SOGNO H2020 PROJECT CLOSE-OUT REPORT

SOGNO – A HORIZON 2020 PROJECT

SERVICE ORIENTED GRID FOR THE NETWORK OF THE FUTURE
(GRANT AGREEMENT NO. 774613)

PROJECT OWNER: CLEM POWER

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For more information on the SOGNO H2020 Project, please see

https://www.sogno-energy.eu

Table of Contents

Table of Acronyms used in this Document			
3G, 4G, 5G	Third Generation, Fourth Generation and Fifth Generation Mobile Phone Operator Platforms	LV	Low Voltage
APMU	Advanced Power Measurement Unit	MAC	Microelectronics Application Centre
BAU	Business as Usual	MQTT	Message Queue Telemetry Transport
CRO	Control Room Operator	MV	Medium Voltage
CT	Current Transformer	NMS	Network Management System
DSO	Distribution System Operator	PF	Power Factor
EN	European Norm	PQ	Power Quality
ESB Networks	Electricity Supply Board, Networks DAC	RTU	Remote Terminal Unit
EV	Electric Vehicle	RWTH	Rheinisch-Westfälische Technische Hochschule
FLISR	Fault Location Isolation and Service Restoration	SCADA	Supervisory Control and Data Acquisition
FPI	Fault Passage Indication	SE	State Estimation
ICT	Information and Communication Technologies	SERVO	Systemwide Energy Resource and Voltage Optimisation
IEC	International Electrotechnical Commission	SMS	Short Message Service
IM	Instant Messaging	SOGNO	Service Oriented Grid for the Network Of the future
Km	Kilometres	TRL	Technology Readiness Level
kVA	Kilovolt Amps	TSSG	Telecommunications Software and Systems Group
kVAR	Kilovolt Amperes Reactive	V / kV	Volts / kilo-Volts
kW	Kilowatt	VT	Voltage Transformer
LA	Loop Automation		
LBFM	Load break, Fault Make		

1. PROJECT OVERVIEW

The SOGNO project is a Horizon 2020 project funded by the European Union (EU) involving 13 project partners from six EU member states with live trials built and run in four EU member states. The project ran for 30 months starting in January 2018 and concluded in June 2020. The project was delivered on time and within budget. SOGNO is an acronym for Service-Oriented Grid for the Network Of the future. The main objective of the SOGNO project was to present and demonstrate a completely new model of automation of the electrical distribution systems, based on the delivery of "automation as a service". This concept builds upon the use of limited (and low-cost) hardware in the field and the full virtualisation of the substation intelligence in the cloud.

According to the SOGNO vision, the virtualised substation automation can be implemented using the latest developments in the ICT domain and exploiting the innovative features brought by the upcoming 5G technology. Moreover, tomorrow's distribution grid automation is expected to be increasingly based on the use of core algorithms, or as support functions, of latest generation machine learning techniques. All of these ingredients have been combined in the SOGNO vision, in which automation functions, ICT components, data analytics tools, artificial intelligence, all co-exist and can be flexibly plugged, removed, substituted and interconnected to create the overall SOGNO eco-system. This modular framework allows the easy deployment of different tools and power system algorithms, according to the DSO (Distribution Service Operator) requirements, which can be delivered as a service to the DSOs similar to other systems as a service (SaaS). The proposed view is an alternative to the current concept of a control centre built upon a large expensive SCADA (Supervisory, Control And Data Acquisition) system. The ideas promoted in SOGNO pave the way for a disruptive market of power system management, control and automation products as a service. The SOGNO concept is to develop and offer a range of cloud-based services tailored to the requirements of DSOs and use the existing telecoms network (5G) to communicate with devices in the field which feed into the service algorithms.

The project comprised of a consortium partnership of 13 organisations that included European and Irish energy, telecoms and research organisations as listed in Table 1.1. To successfully demonstrate the value and the practical feasibility of the concept, five power system services were designed, tested and validated in DSO field trials and laboratory trials in Estonia. Germany, Ireland, and Romania to a technology demonstration level or Technology Readiness Level (TRL) 6.

TRL is an internationally recognised scale developed to quickly ascertain where in the development cycle a particular piece of technology is. The scale is a nine-point scale starting at 1 which is just a concept at early research stage going all the way to 9 which is a fully developed tested market ready product. Currently the services offered by SOGNO are at TRL 6. TRL 6 is at a demonstration stage and not ready for wide scale deployment. Typically, the projects ESB Networks undertakes in the innovation space are TRL 7 or higher, as we believe this level of ambition is appropriate to give best value to our customers in view of the scale of resources available within a utility of our size.

1.1 Project Services and Partners

The services trialled as part of SOGNO are:

- State Estimation (SE) – SE is a method of predicting a parameter (usually voltage) pertaining to an electricity overhead line or cable. By measuring a limited number of points on the network and inputting them into an algorithm, the algorithm can calculate the parameter at any other point on the network outlet based upon pre-programmed information about that outlet.

- Fault Location, Isolation & Service Restoration (FLISR) – FLISR is a method of detecting faults in the network, isolating the fault location and makes sure to restore the service to the upfaulted or healthy network by connecting the resulting isolated loads back to the power source using network automation devices from alternative sources.
- Power Quality (PQ) – PQ monitoring enables DSOs to identify issues with the quality of power in their network and ensure it is operating within regulated limits. DSOs use Power Quality monitoring devices to ensure Power Quality issues that can affect the network are identified and addressed. These include harmonics, poor power factor, voltage instability and imbalance which impact on electrical equipment on the network.
- Power Control (PC) – PC services optimise the management of the distribution grid such as power flows for preventing possible issues, such as the violation of the network's voltage limits and the overloading of the network's components.
- Load & Generation Forecasting (L&GF) – L&GF services enable DSOs to identify and monitor the quantity of power being supplied in their grid basing generation feeding into the network on historical demand

No	Name	Abbreviation	Country
1	Ericsson GmbH	EDD	Germany
2	Altea BV	ALTEA	Netherlands
3	B.A.U.M Consult GmbH	BAUM	Germany
4	Centrul Roman Al Energiei	CRE	Romania
5	CEZ Romania SA	CEZ	Romania
6	Ericsson Eesti AS	EEE	Estonia
7	ESB Networks DAC	ESBN	Ireland
8	Gridhound UG	GH	Germany
9	The National Microelectronics Applications Centre LTD	MAC	Ireland
10	RWTH Aachen University, Germany	RWTH	Germany
11	University of Bologna	UNIBO	Italy
12	Waterford Institute of Technology - Telecommunications Software and Systems Group	WIT-TSSG	Ireland
13	Telekom Romania Mobile Communications SA	TRMC	Romania

Table 1.1: SOGNO Project Partners

As part of the trial in Ireland, ESB Networks supported project partners (RWTH Achen, Grid Hound and the Telecommunications Software and Systems Group (TSSG)) to pilot State-Estimation, Power Quality evaluation and Fault Location, Isolation and Service Restoration (FLISR) technology on areas of the Irish distribution system.

Other services and different versions of some of the services were trialled in other countries. These were Power Control (PC) and Load and Generation Forecasting (L&GF) which were trialled in Germany, Romania and Estonia. Figure 1.1 below shows the different services trialled in each country.

Details of the full project and partners activities can be found on the SOGNO EU web portal - https://www.sogno-energy.eu

	FLISR	PQ	SE	PC	L&GF
Estonia					★
Ireland	★	★	★		
Germany	★		★	★	
Romania	★		★		★

Figure 1.1 SOGNO Project Services Trial Locations

2. PROJECT SCOPE AND SCOPE CHANGES

This report concentrates on the project scope and field trials undertaken by ESB Networks as part of the overall SOGNO project to trial the implementation of cloud-based system awareness services and autonomous self-healing for advanced distribution network management.

