the analysis, in this case, from the 1st of January to the 30th of September, 2015.
- Once all the events were available for being analyzed, they were grouped by the secondary substations that the meters that generated the events belonged to. By proceeding in that way, it was possible to obtain the list of substations that produced more power quality events in the analyzed period. Note that, in general, only relevant conditions maintained along the time should be considered, skipping the ones that happened at a specific point of the time because of any exceptional condition. For each secondary substation, the most frequent events were analyzed in greater detail, in order to find out the most common event, if they were generated continuously or not, etc.
- After the analysis on the substations was made, a similar analysis was performed over individual customers, in order to find out the customers more relevantly affected as per power quality purposes. Every meter (attached to the customer) would then be analyzed in greater detail to get further information about why that situation of possible poor power quality was happening.
- At the end, there will be a list of secondary substations and customers that should be further investigated. Once the list has been obtained, it would be possible to focus on the details of each element of that list:
    - By a continuous analysis of reported power quality events.
    - By an analysis of meter readings and other events.
    - By carrying out field visits.
    - By installing RTU for getting additional information parameters.
- After this new analysis, the utility would be able to define a strategy for solving those power quality issues affecting their customers, thus improving the quality of service they would receive.

Partners of Demo2 agreed on the most interesting events coming from the smart metering system from power quality point of view and that would be useful for monitoring the LV network. Those events and their definitions are listed below:

- Events generated at smart meters
    - **Reverse Energy**. The meter has registered reverse power. Typically occurs if the consumer is generating power, otherwise the meter may be mis-wired. Could also be considered as a possible tamper event.
    - **Sag**. This event occurs when a voltage sag is detected in any phase. The voltage must drop below 10% of the rated voltage (230 V) to be recorded as an event.
    - **Surge**. This event occurs when a voltage surge is detected in any phase. The voltage must be above 10% of the rated voltage to be recorded as an event.
    - **Phase Loss**. Voltage below 61% of the rated voltage has occurred on at least one phase.

- **Power Outage**. Power outage occurred at the meter. Expected when power outages occur. The event will be reported after power is restored.

- Events generated at data concentrators
  - **Phase Inversion**. This event occurs when the meter experiences phase inversion. This alarm may occur because the meter is mis-wired, although in some cases it can occur simply due to noise on the power line.
- Events generated in AMM Platform Titanium, as an algorithm
  - **Zero Fault**. A zero fault event is triggered when there is a surge above 270 V and also a sag event.
  - **Extremely High Voltage**. This event is triggered when there is a surge above 270 V and no sag event.
  - **High Voltage Fuse Broken**. This event is triggered when two phases are below 30% of the nominal value and one phase is within 10% up or down the nominal value.

4 Technical results

During the 9-month period of analysis in 2015, 320 000 power quality events have been registered by the smart metering system. The figure below shows the distribution of those events. As it can be seen from the figure, the most common event is the reverse energy one, followed by sag and power outage ones. The following sections will show the main findings obtained at both secondary substation and end customer level.

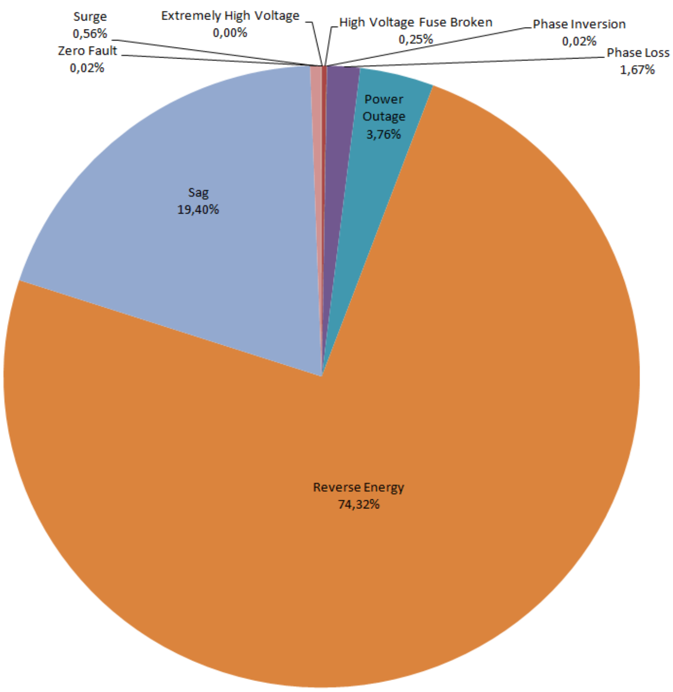

Figure 2. Generated power quality events for Demo2 from January to September, 2015.

