SOGNO

D5.3 v1.0

Evaluation of scalability and performance

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Abstract
This document provides a comprehensive assessment of the scalability performance of the SOGNO solution. This includes a detailed analysis about both the horizontal and vertical scalability of the designed SOGNO services, the evaluation of the available options for the scalability of the most critical platform components, and an overview of the role of 5G to pursue wide scalability of the proposed SOGNO concepts and solution.

Keyword list
Scalability, SOGNO services, SOGNO platform, SOGNO reference architecture, 5G, Edge Cloud.

Executive Summary

The SOGNO project promotes a highly innovative way to monitor, manage, control and automate the distribution grids of the future. The key aspect of the SOGNO vision is the virtualization of the intelligence needed for distribution grid control and automation. Such virtualization process is fostered by the recent developments in the ICT sector and will be further boosted by the upcoming roll-out of the 5G mobile communication. In the scenario envisioned by SOGNO, Distribution System Operators (DSOs) will require new approaches to deal with the new challenges emerging at the distribution grid level and to keep up with the new technologies offered by 5G, ICT, cloud computing and machine learning. This can be achieved by switching from old and monolithic solutions that are currently installed in control centers to service-based software products, which allow for easy configurability, upgradeability, and for a more flexible integration of the specific functionalities of interest for the DSOs. Following this vision, SOGNO delivered the design, implementation and demonstration in the field trials of distribution grid services for system awareness and self-healing.

One of the challenges for the large roll-out of distribution grid automation services is the scalability of the proposed concepts and solutions. SOGNO addressed this challenge taking into account the most innovative approaches used in the Internet of Things (IoT) domain as well as the last developments in the field of distributed computing and optimization. In the following of this document, the scalability problem is analysed looking at three main aspects that have a direct impact. First, the design of the distribution grid services is considered: solutions to distribute the proposed system awareness and self-healing algorithms are described, thus paving the way for an easier and incremental deployment of these services. Secondly, the scalability of the software solutions used to build the underlying platforms, which host the automation services, is analysed. In this case, SOGNO built its solution looking at the microservices approach and embedding the most recent technologies used in the IoT domain. Last but not least, the scalability of the proposed concepts is also analysed from a communication perspective. In this case, the large benefits achievable through the upcoming 5G technology are presented in relation to the potential requirements of the future DSO applications. Overall, this deliverable complements the work presented in the deliverable D5.2 on the outcome of the SOGNO field and laboratory trials, highlighting how the innovative ideas and implementation validated in the pilots can be extended to larger scale deployments.

Authors

Partner	Name	e-mail
RWTH		
	Marco Pau	mpau@eonerc.rwth-aachen.de
	Markus Mirz	mmirz@eonerc.rwth-aachen.de
	Jan Dinkelbach	jdinkelbach@eonerc.rwth-aachen.de
	Jonas Bielemeier	jonas.bielemeier@eonerc.rwth-aachen.de
EDD		
	Robert Farac	robert.farac@ericsson.com

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1. Introduction

The project Service Oriented Grid for the Network of the Future (SOGNO) is funded within the Work Program H2020-LCE-2017-SGS. It officially started in January 2018.

1.1 Related Project Work

This report is directly linked to the activities performed in the Task T5.7 about the scalability evaluation, but is strongly connected also to the activities of WP2 and WP3 in terms of distributed design of the power system services and the work done in WP4 for the definition of the best platform technologies to be used for hosting the grid automation services. Moreover, the 5G angle is also taken into account, which was present in all the above-mentioned WPs as reference communication technology linking field instrumentation and platforms as well as services in the cloud. The Figure 1 below gives the overview of the structure of the SOGNO project. This deliverable belongs to WP5, which is the last step for the demonstration and validation of the proposed concepts and solutions.