Environmental pressures and changes in legislation in European countries will advance the move away from fossil-fuelled transport and heating to an electrical system, which will be increasingly powered by renewable generation sources. As a fuel source, the continued transition to electricity will increase further over the coming years as more consumers are expected to switch to electromobility, electric heating and install various local generation and storage technologies. Consequently, consumers will require a more and more robust electricity system to support their electrified lifestyles.

Traditionally, load changes on circuits and transformers have been gradual and incremental as new connections occurred and load patterns evolved. This gave DSOs, such as ESB Networks, time to assess and observe developing changes to the load patterns or profiles on their network, which in turn allowed sufficient time to plan, invest and implement network reinforcement, as and when required. However, both EVs (Electric Vehicles) and Electric Heating (heat pumps) are changing the electrical landscape at a pace never experienced before by DSOs. This pace is only likely to increase in the foreseeable future. Frequently, the DSO did not have clear visibility of the rapidly developing “new environment” in which they are operating, due in no small part to the complexity and expense of deploying sufficient power monitors on the networks which were traditionally required to paint the overall picture of the operational status of the network.

SOGNO sought to address this challenge by combining the application of deep intelligence techniques, industry grade data analysis and visualisation tools, advanced sensors, an advanced power measurement unit connected by advanced cloud based ICT to provide fine grained visibility and control of the power network using end to end automation in a virtualised environment, validated in DSO field trials Technology Readiness Level (TRL) 6. Table 2.1 shows the range and definition or TRL as per the definitions from the Electrical Power Research Institute (EPRI).

TRL	Definition
TRL-1	Basic principles observed and reported
TRL-2	Technology concept and/or application and/or methodology formulated
TRL-3	Critical function and/or characteristic concept proven through analytical and experimental means
TRL-4	Components validated in laboratory environment; methodology validated via table-top exercise
TRL-5	Components validated in relevant environment; methodology validated in advanced detailed exercise
TRL-6	System/subsystem model or prototype demonstrated in a relevant environment; methodology demonstrated in member utility on pilot basis
TRL-7	System prototype demonstrated in an operational environment; methodology demonstrated in member utility on initial operational basis
TRL-8	Actual system completed and qualified through test and demonstration; methodology demonstrated in member utility on full operational basis
TRL-9	Actual system proven through successful operations; methodology widely adopted throughout industry

Table 2.1: Definition of Technology Readiness Levels (TRLs)[1]

On top of these anticipated operational challenges due to increased electrification, the frequency and intensity of storms is also projected to increase in future. The consequences of storm damage to the electricity grid and the impact that will have on consumers, who will be ever more dependent on electricity for their day to day activities, will put additional pressure on DSOs to restore power after adverse weather events faster than ever. Overall, the day-to-day role of the DSO will become more complicated and pressurised. Greater visibility and understanding of what is happening across its networks at a granular level will be essential. This is where concepts such as the SOGNO solution may be of greatest benefit and learning.

2.1 ESB Networks Project Trials

ESB Networks as a large-scale DSO, has invested in a highly developed (Network Management System (NMS) and SCADA infrastructure, which was provided by a main-stream NMS / SCADA provider. In these circumstances, the NMS / SCADA provider usually has a suite of additional services which the DSO can choose to opt in to, at additional cost. Prior to partaking in this project, ESB Networks had not opted to use any of these additional services from our incumbent NMS / SCADA provider which were then trialled as part of the SOGNO project.

For the SOGNO trial we sought to demonstrate how in a quickly evolving scenario, a more agile implementation of innovative automation services outside of the large NMS providers, can be beneficial in dealing with the arising challenges. ESB Networks is aware that there are many smaller DSOs, particularly across continental Europe, which may not have the finances to invest in such highly developed NMS and SCADA systems or have the necessary back up from a large IT support department. The SOGNO project sought to trial a number of cloud-based software services which would not require an underlying SCADA or NMS infrastructure. All the SOGNO trials conducted on ESB Networks, were independent of our existing NMS / SCADA systems, in so far as possible.

To successfully demonstrate the value and the practical feasibility of these concepts, 5 power system services have been designed, tested and validated. Each one of the trials was different in terms of

[1] Electrical Power Research Institute (EPRI)

network characteristics, availability of measurement equipment and, ultimately, scope. This allowed the evaluation of different aspects across all the trials, leading to a complementary and comprehensive evaluation of each service and of the associated benefits and challenges. Moreover, 4 different platforms have been used for the field deployment of the services, thus demonstrating that the SOGNO vision can be achieved with a variety of software implementations, ranging from commercial to completely open source solutions, provided that they share the same basic architectural principles.

For ESB Networks, we successfully trialled three of the five services, using actual networks. The services trialled in ESB Networks were, Fault Location and Isolation and Service Restoration (FLISR), State Estimation (SE) and Power Quality (PQ).

From the initial finalisation of the grant agreement to the culmination of the project, SOGNO evolved to meet challenges both physical and technical in a flexible and dynamic manner.

For ESB Networks in particular, there were many alterations to the direction and scope of the project, brought about by a changing dynamic from both within the project and what was technically and feasibly achievable.

2.2 FLISR Trial

Initially, for the FLISR trial the project identified two locations, where the Irish field trials were to be conducted. The first was the network around the Ring-of-Kerry in the Southwest of Ireland, involving two MV outlets, which were supplied from two 38kV stations. The second location was the network in Waterford on the South coast of Ireland involving five MV outlets which were supplied from three 38kV stations.

These locations were deemed as being particularly suitable as they were both equipped with significant numbers of existing down-line automated, network switching devices, such as Nu-Lec Reclosers and Soulé switches.

The Waterford trial site contained an unusually high number of Soulé Switches (Figure 1.6) in a geographical area. Soulé Switches are a Load Break, Fault Make (LBFM) MV network switching device. Soulé Switches are not programmed to operate autonomously. They are all SCADA controlled and only operate on command from the Control Centre. It would be possible for these to be controlled directly from a cloud based FLISR service but this test was not in the scope of the project, nor would it be allowed from an ESB Networks point of view for a second point of command to be controlling any of our down-line switching devices. Soulé switches can also be operated locally, either electrically from the control box or manually via a hook-stick. Soulé Switches are equipped with an in-built programmable Fault Passage Indicator (FPI), which can indicate the passage of fault current for either short circuit or earth fault.

The Kerry site was an existing LA (Loop Automation) scheme, which exclusively uses reclosers. Each recloser is programmed to act autonomously, to isolate faulted sections of back-bone lines and restore service to the un-faulted sections of the back-bone lines. All reclosers on a LA scheme are also SCADA controlled but crucially they do not depend on having active communications either with SCADA, or between each other, to reconfigure the feeding arrangement of the outlets in the event of a permanent back-bone line fault. Instead, they rely on logic of loss of voltage, over current and timers to locate faulted sections of the outlet, and to subsequently isolate the faulted section and restore supply to the healthy / un-faulted sections of the outlet from alternative sources.

During the course of the project there were many changes made to the direction and scope of the trials. One of these unexpected delays and changes to the project occurred when the network in County Kerry was made unavailable for SOGNO project purposes due to a refurbishment programme which coincided with the planned deployment of the additional modems in the reclosers on the chosen networks. An alternative network near Mullingar, County Westmeath was chosen instead as it was also a Loop Automation scheme, which closely resembled the original network in County Kerry.