4.1 Findings obtained at secondary substation level

As it has already been mentioned, all the events are related to end customers, but by grouping them by secondary substations it will be possible to get some insights about the behaviour experienced at secondary substation level, thus also support LV network monitoring operations and analysis.

Sorting all the secondary substations by the number of generated events will structure the big volume of data and group the substations in order to get the most affected ones as per power quality purposes, allowing to focus on the most critical ones.

After carrying out a preliminary analysis on the events, it has been possible to determine that most of reverse energy events are generated only by about 20 meters. In order not to distort the analysis, reverse energy events will be addressed separately. After removing reverse energy events, it has been possible to obtain the 20 secondary substations that have produced most power quality events (62% of total events).

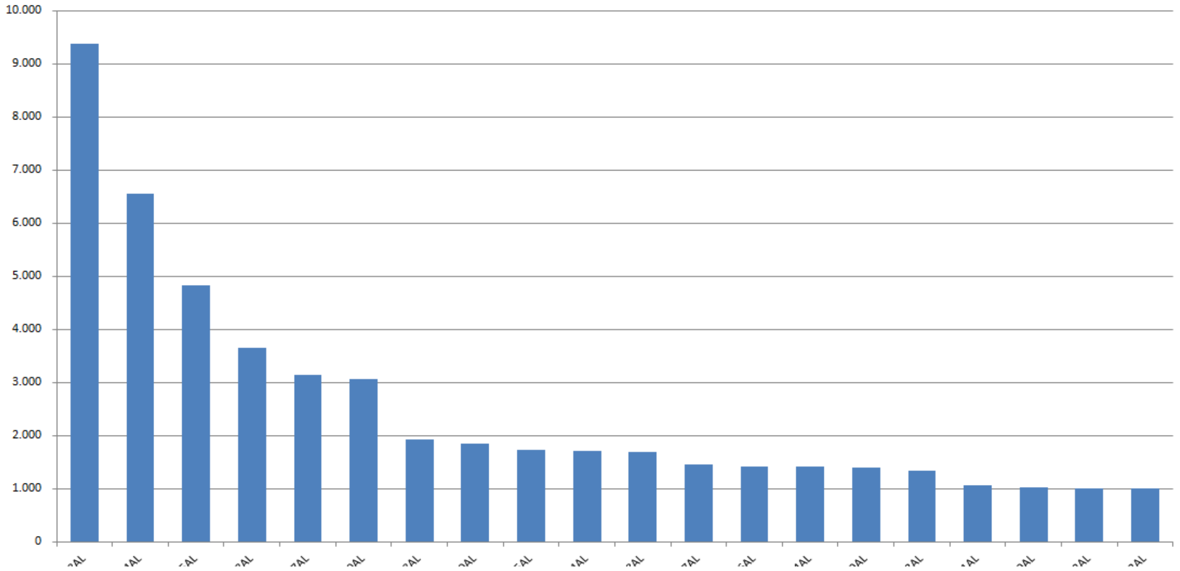

Figure 3. Secondary substations sorted by amount of reported power quality events, Jan-Sep 2015.

Following that first filtering technique, this section will describe which general conditions have been detected to affect all or most of the meters below a secondary substation.

4.1.1 Sag events

In the next table it is possible to find the main remarks obtained from the secondary substations that have reported more sag events.

Secondary Substation Id	Number of customers	Number of sag events	Remarks
SS1	408	8 857	- **20 customers** have generated more than 70% of all sag events. - Nearly 60% of the analyzed days present at least one sag event (56 sag events average per day).