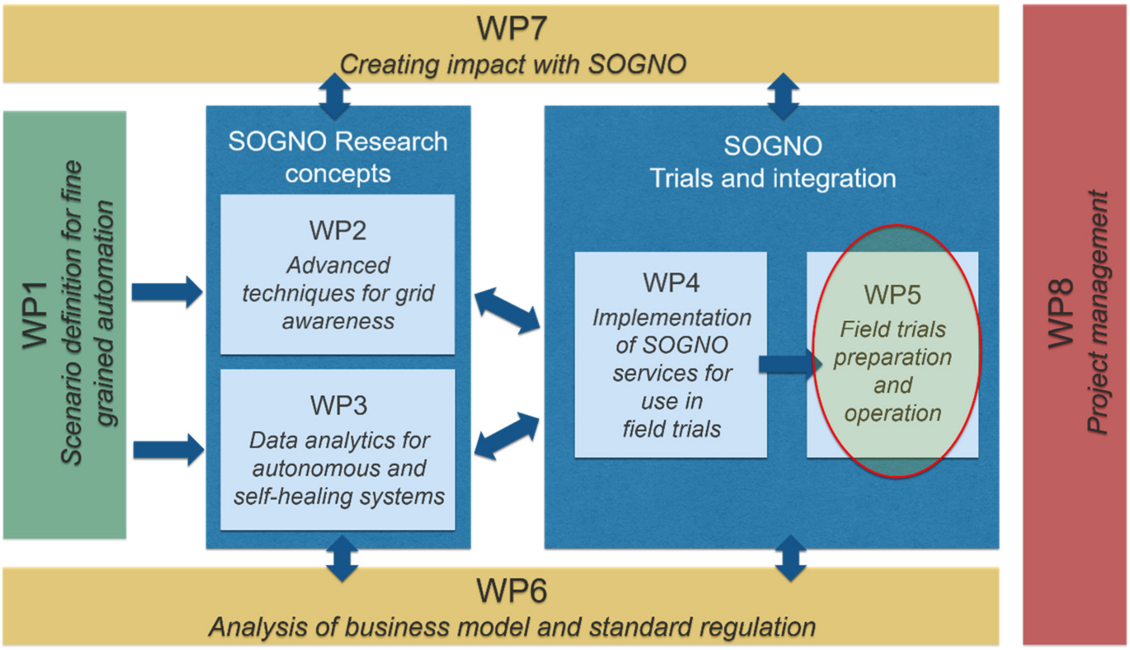

Figure 1: Overview of SOGNO activities

1.2 Objectives of the Report

The objective of this report is to complement the demonstration and validation wok carried out in the field trials (presented in deliverable D5.2) by showing how the power system services developed in SOGNO can be deployed in a larger scale roll-out. Three aspects are considered in this report: i) the scalability of the designed power system services; ii) the scalability of the proposed platform and middleware components; iii) the scalability from a communication perspective, focusing on the large set of benefits unlocked by the future availability of the 5G mobile communication.

1.3 Outline of the Report

This report details the scalability issues to be considered for a large roll-out of the SOGNO services and presents the proposed solutions conceived to address those issues. Before entering into the details of the scalability problem, Chapter 2 gives a starting introduction about the envisioned requirements, from a DSO perspective, for the monitoring, management, control and automation of future distribution grids. This serves to underline why the scalability problem is particularly relevant, above all at the distribution level of the electric grid and when considering the installation of grid intelligence not only in Medium Voltage (MV) but also at the Low Voltage (LV) level of the system. Chapter 2 also provides a short summary of the main features of the SOGNO solution with respect to mentioned DSO requirements, in order to make this report as self-consistent as possible.

Chapter 3 addresses the probably most important problem for scalability, namely how to distribute the implementation of the designed services for system awareness and self-healing provision. To this purpose, Chapter 3 will refer explicitly to the services designed and demonstrated during the SOGNO project, namely: State Estimation (SE), Power Quality Evaluation (PQE), Power Control (PC), Fault Location Isolation and Service Restoration (FLISR) and Load and Generation Forecasting (LF and GF, respectively). For each one of these services, the particular requirements and potential issues for their large scale roll-out will be presented and, where needed, the particular solutions devised within the SOGNO project to guarantee the scalability will be presented.

Chapter 4 deals instead with the scalability of the proposed SOGNO platform. Since the virtualization of the grid intelligence and the possible use of cloud solutions are among the key features promoted by the SOGNO project, this aspect plays of course a primary role in the overall evaluation of the SOGNO solution. Even in this case, the ICT solutions considered and recommended by SOGNO to ensure a large roll-out of the proposed services are presented and discussed.

Chapter 5 covers the third main aspect to be considered for a large scale roll-out, namely the used communication infrastructure. The focus in this case will be on the potential unlocked by the 5G technology. In fact, several innovative features coming with the 5G would perfectly fit the requirements for a large roll-out of the grid automation services, thus offering a unique opportunity for a smart and future-proof deployment of the smart grid functionalities.

Finally, Chapter 6 summarizes the main results of the performed scalability analysis and provides the last remarks that conclude this report.

1.4 How to Read this Document

The document can be read on its own but other SOGNO Deliverables are important to fully understand the vision and solutions offered by SOGNO. In particular, the following Deliverables are important to have a complete view of the discussed aspects.

- D2.3 – Validation of techniques for grid awareness and their interfaces and services for grid awareness: it gives more details about the concepts behind the State Estimation (SE), Power Quality Evaluation (PQE) and Power Control (PC) services and about the required interfaces.
- D3.3 – Validation and description of the techniques, interfaces and services for autonomous & self-healing power systems: it gives the details about the implementation of the Fault Location Isolation and Service Restoration (FLISR) and Load & Generation Forecasting (LF & GF) services, as well as about the required interfaces.
- D4.1 – Definition of overall SOGNO System Architecture: it provides the details on the overall architecture used for the implementation and virtualization of the SOGNO services.
- D5.2 - Report on the outcome of the SOGNO Field Trials and laboratory tests: it provides the report on the final SOGNO solution as well as the demonstration and validation of the SOGNO services in both laboratory and field trials.

2. Distribution Management System requirements

Future distribution grids will be more and more characterized by an increasing penetration of Distributed Generation (DG), mainly based on Renewable Energy Sources (RES), and by the presence of new components such as electric vehicles and electric heating, ventilation and air conditioning systems. All these components are generally connected to the main grid via power electronics interfaces, which can be cause of potential power quality issues and determine different dynamics in the grid, which need to be carefully monitored by distribution grid operators. These changes will bring several challenges for the Distribution System Operators (DSOs) in the next future in terms of network management, control and planning. While these challenges are often tackled by investing in network reinforcements, this solution is not the most cost-effective and sustainable, above all from a final customer, environmental and social perspective.