For the FLISR service only, we investigated and procured a totally separate modem, which was installed within each down-line recloser and Soulé switch. In order to connect the modem into the communications circuit, a special lead, with unique wiring connections, had to be sourced However, in order to gain permission to proceed with the installation of these leads and modems, extensive tests had to be performed to ensure that no signal could be sent from an external source via this new modem, which could be received by the down-line network switching device. Furthermore, the project was mandated to perform a number of additional tests to ensure that the installation of the second modem would not degrade or cause any other detrimental effects to the quality of the signal going to the SCADA modem. Despite the extensive testing, the project still encountered issues when it was attempted to install modems in a particular type of down-line network switching device. This required further investigation and the adoption of a special version of the communications connection lead. While this testing was very time consuming it was necessary to ensure compatibility with our existing SCADA system.

SOGNO partners ALTEA and MAC collaborated to integrate their products. ALTEA manufacture Low Power sensors for both MV and LV applications. ALTEA provided a combined MV voltage and current Low Power device. MAC integrated the ALTEA sensors with their Advanced Power Monitoring Unit (APMU), which could communicate with the ESB Networks SERVO platform [2]. This platform was hosted by TSSG in Waterford Institute of Technology, who were another SOGNO partner. The APMU installation was powered by a solar panel and battery combination. Once the sensor and measurement devices had been successfully integrated, ESB Networks devised the risk assessment and installation methods for the MV measurement equipment and monitoring device.

Figure 2.1 MAC APMU and ALTEA combined Voltage and Current Sensors

[2] The SERVO platform, ESB Networks' cloud platform consists of three high level components, SERVO Live, SERVO Flex and SERVO Modeller. These three components perform specific functions within the ESB cloud platform with SERVO Live tasked with the collection of live data from field devices, SERVO Flex providing an interface for entities to interact with the flexibility functions of the grid and SERVO Modeller tasked with the storage and normalisation of the live data and data from other ESB DSO management systems, like SCADA and Geographic Information Systems. SERVO Modeller also has the capability to perform algorithmic execution functions on its stored data. The main set up from the perspective of integrating and enabling the SOGNO services will involve developing further extensions to the SERVO Live component to communicate with the new field devices that will be installed on the trial sites.

Extensive examination of test certificates was required to ensure that the installations did not pose any additional risks to plant or more importantly staff / public. Further MV testing and accuracy trials were conducted by ESB Networks in our National Training Centre in Portlaoise prior to the actual installations.

Existing Overhead Line Hardware equipment was adapted specifically to allow the installation and connection of the MV sensors.

2.3 State Estimation Trial

For State Estimation, the bespoke algorithms, were written to compute the parameters of the power network. It was deemed necessary to model the outlets in Waterford trial site in its entirety. The extensive nature of the Waterford Networks was considered to be too large for the limited resources of the SOGNO partner, who was tasked with writing the algorithm. It was therefore decided to apply the State Estimation service on one outlet, called “Dunmore Interface Outlet” ex Tramore 38kV Station. This outlet, which is approximately 19km from station to Normally Open Point, was modelled in detail and contained over 100 node points, each of which could be interrogated to provide the State Estimated value for the voltage and current at that point.

In order to validate the output of the State Estimation service, ESB Networks installed a number of other MAC APMU power monitoring devices on the secondary side of some MV/LV transformers. These transformers were a combination of a three-phase ground mounted 200kVA and three 15kVA pole mounted single phase substations. The single phase units were chosen strategically so as to be across all three phase combinations, at different points along the outlet.

2.4 Power Quality Trial

For the Power Quality trial, the same data was used from the prime MAC APMU / ALTEA three phase device as was used for the State Estimation service. The data from the MAC APMU was analysed by an algorithm, which was specifically written for SOGNO by TSSG. The algorithm examined the data on the current, voltage and the power factor. From these readings the algorithm could detect abnormalities with the power system, which would have otherwise gone unnoticed. Abnormalities such as voltage imbalance, or the voltage being too high or too low or excessive harmonic distortion on the network, can lead to customer complaints and or inefficiencies from higher losses associated with the transportation of electrical power. There are international recommended limits set out for “Voltage Characteristics of Electricity Supplied by Public Electricity Networks. These are contained within an IEC Standard, 50160. The algorithm which TSSG wrote took into account the limits as recommended in the IEC Specification.

3. OBJECTIVES AND MEASURES OF SUCCESS

The objectives of the project are aligned to the scope above and reflect both the broader SOGNO objectives and the specific objectives and measures of success in trialling the three services in ESB Networks. This can be summarised as aiming to conduct suitable trials and learnings for the three services on the MV network reflective of the scope and ambition of the SOGNO project and to enhance knowledge and understanding in relation to:

- To successfully develop, test, trial and validate the three services, hardware and software solutions with our project partners for the Irish trials to TRL 6.

- Testing the benefits of the three services of State Estimation, FLISR and Power Quality, being trialled on our distribution network and consider how they could be used and adapted for use in managing and operating the distribution network.
- To assess the techniques and develop the methods, processes and procedures for safely installing and connecting the devices to the distribution network and the systems for monitoring and gathering the data for analysis.
- To develop learnings on the use of the new hardware, IT and communication systems being developed and tested under the SOGNO project in order to determine their value and suitability for use by ESB Networks and other DSOs internationally.
- Assess how the SOGNO automation functionalities and cloud-based business offerings could be provided as turnkey services, which can be deployed either as an alternative or in addition to the existing SCADA systems to provide additional functionalities and capabilities in managing and operating DSO networks.
- Support the broader objective and learnings in conjunction with our partners as part of the Horizon 2020 project to successfully demonstrate the value and the practical feasibility of the SOGNO concepts for designing, testing and validating the 5 power system services to TRL 6.

4. PROJECT MANAGEMENT REPORTING - HORIZON 2020

The SOGNO project was split into two distinct periods, each with their own set of reports. The first reporting period concentrated on investigating the possibilities of what could be achieved within the overall SOGNO project resource and technological constraints while managing expectations. For instance, a SOGNO partner was particularly keen that the communications between the field sensors and the platform would be achieved by utilising 5G technology, however in the absence of an available 5G service in any of the areas where the field trials were being undertaken, the project relied upon 3G and 4G technology.

The second reporting period concentrated upon the actual installation of the hardware on real live networks, which had been researched in earlier parts of the project, and the implementation of three services. FLISR, State Estimation and Power Quality.

The SOGNO reports and published papers are available on the SOGNO website - https://www.sogno-energy.eu.

5. TRIAL RESULTS - LEARNINGS AND RECOMMENDATIONS

In order to validate the concepts developed in the SOGNO project ESB Networks led the co-ordination and installation of the hardware and activities required to deliver and validate field trials on the Irish distribution network. This required the coordination of ICT architectures and the physical installations at the trial sites. ESB Networks succeeded in designing the installations, securing permission for the installations from Asset Management and local networks management, commissioning the operational monitoring and data collection technologies at the trial sites which included;

- Installation of MQTT modems in all network switching devices in both Mullingar and Waterford Trial Sites, to input into the SOGNO FLISR service

- ➢ Installation of current / voltage MV sensors and associated monitoring / communications devices, to input to the SOGNO State Estimation and Power Quality service on the Dunmore interface outlet
- ➢ Installation of four voltage only monitoring devices at various points along the Dunmore interface outlet, for the validation of the State Estimation service

5.1. State Estimation

For State Estimation, we built two MV monitoring points on an MV outlet, one at approximately 25% along the line and another on a single-phase spur, near the end of the line. Based upon the readings from just these two points the service has been proven to accurately predict the voltage and current at any point along the outlet.

We deployed Advanced Power Monitoring Units, which were developed by our SOGNO partner MAC in Limerick.