Secondary Substation Id	Number of customers	Number of sag events	Remarks
			- **There could be some localized undervoltage problems in the area.**
SS2	767	3 167	- Almost 2/5th of the days there are sag events affecting those customers. - There are a lot of customers with very few or no sag events at all. - There are about 20 customers with more than 40 sag events, and 4 customers with more than 100 events. - **There could be some localized undervoltage problems in the area.**
SS3	677	1 774	- About 1 day out of 6 there is at least a sag event. However, in just 10 days, 95% the events were generated. - The events were generated by about 75% of the meters connected to the substation, **so there could be some localized undervoltage problems in the area**.
SS4	182	1 701	- Almost 1/3rd of the days there are sag events affecting those customers. - Only 22 customers have been suffering most of the undervoltage situations. - **There could be some localized undervoltage problems in the area.**
SS5	10	1 647	- Half of the customers have been relevantly affected by sag conditions. All these customers have generated between 100 and 500 SAG events each one. - It's relevant the amount of sag events generated for so few customers connected at the substation. - Sag events have been occurring 1/3rd of the time of the analyzed period. - **There could be some localized undervoltage problems in the area.**

Table 1. Main secondary substations with customers affected relevantly by sag events.

4.1.2 Power outage events

Regarding power outage events affecting customers located at secondary substation, in total there were generated 12 009 events in the analyzed period. However, it is important to notice that in only 6 days, 72% of all those events were produced. The rest of the days, the behaviour of the secondary substations regarding power outages is normal.

Out of the 100+ secondary substations, only 10 of them were the most affected ones in those 6 days. In 9 of those secondary substations, 90% of their power outage events occurred in just 1 or 2 days, so for the rest of the analyzed period, they behaved well regarding power outage perspectives.

With this it is possible to conclude that there might have been some major disturbances that affected those 10 secondary substations in just a few days, but for the rest of the time, the LV network didn't show any relevant power outage condition of interest to be mentioned.

4.1.3 Phase loss events

In the next table it is possible to find the main remarks obtained from the secondary substations that have reported more phase loss events.

Secondary Substation Id	Number of customers	Number of phase loss events	Remarks
SS1	162	249	- **33 customers** have generated all phase loss events.

Secondary Substation Id	Number of customers	Number of phase loss events	Remarks
			Only 5 customers have generated 70% of all reported phase loss events. - Nearly 50% of the analyzed days present at least one phase loss event. - **There could be some severe localized undervoltage problems in the area.**
SS2	182	179	- 24 customers have generated all phase loss events. - Nearly 30% of the analyzed days present at least one phase loss event. - **There could be some severe localized undervoltage problems in the area.**

Table 2. Main secondary substations with customers affected relevantly by phase loss events.

4.2 Findings obtained at end customer level

After analyzing the events grouped by substation, the focus now will be to analyze individual customers that have produced an abnormal amount of power quality events.

4.2.1 Reverse energy events

As described earlier in the document, reverse energy events represent 74% of collected power quality events. It's worth noticing that only 16 meters have generated 99% of those reverse energy events. Those reverse energy events have been occurring on a daily basis and in most of the cases, are the only events reported by those meters. The reason for those customers generating so many reverse energy events could be because of having local generation. However, customers from Vattenfall that have local generation have a different kind of meter not included in Grid4EU project, so they shouldn't have local generation with the kind of meter they already have.

Field visits were performed by Vattenfall, and they discovered that one of those 16 meters was wired in a wrong way, and thus, it had originated more than 25 000 reverse energy events during 2015. After the meter was wired properly, it has not reported more reverse energy events. As for the rest of the meters, apparently there were not local generation, and the wiring on them was correct. Further investigation is required to find out the causes of this situation for the rest of the meters. One action for example could be to bring the meter to a meter test lab to test if the meter is broken.

4.2.2 Sag events

Contrary to the reverse energy scenario, sag events are generated by a larger set of meters. In fact, more than 80% of the meters have generated at least a sag event. However, a few meters have suffered a great number of sag events by themselves only. The list of those meters is the following one:

End Customer Id	Number of sag events	Remarks
EC1	3 604	- About 75% of the days the meter has reported at least one sag event. - During January, the meter reported a lot of sag events, especially by the middle of the month. - Sag events have been reduced a lot since then, although there are about 10 sag events per day still.
EC2	723	- More than 20% of the days the meter has reported at least one sag

End Customer Id	Number of sag events	Remarks
		event. - In those days, there is an average of 12 sag events being generated.
EC3	666	- More than 15% of the days the meter has reported at least one sag event. - In those days, there is an average of 14 sag events being generated.
EC4	553	- More than 15% of the days the meter has reported at least one sag event. - In those days, there is an average of 13 sag events being generated.
EC5	522	- More than 20% of the days the meter has reported at least one sag event. - In those days, there is an average of 10 sag events being generated.