The SOGNO project promotes the use of software and grid intelligence to address the above mentioned challenges. Using software solutions is an alternative that allows having a better utilization of the network assets and removes, or postpones, the need for expensive and invasive reinforcement actions. Moreover, the deployment of smart solutions based on intelligent software enables the system operators to have a better awareness on how their grid is operating and evolving. This, in turn, opens the opportunity to further improvements in the grid management, which would eventually translate into better efficiency and reliability, from a grid perspective, and into a better business from the DSO side. It is worth noting that the need to find a better balance between hardware and software investments of the DSOs has been recently recognized also by the European Commission with the Clean Energy Package, with which the EU national regulators are recommended to take concrete actions for better supporting the investments in Operating Expenses (OPEX).

The disruptive concept promoted in SOGNO is that software intelligence can be provided as a service to the DSOs, in contrast with the provision of monolithic and expensive SCADA systems. There are multiple reasons for aiming at this change of paradigm, above all when looking at the distribution system scenario. Among these reasons, the most relevant ones are:

- The implementation of algorithms as modular microservices gives huge flexibility to the DSO in terms of choice of the specific algorithms/services to be integrated in the Distribution Management System (DMS), the time of deployment of each service (timely reaction to possible issues detected in the grid), possibility to upgrade the underlying software to import more advanced functionalities, substitution of obsolete software or services, integration and interconnection of different algorithms.

- The use of modular microservices in a platform with open interfaces removes any need to adopt a vendor lock-in monolithic system and opens to the integration of multi-vendor solutions, where each service can be potentially purchased by a different vendor according to the trust, quality and set of functionalities offered together with the service.

- The shift of paradigm towards a service-based management and automation of the distribution system will be implicitly required by the same nature of the distribution smart grids, since distribution systems are changing, and will keep changing, with a pace never experienced before, thus requiring DSOs to quickly adapt and update their grid intelligence accordingly, on the basis of the new challenges present in the grid.

- The frequent changes that will occur in the distribution grid also concern the components and resources that will be available in the system; this brings a need for frequent updates of the applications to integrate new functionalities or to adjust configurations and settings in order to follow the changes occurred in the grid; all these updates and modifications are easier to implement when having small services running on independent modules that can be remotely upgraded and configured.

- The effective realization of the smart grids is more and more an interdisciplinary task that requires deep expertise in different domains, such as power systems, power electronics, telecommunications, ICT, operating systems, cybersecurity, etc. The use of service-based platforms allows DSOs to flexibly select the service providers on the basis of their focus and expertise. As an example, the core automation algorithms could be provided by providers with strong background in power systems, while visualization tools and other

ICT components can be offered by different companies with a stronger expertise in this area. In this way, it will be possible to fully meet the DSO requirements and to provide the best possible solutions with the most advanced technologies available in each domain.

- The components available in the grid will generate a large amount of data over time, above all when the number of resources and monitoring devices in the system will start growing. Recent data analytics tools based on machine learning can make the best use of these heterogeneous data, offering auxiliary functionalities and insights that are not possible to obtain with conventional power system algorithms. A service-oriented paradigm allows for an easy and smooth integration of these functionalities/services in parallel to traditional power system automation tools.

- From a purely economic perspective, the use of service-based platforms opens a larger and more flexible set of options for the DSOs, allowing them to step into the smart grid without large upfront investments and with the possibility to incrementally add intelligence and functionalities in the grid. This can be a key aspect above all for small-medium size DSOs, which otherwise could find more difficulties in digitalizing their grid and making their grids smarter.

In view of the above considerations, SOGNO developed, deployed and demonstrated different power system algorithms deployed in an IoT platform as a service for DSOs, proving thus the concept of "automation as a service". The developed services can be classified in two macro-categories, namely services for grid awareness and services to provide self-healing capabilities to the distribution system (see Figure 2).

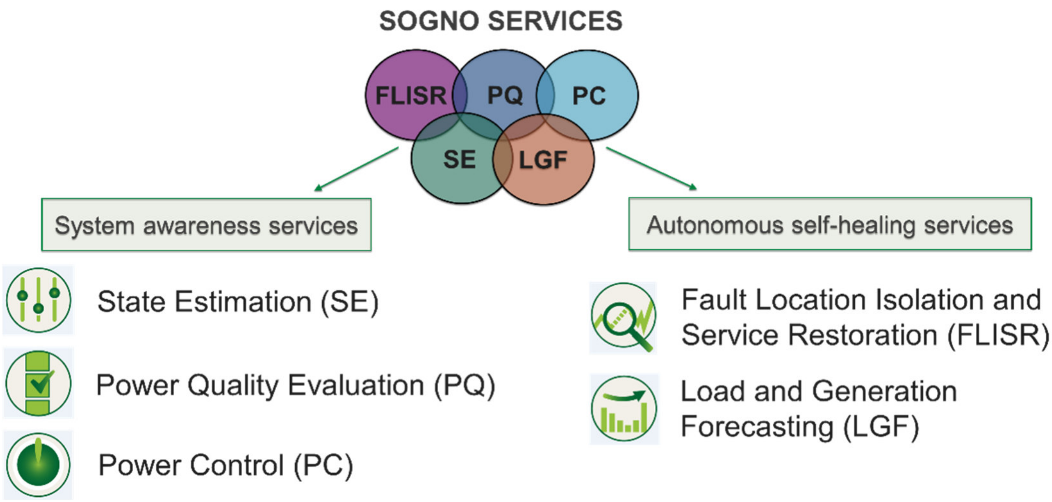

Figure 2: Classification of the SOGNO services.