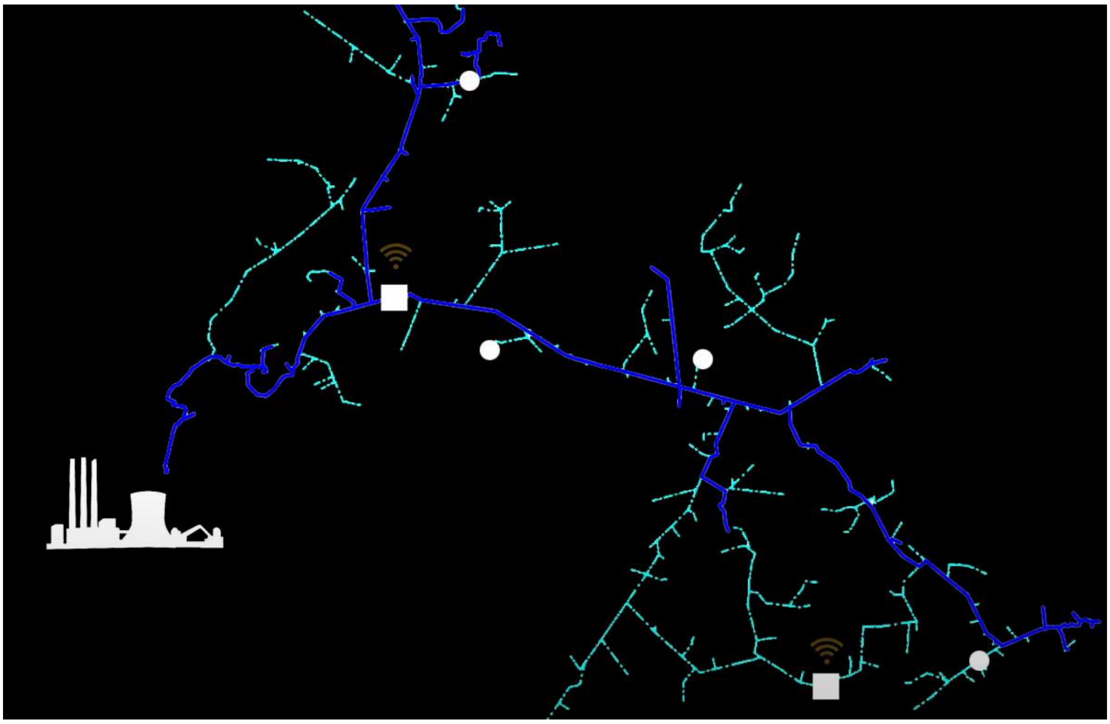

Figure 5.1 State Estimation Test Network

The State Estimation outputs were visualised through the Grafana interface, which is a visualisation programme and from where results can be downloaded for off-line evaluation (see Figure 5.2). The Grafana visualisation tool allows the selection of historical data by selecting the appropriate time period from the database. All the State Estimation results, namely voltage, phase angle, current and power, as well as power consumed at the substation nodes can be selected and visualised through the user interface. The results are available for each node and line of the grid, thus providing full visibility of the operating conditions, using just two devices to feed the State Estimation algorithm with input measurement data.

Figure 5.2: Visualization of ESB SE results via Grafana interface

The evaluation of State Estimation outputs was carried out as follows:

- Download the State Estimation voltage data for off-line evaluation for a given time period.
- Download the LV voltage data at the comparable points on the network for the exact same time period from a validation APMU.
- Convert LV voltage data to the equivalent MV values reversing the fixed iron losses and dynamic copper losses over the MV/LV transformer based on the measured current values.
- Calculate average voltage data across all phases for the MV equivalent at the LV measurement points and compare with the calculated average MV voltage (across all phases) from the State Estimation output.
- Using this process, compare the results and create the graphs of the results of the comparison.

To validate the State Estimation service, ESB Networks installed four validation MAC APMUs on the secondary side of distribution substations along the network. The estimated voltages provided by the State Estimation service were then compared to actual measured voltages from the validation units.

Note: the data from the validation units was not used as an input to the State Estimation algorithm. The first of these validation units was positioned within 2km of the primary State Estimation monitoring point. The results of the accuracy analysis for this location showed that the State Estimation service was accurately calculating the voltage to less than 0.5% error. The graph of this is shown in Figure 5.3. We then compared the State Estimation estimated voltages with the voltage measured at a point more than 10km away from the State Estimation monitoring point. This highlighted that the State Estimation service had peak errors up to 2.7% maximum, but that it is generally able to provide estimations with an accuracy between 1% and 2% even at the extremity of the outlet. This is shown by the grey trace depicted in Figure 5.4.

Overall, the performed validation proved that the State Estimation service delivered by SOGNO partner, RWTH can provide full observability of very large grids even with only few measurement points available in the field. This was further confirmed during a period of the trial when the second State Estimation injection point, located near the end of the feeder was out of order. The State

Estimation service operated for several weeks using only a single measurement point. The same validation results have been produced referring to the State Estimation output obtained with only the data from a single measurement unit (Drumcannon) actively operating in the grid.