Table 3. Main customers affected relevantly by sag events.

4.2.3 Power outage events

In this case, power outage events have been generated by a lot of meters, mainly because of some specific conditions affecting entire secondary substations, or at least part of them. However, it's remarkable to highlight that one meter has been reporting a power outage event every day in the analyzed period, so 270 events have been reported so far. After checking on that meter, it was discovered that the meter is continuously reporting measurement error with every outage. Most likely this meter could be faulty, but it would be interesting to further investigate that meter to see why this is happening.

4.2.4 Surge events

For surge events, they have been reported by some meters from time to time. However, there is a single meter that has reported nearly 80% of the total surge events. That meter has reported 1 409 surge events, with an average of 5-6 surge events every day. It would be interesting to further analyze that meter, in order to see if that situation can be solved.

4.2.5 Phase loss events

Phase loss events have been generated by a large population of meters, most of them reporting just a few phase loss events in the analyzed period. However, a few meters have suffered a great number of phase loss events by themselves only. The list of those meters is the following one:

End Customer Id	Number of phase loss events	Remarks
EC1	454	- About 60% of the days the meter has reported at least one phase loss event. - In those days, there is an average of 2 phase loss events being generated.
EC2	306	- About 55% of the days the meter has reported at least one phase loss event. - In those days, there is an average of 2 phase loss events being generated.
EC3	150	- About 45% of the days the meter has reported at least one phase loss event. - In those days, there is an average of 1 phase loss event being generated.

Table 4. Main customers affected relevantly by phase loss events.

5 Elements of Cost & Benefits Analysis

As described previously in the document, the outlined methodology makes use of the existing smart metering infrastructure deployed at Vattenfall. It hasn't been necessary to install additional devices or configure the meters to send different events than the ones that were already sent to Vattenfall. Because of that, the costs for being able to perform this kind of this analysis were already taken into account in the cost benefit analysis performed when the smart metering rollout was being considered.

6 Replication, next steps and up scaling

Replication and up scaling (exploitation) of the solution for Vattenfall is dependent on a) choice of strategy for LV monitoring, b) funding for the investment, c) back-end system implementation in production system environment and d) process re-engineering and organisational change of work in the control center.

Exploitation in line with the Demo2 technical solution will require the implementation of the described methodology in one of the back-end systems available at Vattenfall, as well as the creation of the required interfaces among all the involved systems in production. The choice of the final solution depends on the cost for development, implementation, license fees and access to the application by the different user groups within the DSO.

7 Intellectual property (IP)

Any IP rights are not identified for the DSOs, such rights are more of interest for system vendors and manufacturers of equipment. IP rights will be applicable for system application functionality as well as equipment design and functionality. In the Demo2 case this will be applicable for the Schneider Electric AMM solution, and the provider of the meters and data concentrators (NES).

8 Regulatory challenges

The roll out of Smart Meters in Sweden was driven by new regulations in 2009.

9 Conclusion and key messages

The event analysis for the Demo2 meters has shown potential usage of event data for several different purposes.

- In order to be able to process all data generated by the meters, a big advantage is to build a filtering functionality which also is able to consider the LV network topology.
- Structuring the events in different aggregated levels will give insight about how the situation looks like in different geographical regions. Filtering the events will make it possible to zoom in down to the individual event type, or meter.
- Grouping the secondary substations by the number of events from smart meters will indicate which substations to select for further analysis. Such a grouping may support an identification of the substations with poor power quality in general.
- Gives a possibility to easily find potentially mis-wired meters.
- Gives a possibility to easily find potential customers with installed micro-generation without approval from the DSO.
- Gives a possibility to easily find potential broken meters.
- Gives a possibility to easily find potential customers suffering heavily of voltage variations.
- Gives a possibility to easily find potential customers suffering other power quality problems, e.g. zero fault and extremely high voltages.