More in detail, the algorithms developed and demonstrated in the SOGNO project are:

- State Estimation (SE): provides the real-time monitoring of the system, allowing grid operators to have a detailed view of the grid operating conditions and, in this way, to acquire better system awareness. Thanks to the SE service, operators can obtain the full visibility of the grid. Such information can, optionally, be used to trigger specific automation or control routines (e.g. in case of detected anomalies) or can be provided as input to other control functions.

- Power Quality Evaluation (PQE): provides an insight on different parameters associated to the quality of the power supply, such as maximum and minimum voltage levels, maximum and minimum frequency levels, amount of power losses, voltage and current unbalance, individual and total harmonic distortion indexes, etc. Thanks to the PQE service, DSOs can easily monitor the state of health of their grid, detect possible power quality issues that are likely to degrade the power system and, in case, identify the need for specific countermeasures to improve the quality of the power supply.

- Power Control (PC): provides a smart control of the DG and possible other resources available in the grid (e.g. storage systems) in order to solve potential issues associated to a large penetration of RES and to a large mismatch between locally generated and consumed power. Thanks to the PC service, DSOs can avoid overvoltage problems in their grid, can foster the installation of a larger number of RES, can minimize the curtailment of renewable energy generation and can contribute to the overall goal of minimization of CO2 emissions.

- Fault Location Isolation and Service Restoration (FLISR): provides fully automated procedures to detect the presence of a permanent fault in the grid, to localize and isolate the portion of the grid where the fault is and to restore the power supply for all those areas that are not directly affected by the fault. Thanks to FLISR, DSOs can maximize their reliability performance indicators and customers can benefit from a significantly reduced number and duration of the power system service disruptions.

- Load and Generation Forecasting (LF & GF): provides a forecast, with a desired time horizon, about the expected power consumption or generation at specific points of the electrical grid. Thanks to the LF and GF services, DSOs can know in advance what operating conditions will be found in the grid and they can take, or be prepared to take, countermeasures for possible critical periods and conditions.

The above mentioned services open the possibility for the DSOs to acquire a better visibility and awareness about the grid operating conditions and gives them the chance to have fully automated procedures for DG control, fault management and predictive contingency analysis. However, a full roll-out of these services also poses some challenges, above all from a scalability perspective.

A first challenge is the fact that, in the distribution system scenario, the above functionalities and services are critical not only at MV level, but also, and probably above all, at the LV level of the system. In fact, many critical conditions can be expected to occur in the LV grid, since most of the new components, such as renewable energy sources, electric vehicles, electric heat pumps, will be directly connected to the LV level [1]. As a matter of fact, the above services need to be able to cover the entire distribution system, namely both MV and LV grids. From a scalability perspective, this is an important challenge, above all because MV and LV grids are generally very large grids from a topological perspective, namely in terms of number of electrical nodes and branches. As a consequence, the design of the services has to duly take into account this aspect. The solutions conceived in SOGNO to address this aspect will be discussed in Chapter 3.

A second challenge is the large amount of data that will be generated from the components and resources available in the field. While at the very beginning it is likely to expect that only few monitoring devices will be installed in the grid and only few resources will be available for smart control and management, this will quickly change over time. The number of monitoring units and resources in the field, which will be generating data, will progressively grow, thus calling for solutions that are future-proof and that can easily accommodate such a large amount of incoming data. In addition to this, it is worth noting that distribution systems are, due to their nature, grids much more dynamic than the transmission ones. This aspect will be further exacerbated by the increasing share of renewable energy sources, due to their highly unpredictable and intermittent operation. From a DMS perspective, this requires the use of high time resolution data in order to accurately and promptly track the changes and variations occurring the grid. As a matter of fact, the distribution systems of the future will be composed of a very large number of components in the field that are generating data with very high reporting rate. This poses some clear challenges in terms of scalability above all from an ICT perspective. The solutions devised in SOGNO to build a scalable and future-proof ICT ecosystem will be discussed in the Chapters 4 and 5, which deal with the SOGNO platform and the 5G communication, respectively.

In general, in line with the vision and challenges described above, the SOGNO project envisioned two different scenarios for the deployment of the SOGNO services in future DSO platforms. The first scenario refers to the potential deployment of the SOGNO services in the next future, namely in a short-term period (see Figure 3). Due to the disruptive changes associated to the proposed vision, and the lack of a mature market in this direction, it is easily predictable that DSOs will not want to use the automation services as an alternative to existing SCADA systems. The SOGNO services, in this case, can be deployed in parallel to the existing SCADA infrastructure and can offer additional functionalities (with respect to those already given by the traditional SCADA) to tackle specific challenges DSOs are facing due to the evolving grid scenario. SOGNO services could be installed also just for investigation purposes and to build that trust that DSOs need to have before investing in such a kind of solution. The deployment of the services would be in this case centralized, likely in servers or hosting clouds of the DSO, and possible AI-based services or data analytics tools could be implemented to offer new functionalities or insights into the data patterns for the DSOs. In the next future, the communication between field devices and DSO platform would be still based on 4G (or wired) communication.