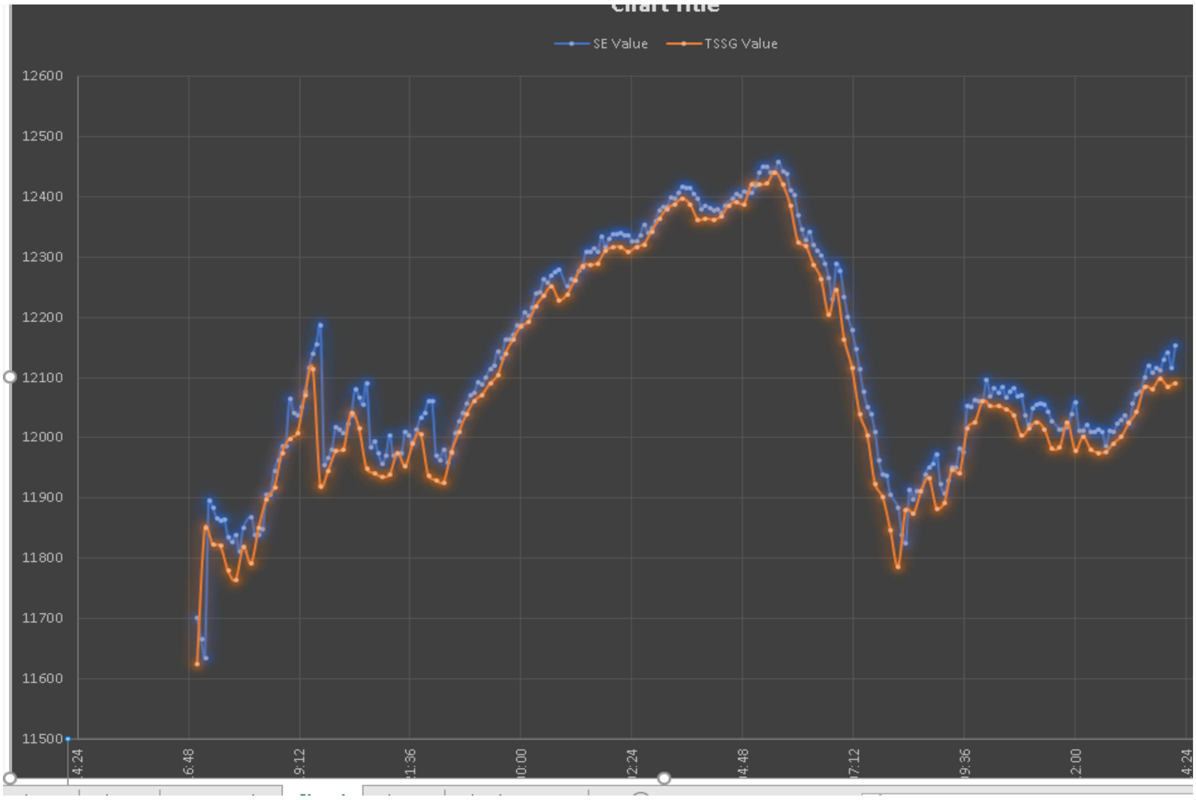

Figure 5.3 – State Estimation values in blue vs the measured value in orange

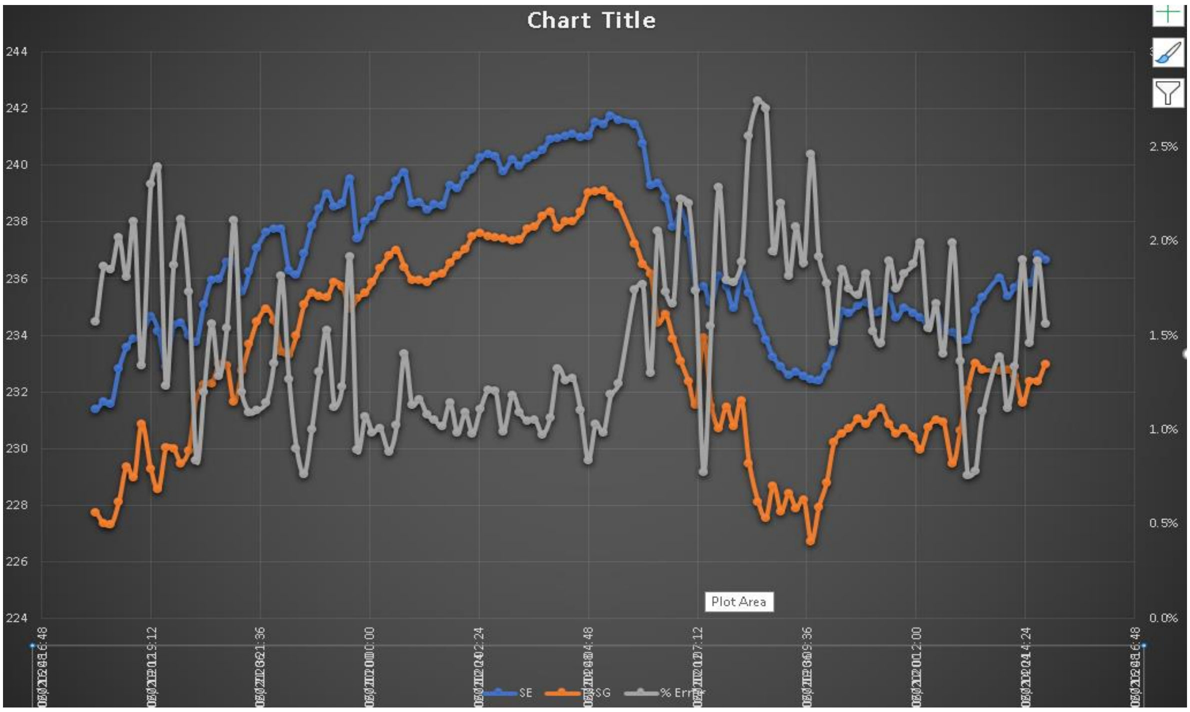

Figure 5.4: Voltage estimation (blue), measurement (orange) and percentage error (grey)

Conclusions on SOGNO State Estimation

The accuracy of the State Estimation outputs, according to the validation procedures put in place, has been found generally to be between 1% and 2%. Beyond the technical validation of the power system algorithms, the trialling of the State Estimation service also served for some additional purposes. In particular, the trials allowed the analysis of the behaviour of the low-cost measurement units and the validation of the proposed architecture, virtualisation concepts and platform promoted in SOGNO.

5.2. Fault Location Isolation & Service Restoration (FLISR)

Although ESB Networks has a highly developed and extensive NMS / SCADA system, there are times when the ability of the system and of the Control Room Operator (CRO) to maintain an accurate situational awareness of the networks can be compromised. This is especially true during adverse weather conditions, when there may be multiple, near simultaneous events occurring on the network. A fault event occurring, even when the network is operating under “normal conditions” may lead to several network devices such as Reclosers and Soulé Switches to relay alarms simultaneously to the CRO. This can take a significant amount of time and concentration, from the CRO to establish:

- the type of fault or event,
- to ascertain the most likely location of the fault,
- to isolate the faulted section,
- to restore the supply to the healthy sections of the network from alternative sources.

At distribution level, one of the limitations currently present is the lack of automated FLISR algorithms able to automatically process the information provided by the network switching devices and to recommend the switching actions in complex grid scenarios. The FLISR service within the SOGNO project allows the automatic processing of the multiple messages generated by the switching devices in the grid and generates recommendations (in the form of an emailed switching plan to the CRO) or the actual commands for the field components to isolate the fault and restore the power supply wherever possible.

The SOGNO FLISR service was deployed using relatively inexpensive additional hardware in the form of additional MQTT modems, which were installed at the downline switching devices. Each remotely controlled network switching device in the trial areas were fitted with an additional IEC 101 to MQTT translation modem. This modem translates the IEC 101 signals which were being sent between the switch RTU (Remote Termination Unit) and the existing SCADA modem and relays the MQTT version of the signals (including alarms) to the SOGNO broker. Figure 5.5 shows the installation of two MQTT modems in connection to a Nu-lec recloser and to a Soulé switch, respectively.

	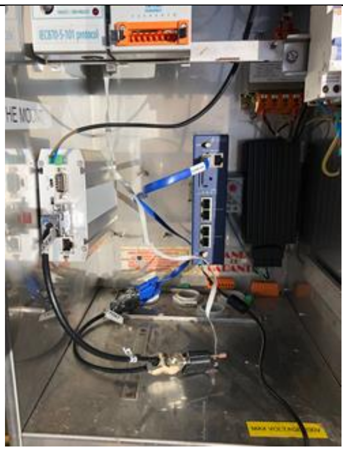
MQTT Modem installed in a Nu-Lec Recloser	**MQTT Modem installed in a Soulé Sectionaliser**

*Figure **5.5: MQTT modems (blue modem) installations at the switching devices.***

Waterford FLISR Trial Site

The FLISR algorithm in Waterford utilises network operational data gathered by Soulé switches and Nu-Lec recloser devices. Figure 1.6 shows a Nu-lec recloser and a Soulé switch connected to one of the overhead lines of the Waterford trial. As previously mentioned, to collect the data from the switching devices, ESB Networks installed an MQTT modem at each Soulé or Recloser site and this data is transmitted to the SERVO platform at TSSG, which hosts the FLISR service developed by RWTH. For the Waterford trial site, based on the information produced by the FLISR service, an isolation and restoration switching sequence is generated for the affected network. This can be sent via email, or through other notification channels, to the CRO to enact the recommended switching sequence.

Figure 5.6 Network automation equipment

Figure 5.7 shows a representative example of the operation of FLISR for the Waterford trial. In this example, a permanent fault at the location indicated on the diagram, will cause the recloser E11 to go through the trip and reclose cycle and will eventually go to “lockout”. Consequently, all the “Passage East” feeder (blue line) will be without supply. Simultaneously, due to the fault, all the switches between recloser and fault (namely S696, S507 and S508 in the Figure) will send a notification of FPI. With this information, FLISR can calculate that a permanent fault has occurred in the grid and that the fault is in the segment immediately downstream the switch S508. Consequently, it will generate a restoration plan for the affected network, so that the CRO can issue commands to the switches/reclosers around the fault. This plan would be as follows:

1. Switch S508 Knocknagapple…………………. Open
2. Recloser R518 Knockroe Passage East ….Open (This will isolate the faulted network section).
3. Recloser E11 Passage East in Kilcarragh 38kV Station, (which initially tripped), will be commanded……Close

At the same time, a forward sweep will be performed for the part of the grid downstream the recloser R518 (the second switching device opened to isolate the fault). This procedure will identify the Normally Open switch S697,

4. Switch S697 Woodstown NO Point ……Close

In this way, the part of the feeder between R518 and S697 will be re-energised, from alternative supply from the “Gaultier E13” feeder (yellow feeder in Figure 5.7).

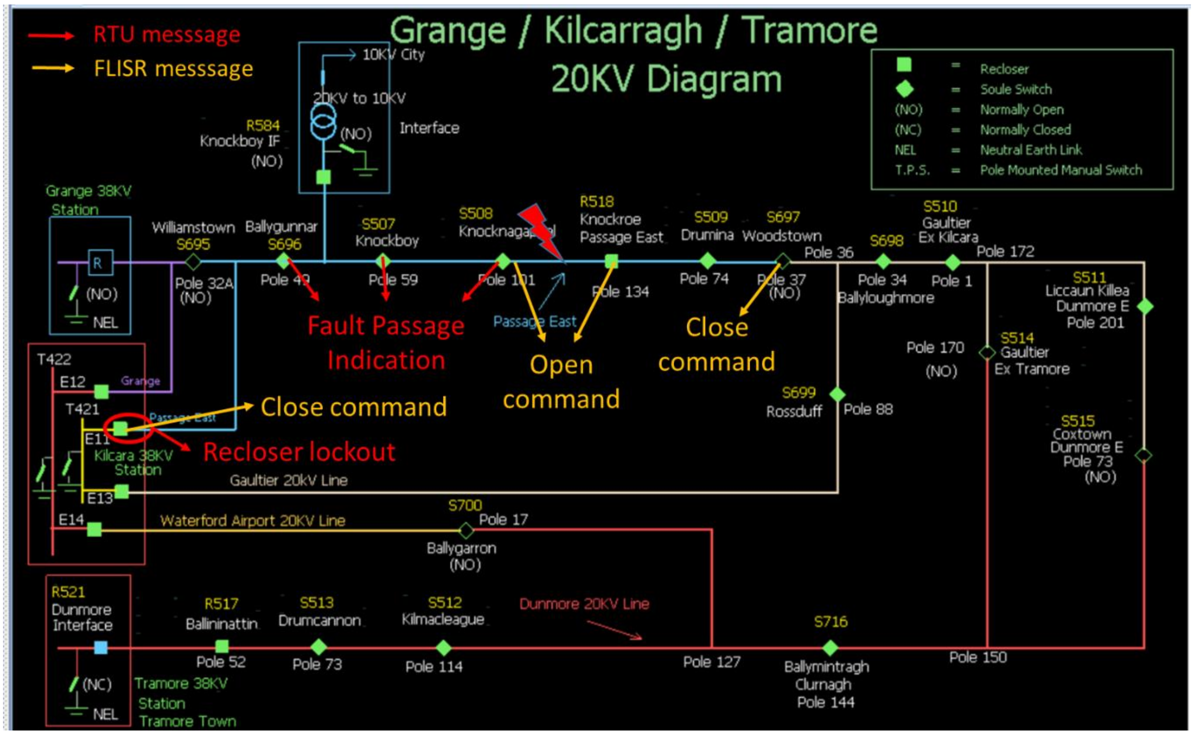

Figure 5.7: Example of FLISR operation in the Waterford trial

Mullingar FLISR Trial Site

The Mullingar trial site is an automatic FLISR scheme called “Loop Automation”. There are five down-line reclosers in this scheme, which are each programmed in a specific way. These are in addition to the main outlet protection devices located in the feeder stations. Each recloser in the scheme is designated whether it is close to the feeder station (Feeder Recloser), halfway along the outlet (Mid-Point Recloser) or the Recloser at the Normally Open (NO point), which is between the two outlets (Tie Recloser). For the Mullingar trial site, data is gathered from Nu-lec recloser devices only, as Soulé switches are not installed on that circuit and are also incompatible with Loop Automation schemes.

This existing automation scheme does not rely on any form of communication between the individual reclosers or with the SCADA control room. Each recloser operates autonomously based on over current, timers and loss of voltages, to take certain actions. In this way, the scheme works to isolate the faulted section of the outlet and to restore the supply to the un-faulted part of the network. This however results in the fault site being re-energised a second time from the alternative supply before the faulted section of network is eventually isolated.

The purpose of installing the SOGNO FLISR service in the Loop Automation scheme in Mullingar, was to establish how effective the SONGO FLISR service was, when compared to the existing LA scheme.

Figure 5.8 shows an example of the FLISR operation logic for the Mullingar trial. In the example, following a back-bone line fault at the indicated location the following sequence will happen automatically

1. Recloser R186 will open to isolate the fault and, if the fault is permanent, it will go through the reclose sequence to “lockout”.
2. R185 will have lost supply completely. In its logic, it will invoke a reverse “alternative” set of protection settings which are much lower than the forward feeding settings
3. Once R186 had opened, R184 experienced a loss of supply on one side of the recloser.
4. After 60 seconds, R184 will close automatically, re-energising the fault (as R185 is still closed)
5. R185 will now be feeding into the fault, and will trip, thus isolating the faulted section of the network.

During this time all alarms, circuit breaker positions etc are being relayed to the SONGO FLISR algorithm, which is processing the information in real-time.

After the initial fault occurrence and reclose sequence, all the reclosers affected by the fault, will relay their status and alarm information to the SOGNO FLISR service. The algorithm will then deduce the location of the fault from the fault passage and alarms which are generated from each recloser.

Even though the LA scheme will continue on automatically and reconfigure the network as described above. The FLISR algorithm will generate an alternative switching plan as if the LA scheme was not operating. Following the fault and the tripping of Recloser R186, the switching plan to isolate the faulted section of the network and restore the supply to the un-faulted section(s) would go as follows:

1. FLISR will generate an “open” command for the recloser R185,
2. The Normally Open recloser R184 will be commanded to “close”.

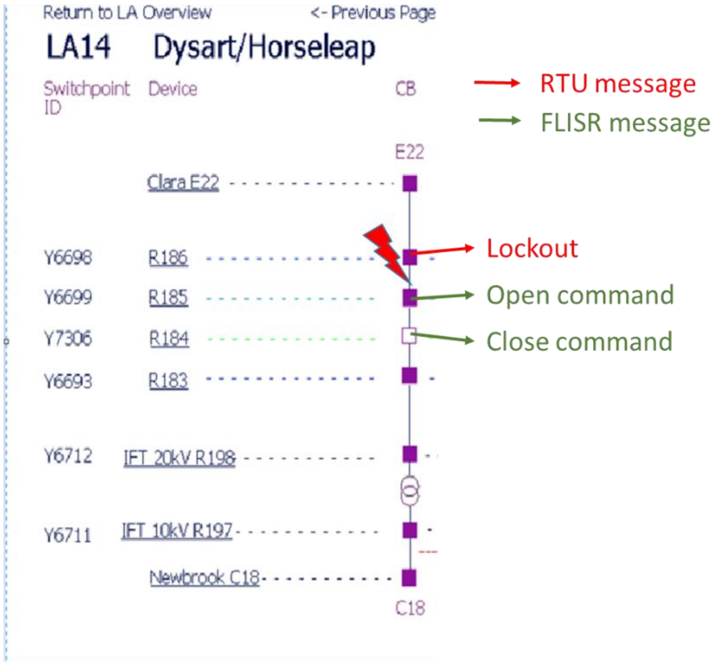

Figure 5.8 Mullingar Loop Automation Scheme

After a fault, such as the situation described above, it was hoped that we would have sufficient data in order to compare the operation of all schemes. Unfortunately, at the time of writing this report, there have not been any permanent back-bone line faults on either the Waterford or Mullingar networks since the FLISR service went live.