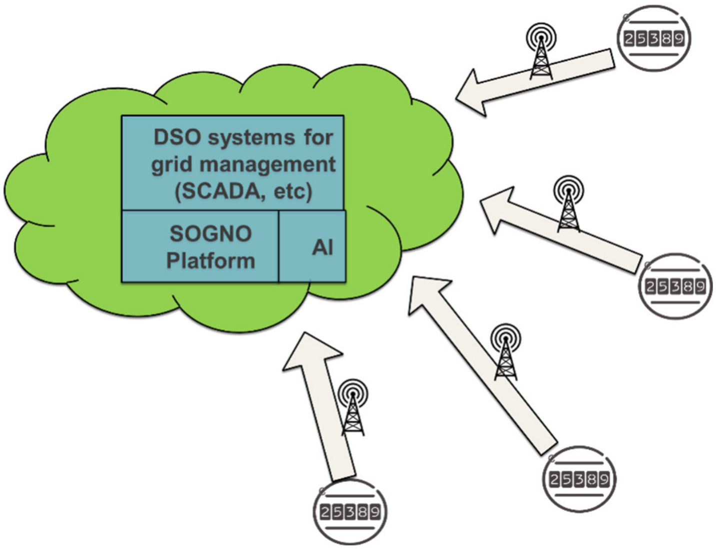

Figure 3: Deployment of SOGNO services in the short term future.

The full potential of the SOGNO solution can be unleashed in a medium long term period, once the market for power system services becomes more mature and when the full roll-out of 5G will be completed. In theory, in future, the entire DMS of the DSOs could be fully built using a microservice approach, thus overcoming the old view of a monolithic SCADA system with a vendor lock-in solution. This scenario is captured in Figure 4. Thanks to the availability of 5G and the edge cloud computing capabilities offered by 5G, it could be possible to have a completely decentralized implementation of the services, which could be installed closer to the field devices, thus improving security and fostering large scalability. Remotely deployed services would provide only the processed data to the central management system (which will be kept to visualize the service results and to give them system awareness to the grid operators), thus minimizing the need of communication of raw data towards the central system. This type of solution will also allow facing the problem of a progressively increasing number of monitoring/measurement units and resources being installed in the grid.

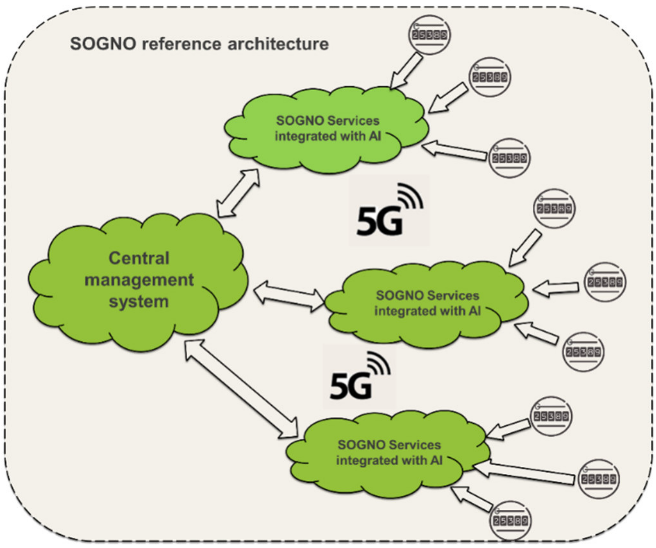

Figure 4: Deployment of the SOGNO services in the medium/long term future.

3. Scalability by design of the SOGNO services

One of the most important challenges for the application of smart services in the distribution system is given by the size of the networks. Distribution grids are in fact, generally, large grids with a very high number of electrical nodes and branches. This can create difficulties in the development of the system models and for the large scale roll-out of specific algorithms, above all for those services that require a detailed model of the grid and that are based on optimization procedures with a large search space. As anticipated in Chapter 2, the deployment of the services is generally needed both at MV and LV level. While often the adopted solution is to decouple the MV and LV grids and to run the management algorithms in a completely separated and independent way, for some services better results could be obtained when considering the interactions between MV and LV grids. This is particularly important above all in scenarios where the available measurement units and/or resources in the grid are reduced to a minimum and thus the services should try to get the best out of the available data and resources, regardless of where they are located. This implies that the services running in the MV and LV grids can require to be coordinated, so that the results or conditions found at one voltage level can be used to improve the outcome of the service running on the other grid level. Such an assumption creates requirements for the design of suitable coordination schemes that could make a little more complex the basic design of the system services. In the following of this Chapter, these aspects are discussed more in detail and the specific challenges and solutions conceived for each of the services developed within the SOGNO project will be presented.