In principle it can been seen that there may be an advantage to having a FLISR service, in that the fault is not re-energised after the initial tripping. However, the SOGNO FLISR scheme relies on fully functioning 100% reliable mobile communications platform to operate correctly. During adverse weather conditions, the reliability of the communications networks, especially the public mobile phone operators' networks can be sub-optimal and not be sufficiently robust for the requirements of ESB Networks. The SOGNO FLISR service was successfully tested and demonstrated using simulation software by our SOGNO partner RWTH.

5.3. Power Quality

In ESB Networks, the evaluation of Power Quality has been conducted referring to the standard IEC 50160 "Voltage Characteristics of Electricity Supplied by Public Electricity Networks". ESB Networks has implemented Power Quality alarms for three use cases based upon the above specification:

- Voltage Violations Detection
- Voltage Unbalance Detection
- Harmonics Issues Detection

The Power Quality was processed using an algorithm, written and developed by SOGNO partner, TSSG. It was displayed using the Grafana visualisation tool. The data from the primary SE monitoring point at Drumcannon, on the Dunmore interface outlet, was used as the input to the Power Quality service. Violations of any of the three parameters listed above generated alerts in the Grafana platform. Alarms are defined on the Grafana User Interface, providing alerts when Power Quality data breaches a defined threshold or when no data is received from an APMU for a 30-minute period (thus signifying a possible communications issue). These alerts are presented to relevant personnel through an IM service and/or email/SMS message once a relevant measurement breaches its defined thresholds or fails to receive communication.

Voltage Violation Detection

In Ireland the nominal LV voltage is 230V, so the Power Quality alarm threshold was set at ±10% of that figure, i.e. 207V – 253V (or 18.237 kV – 22.289 kV when converted to MV). If the voltage goes outside these limits, alerts are sent as described above through the dedicated notification channels.

Voltage Unbalance Detection

This Power Quality indicator relates to the relative voltage variance measured between each of the phases on the 3-phase network. On an ongoing basis, the R, S and T voltage values are compared. Then, for each period, the % variance between recorded voltage values R&S, R&T and S&T is calculated for each interval. A look-back calculation is then performed (every interval, i.e. every 10 minutes) to determine the voltage distribution for each of R-S, R-T and S-T, i.e. the percentage variance for the previous week, namely the previous 1008 10-minute periods.

Section 4.2.4 of IEC 50160 states the following: "*Under normal operating conditions, during each period of one week, 95% of the 10 min mean r.m.s. values of the negative phase sequence component (fundamental) of the supply voltage shall be in the range of 0% to 2% of the positive phase sequence component (fundamental)*."

Readings outside these parameters would constitute a fail, requiring the DSO to act to bring the unbalance figures within the acceptable range. A visualisation of the voltage unbalance factor for the Waterford grid is shown in the Figure 5.9 below, which displays the unbalance factor for several days of a week. Note that the voltage unbalance does not exceed the 2% limit on the graph. The network is therefore within the acceptable voltage unbalance limits. Such results were confirmed also by longer-term analysis of the measurement data collected in the field. It is also worth noting that the Grafana data analytics tool does not support the data analysis capabilities to perform the calculations and necessary to enable Voltage Unbalance Detection, therefore TSSG developed a separate piece of software to perform the necessary analysis and output the results. These results are fed into a time-series database and from there are visualised through the same Grafana interface as the device measurements.

Figure 5.9 Voltage Imbalance, expressed as a %

Total Harmonic Distortion of the Voltage

Harmonic currents occur at frequencies of multiples of the fundamental, due to non-linear loads such as those found in heavy industrial machines. Current at higher frequencies can present issues in power systems such as communications errors, overheating and hardware damage, which necessitates the monitoring of these parameters. The 3rd, 5th and 7th harmonic for current and voltage as well as the total harmonics value are read from MV APMU devices and stored in a time-series database which is then visualised on the Grafana interface as shown in Figure 5.10.

Section 6.2.5 of EN 50160 states (edited): *Under normal operating conditions, during each week, 95% of 10 min mean r.m.s. values of each individual harmonic voltage should be less than or equal to the indicative values given in the IEC specification*.

EN 50160 does not set out hard and fast limits for any particular harmonic order but provides indicative values of individual harmonic voltages for the 3rd, 5th and 7th expressed in percent of the fundamental voltage.

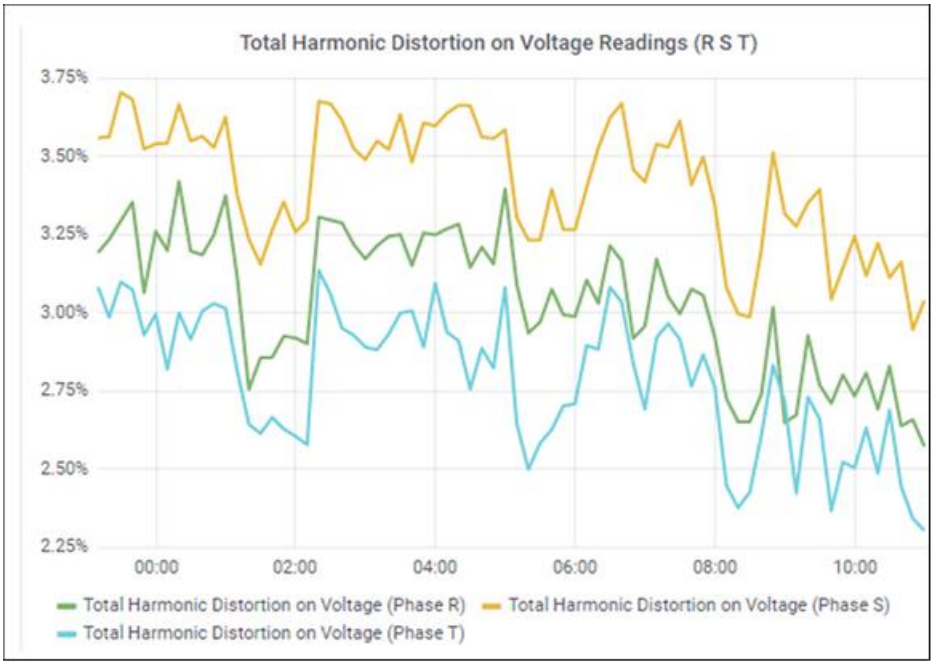

Figure 5.10: Visualisation of the Total Harmonic Display

Conclusions SOGNO Power Quality

The SOGNO project proved that the monitoring of the advanced Power Quality parameters is possible both via the deployment of smart measurement devices in the field and as an indirect result of other services, such as the SE service. Accordingly, promptly activating suitable procedures and countermeasures needed to mitigate the effects of the detected anomalies, can be a key factor for the efficient and reliable operation of the grid.

It is worth highlighting that the monitoring of the Power Quality parameters will become more and more important in the near future, due to the large penetration of Low Carbon Technology such as, electric vehicles, heat pumps, the connection of battery storage and multiple components equipped with disturbing power electronics interfaces.

6. PROJECT TIMELINES

The Horizon 2020 EU Grant awarded ESB Networks €575,333. The project was delivered successfully on time and in budget. The delivery programme ran for a duration of 30 months from January 2018 to end June 2020 in line with its originally envisioned timeframes.