3.1 State Estimation

State Estimation (SE) is the service in charge of providing the real-time view of the operating conditions to the DSOs. This is a key service for DSOs to immediately detect possible anomalies in their grid and to promptly identify the need for specific countermeasures. As a matter of fact, SE is an essential service both at the MV and LV level of the distribution grid, since critical conditions or operating states close to the boundaries can occur both in MV and LV, depending on the particular characteristics of the grid and the particular distribution of loads and DG over the network.

The SE service operates by processing the measurement data provided by the monitoring units installed in the grid. Currently, most of the distribution grids only have a very limited number of measurement devices deployed in the field. The SOGNO project proved that is possible to obtain a first level of system awareness also using only a very limited number of monitoring units in the grid. However, it is clear that the larger the number of monitoring points in the grid, the better the accuracy and the reliability of the results provided in output from the SE service. In order to maximize the accuracies, theoretically, the best option would be to have a single SE algorithm processing simultaneously all the available measurements, covering both the MV and LV levels of the distribution system. This intuitively difficult to realize and a more practical solution is to decouple the MV and LV grids and to have different SE algorithm providing the monitoring for each grid level. Even in this case, MV and LV grids can be still too large to be processed by a unique algorithm, above all when there are strict computation time requirements to comply with and when the SE service should generate its results as quickly as possible. To this purpose, further partitioning of the MV and LV grids can be required to fulfil the practical requirements for a large scale deployment. The division of the SE task among smaller portions of the network allows distributing and minimizing the computational requirements of each SE algorithm, leads to distribute the communication of the measurements among the different zones and permits running in parallel multiple SE instances on smaller areas, thus leading to an overall reduction of the execution times. On the other side, the drawback of this solution is the degradation of the accuracy performance that, as previously explained, is strictly depending on the overall number of input measurements processed by each SE algorithm.

A trade-off between the needs of distributing the computational burden of the SE service and the requirements for sufficiently accurate results is given by the adoption of specific multi-area state estimation approaches. In a multi-area framework, the overall grid is divided into multiple areas, each one having its own SE algorithm. The specific feature of the multi-area SE formulations is that, instead of running the SE services on the individual areas in a completely decoupled and independent way, they implement specific coordination, integration and harmonization procedures that allow combining the local SE results to improve the final results. Such a kind of solution allows keeping the distribution of the SE tasks over multiple areas while mitigating the effects of accuracy degradation arising due to the grid partitioning [2]. Using multi-area SE formulations it is thus possible to decide the compromise to meet, at the same time, the requirements of computation and communication distribution and those of estimation accuracy.

Figure 5 shows an example of multi-area partition for the SE service, which accounts for both a multi-level partition of the distribution grid based on the different voltage levels [3] and for a division in different areas for grids at the same voltage level. Referring to the example, it can be noted that the MV grid can be divided for example in different areas. Different levels of overlapping (no overlapping, minimum overlapping, extended overlapping) can be flexibly selected, also according to the harmonization logic that will be implemented in the SE algorithms [2]. Similarly, the LV grid can be divided in different areas: since LV grids are often composed of multiple feeders, a simple option is to split the SE process among the different feeders, but intra-feeder partitioning can be also applied, similar to what is shown for the MV grid. A further option, which is available both at MV and LV level, is to decouple the SE process on the backbone feeders from the one on the laterals. In the example of Figure 5, this option is presented for example for the LV grid, where feeder-level and concentrator-level (associated to the laterals of the LV grid) estimators are considered separately.

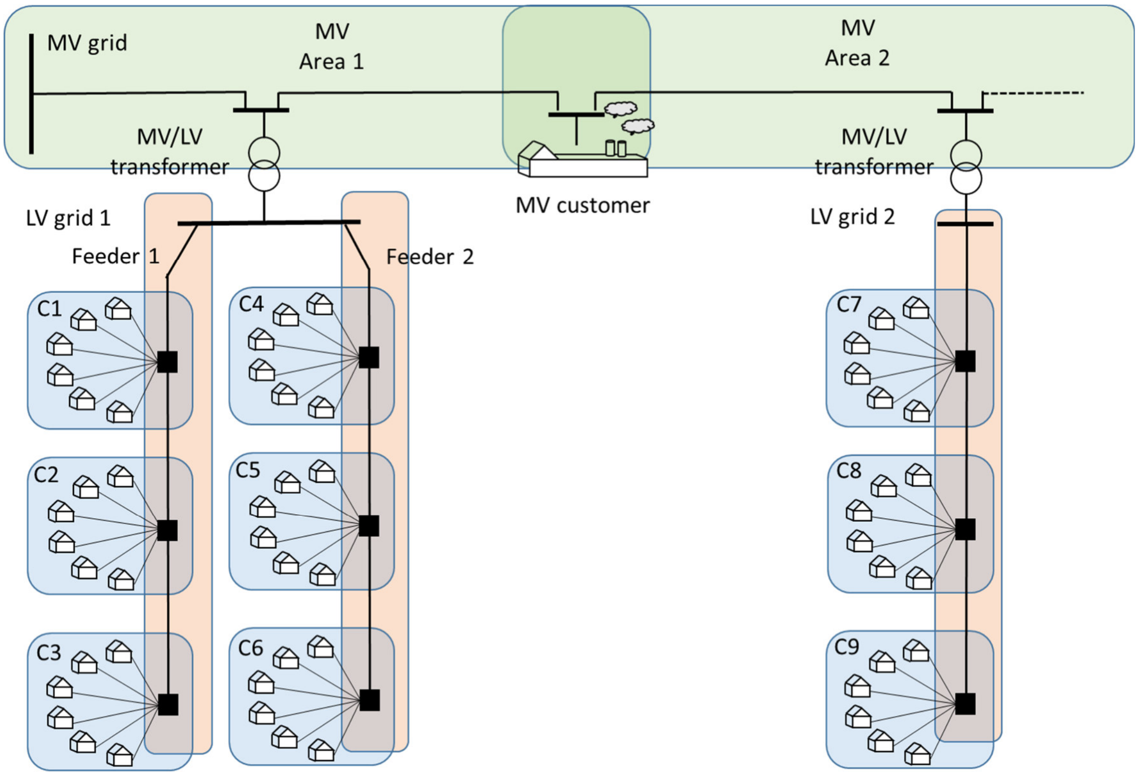

Figure 5: Example of multi-area partition for SE service deployment.

Figure 6 shows instead the different options available for the coordination process and the harmonization of the local SE results. As the figure suggests, the coordination can be obtained via a hierarchical harmonization (vertical integration) of different SE levels and/or via the distributed harmonization (horizontal integration) of SE instances running at the same grid level. With reference to Figure 5 and Figure 6, the concentrator level, LV level and MV level estimators can be thought as belonging to different hierarchical levels. Both a bottom-up and a top-down approach can be applied to transfer the SE results from a hierarchical level to another. In this case, the SE processes at the different hierarchical levels can be executed sequentially and each hierarchical level can send the SE results associated to the interconnection point, for being used as input by the SE instances running at the following hierarchical level [4]. In the proposed example, if a bottom-up approach is considered, the concentrator-level SEs should send the voltage and overall power consumption seen at the LV feeder node to LV level SE, while the LV level SE should send the voltage and overall power seen at the MV/LV transformer to the upper level MV grid SE.

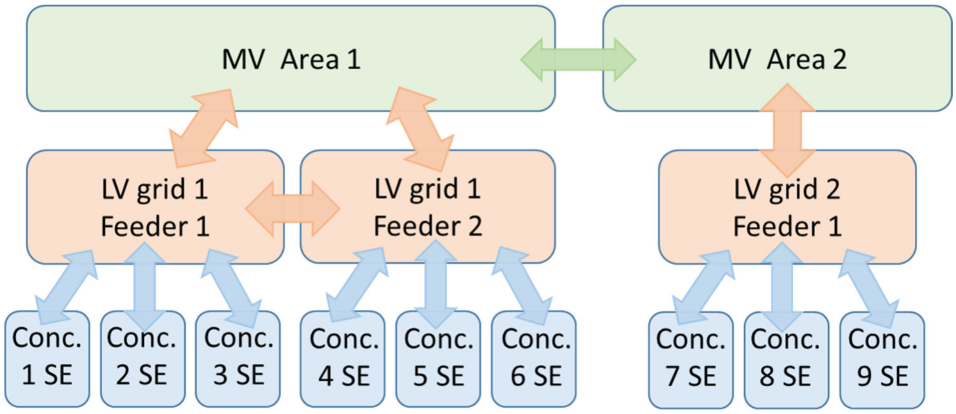

Figure 6: Example of SE coordination in a multi-area framework.

Considering the same hierarchical level, from Figure 5 and Figure 6 the distribution of the SE task is again evident. At concentrator level, all the SE instances can be performed in parallel and do not require any coordination because their grids are physically decoupled. At LV level, instead, a harmonization procedure can be applied to refine the results that are obtained for each LV feeder SE (for feeders belonging to the same LV grid). Similarly, at MV level, a harmonization procedure can be applied to improve the SE results obtained in each MV area [5]. In both the cases, the SE results obtained at the boundary nodes (or branches) are usually the data exchanged for enabling the harmonization procedure. It is worth highlighting hat, form an implementation perspective, many different harmonization procedures have been proposed in the literature. While specific implementations of the SE service have been used in SOGNO, the proposed platform and architecture allows the SE service provider to freely decide: i) the SE algorithms to be used; ii) the partition logic; iii) the SE architecture; iv) the desired harmonization procedure to be applied. These settings can be in part conditioned also by the possible limitations present in the grid, above all in terms of availability and placement of the monitoring points.

A multi-area SE formulation is easily implementable in the proposed SOGNO architecture. In fact, since the proposed architecture is based on the use of microservices, each SE instance can be seen as an independent module that is connected to the platform. The coordination and harmonization procedures can be easily implemented because all the services can be linked each other via the integration bus (see D4.1 and D5.2), which allows freely exchanging the data required for the harmonization process. Moreover, the communication paradigm used internally to the SOGNO platform, namely the publish/subscribe mechanism, further facilitates the data exchange process. In fact, each SE instance can publish the SE results under a dedicated topic, and the harmonization procedure can be activated by simply subscribing to the topics used by the other SE instances from which the SE results are to be acquired.