In conjunction with the SOGNO partners, ESB Networks completed all its objectives for the SOGNO project and submitted and disseminated all the necessary reports required under the Horizon 2020 Grant requirements. Table 6.1 highlights the project objectives and identifies that the objects were successfully met for each of the cloud base services in conjunction with our SOGNO partners.

Project Objectives		
1	To successfully develop, test, trial and validate the three services, hardware and software solutions with our project partners for the Irish trials to TRL 6.	✓
2	Testing the benefits of the three services of state estimate, FLISR and Power Quality, being trialled on our distribution network and the value in how they could be used and adapted for use in managing and operating the distribution network.	✓
3	To assess the techniques and develop the methods, processes and procedures for safely installing and connecting the devices to the distribution network and the systems for monitoring and gathering the data for analysis.	✓
4	To develop learnings on the use of the new hardware, IT and communication systems being developed and tested under the SOGNO project in order to determine their value and suitability for use by ESB Networks and also other DSOs internationally.	✓
5	Assess how the SOGNO automation functionalities and cloud-based business offerings could be provided as turnkey services, which can be deployed either as an alternative or in addition to the existing SCADA systems to provide additional functionalities and capabilities in managing and operating DSO networks.	✓
6	Support the broader objective and learnings in conjunction with our partners as part of the Horizon 2020 project to successfully demonstrate the value and the practical feasibility of the SOGNO concepts for designing, testing and validating the 5 power system services to TRL6.	✓

Table 6.1 – Project Objectives

7. TRANSITION OF LEARNINGS

FLISR

ESB Networks has invested heavily in an extensive Network Management and SCADA Systems to control and operate the distribution network in the Republic of Ireland.

Working on this project has highlighted aspects where ESB Networks may be able to improve our service to our customers, especially in terms of improving our response times in restoring supply following a fault. However, given ESB Networks investment and buy-in to our existing NMS / SCADA systems, DSOs such as ESB Networks would find it almost impossible to move away from the existing business model in favour of a cloud-based solution for mission critical services such as FLISR. FLISR will be one of the streams of work being undertaken as part of the Active System Management project.

State Estimation

It was not proven in the project, how State Estimation would be affected by the presence of a voltage regulator in the circuit or how the service would be affected during back-feeding arrangements, therefore ESB Networks would require far greater development of the service, above the TRL 6 currently achieved.

It was also noted, that although State Estimation could predict voltage, current and therefore power levels at over 100 nodes on the Dunmore interface outlet, it was not possible to verify the accuracy of the current element of the SOGNO service due to the strict Covid-19 restrictions, which were in place during the validation stages of the SOGNO project. It was also noted that during the installation of the validation APMUs for State Estimation for the voltage, that it was far easier and significantly more cost effective to install the APMUs at LV and use simple calculations to convert these values to MV, rather than install the MV CT / VT / APMU combinations.

Installing the MV ALTEA / MAC APMUs required significant hardware and an outage of the MV circuit to install, whereas the LV APMUs were all installed live with a very small team, without requiring any supply interruption to our customers. The installation of LV APMUs also had the added value of giving actual measured values, rather than estimated values. The measured values would reflect the effects of any voltage regulator in the circuit and back feeding arrangements, as they would be the actual voltages being supplied to our customers at those points.

As a counter point, the Power Quality would only be achievable by using the MV ALTEA / MAC APMU.

Power Quality

Power Quality is currently measured on ESB Networks using Power Quality monitoring devices installed in different locations across the distribution network in line with regulatory approved requirements to monitor and coordinate with the TSO on operating the network within the regulated limits. ESB Networks will continue to install Power Quality monitoring equipment as approved under PR5. Power Quality will be one of the streams within the Active Systems Management (ASM) project in ESB Networks with the learnings from the SOGNO project being transitioned into the ASM project.

Developments of ESB Networks SCADA displays & FPI's in Soulé Switches

We have learned that there is room for improvement, when it comes to how we depict some of our network switching devices in our SCADA system. It was apparent that the display of our Soulé switches in particular could be improved. This is especially true for Soulé Switches at Normally Open Points on the network. It is recommended to add the name and feeding station for the two outlets either side of the switch for clarity. Additionally, it is recommended to indicate the side of the switch which the internal VT is connected to, as this identifies the outlet to which the "AC Supply Fail" alarm refers to. This could be as straightforward as putting a symbol of a transformer on one side or the other of the breaker symbol on the screen.

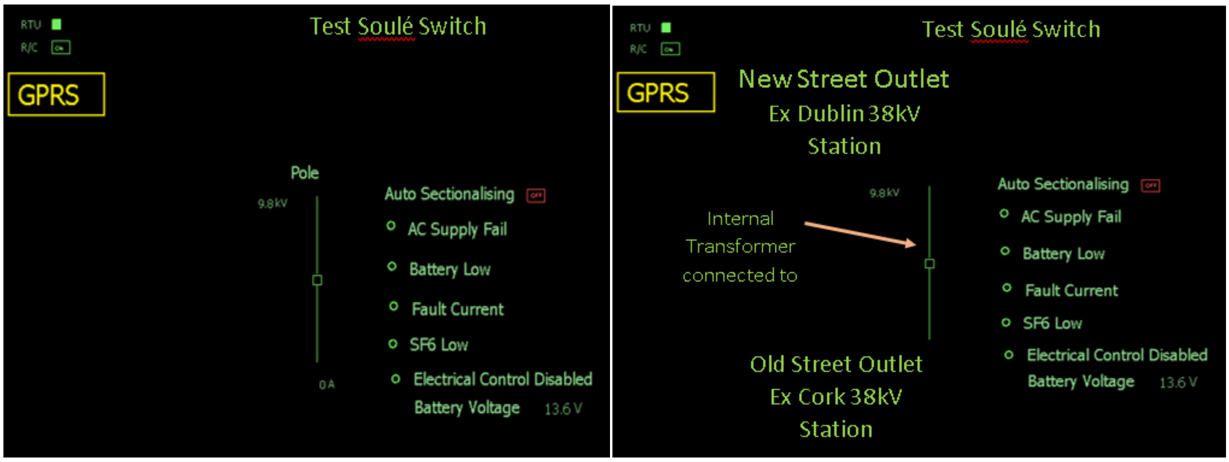

Figure 8.1 EXISTING SOULÉ SCADA SCREEN vs Proposed additions to Soulé SCADA Screen

The Fault Passage Indicator within a Soulé Switch is a programmable setting. Frequently, these FPI trigger levels are set generically. It is recommended that the settings for the FPI trigger levels be set individually according to the protection settings on that particular outlet and should be site specific.

Future of SOGNO in ESB Networks

As SOGNO's objective was only to develop cloud-based energy services to TRL 6, it is considered by ESB Networks that these services will not be sufficiently mature for their transition to BAU at this technology readiness level.

The new energy services may be evaluated in the future when they have achieved market ready TRL status and when deployment and integration challenges with existing core network management systems have been demonstrated and proven.

Dissemination of Learnings

Throughout the SOGNO project ESB Networks worked with our project partners to disseminate the developments and learnings of all aspect of the project through the regular project meetings and the detailed reporting requirements required as part of the Horizon 2020 Grant.

ESB Networks presented at industry conferences such as the National Power Summit 2018 and FNN-Kingress Netze 2019. The SOGNO project was presented as part of our Autumn Innovation webinar series and we have developed a video to disseminate the project to the wider public. A detailed report on the dissemination events can be found on the SOGNO-energy.eu website media section here.

Details of the reports, publications and videos can be found on the media section of the SOGNO website www.sogno-energy.eu.

If you would like further information/data from this project, please contact us at innovationfeedback@esbnetworks.ie