The proposed vision for a large scale roll-out of the SE service perfectly fits to the two deployment scenarios described in Chapter 2. In the first case, if the SE is deployed centrally at the DSO control center, the different SE instances can be easily run within containers or virtual machines in any hardware, computer or server, provided that they have free access to the integration bus. In the second case, namely if a completely decentralized implementation is used, each SE service can be run in the decentralized computing units (e.g. edge cloud) and, again, the only constraint is to make sure that all the SE instances can access the shared integration bus. Overall, therefore, the proposed architecture and the proposed design of the SE service allow easily scaling up the deployment of SE to very large grids, thanks to the possibility to split the overall SE problem both vertically (between different hierarchical levels) and horizontally (through the partition of the grids in multiple areas) and thanks to the possibility to easily integrate suitable coordination logics in the used platform.

3.2 Power Quality Evaluation

The Power Quality Evaluation (PQE) service provides, with respect to the SE service, a more detailed view and monitoring of specific parameters and indicators associated to the quality of the electricity supply. In SOGNO, the PQE service can be obtained in two complementary ways. First, it can be directly provided by the measurement units installed in the grid. This is the case when the installed devices have power quality analysis functionalities embedded. In this case, the evaluation of the power quality parameters is locally performed and it gives an indication of the quality of the electricity supply at the point of the grid where the corresponding measurements are taken. As a matter of fact, in these circumstances there are not specific scalability issues in the design of the algorithm and all the potential issues associated to a large scale roll-out are shifted to the platform and the communication technology, which need to be able to support the data transmission expected from the devices.

A second option to extract some power quality parameters potentially of interest for the DSO is to derive them directly from the SE service results. In this case, the analysis of the power quality parameters is still applied at specific points of the grid, but is based on the electrical quantities estimated by the SE service rather than on the direct measurements of the monitoring devices installed in the field. Even in this second case, no particular scalability challenges can be identified for the computation of the power quality indicators. The only aspect to be kept in mind is that the reliability of the derived power quality parameters is strictly dependent on the accuracy achieved via the SE process. Therefore, the main problem for the safe execution of this second option is obtaining SE results as accurate as possible, both at LV and MV level. To this purpose, the multi-area approaches described in the previous subsection can be successfully applied.

3.3 Power Control

The Power Control (PC) service is an important tool to foster a larger penetration of renewable sources in the distribution grid while avoiding expensive and invasive network reinforcement actions. The PC service developed in SOGNO differs from the local strategies typically in place in many distribution grids as it implements a coordinated action of multiple resources to solve the problems occurring in the grid. Using sophisticated power control algorithms allows solving more efficiently the potential problems in the grid and minimizing the curtailments of renewable energy, thus leading to the full exploitation of the CO2-free resources available in the grid.

The large scale roll-out of the PC service presents many challenges in common with the SE service. First of all, the PC service is needed both at the MV and the LV level of the grid. In fact, the possible occurrence of overvoltages or overloading of the network components, due to a too large mismatch of generated and consumed power, can occur both at the MV and LV level of the grid, depending on the particular network characteristics and the distribution of the DG units over the network. As indicated in [1], the most critical problems are usually encountered at the LV level, where most of the photovoltaic plants are installed. This clearly calls for a deployment of the PC service in the whole distribution grid, down to the LV level.

Another aspect in common to the SE service is the need to coordinate in a smart way the PC procedures performed at LV and MV level in order to obtain the best possible results. In fact, while the PC service could be deployed separately in the different areas and feeders of the grid, solving the control problem independently in local areas would significantly underexploit the potential associated to the use of a smart PC service. For this reason, the full roll-out of the PC service envisioned by SOGNO entails the partition of the distribution grid in multiple areas and, when needed, the coordination among these different areas to achieve the desired objectives.

A practical example of the beneficial effects of a coordinated process can be done using the simple scenario depicted in Figure 7 as an example. Let us assume that the LV grid 1 experiences an overvoltage due to a large mismatch between generated and consumed power in the grid. The local instance of the PC service will try first to solve the overvoltage problem using the locally available resources, e.g. asking the local DG units to absorb reactive power. If no additional resources (e.g. storage systems) are available and if the absorption of reactive power is not sufficient to solve the overvoltage problem, a completely decoupled implementation of the PC service would eventually lead, in the assumed scenario, to a curtailment of the active power generation. If, instead, a coordinated PC process designed, if the LV grid 1 is not able to solve the overvoltage problem with the local resources, it can forward a request to the upper level grid (i.e. the MV grid in this case). The MV grid could in this case react in two different ways, depending on the implemented logic. In the first case, it can try to support the LV grid 1 by using its own resources: this can imply the request of support to the PV plant connected at the MV level or also the regulation of the tap changer in the primary substation transformer. In the second case, it could forward the request of support to the other connected LV grids. In both the cases, the objective would be simply to put in place actions aimed at decreasing the voltage profile of the MV grid, which, as a direct consequence, would also automatically shift down the voltage of the LV grid 1 (under the assumption, realistic for most of the LV grids, that the secondary substation transformer has a fixed transformation ratio). In this way it could be possible to solve the overvoltage problem in the LV grid 1 avoiding any curtailment of renewable energy and using instead the aggregated contributions from all the resources available both at MV and LV level.

The design of the coordination scheme between MV and LV grids was out of the scopes of the SOGNO project. However, the proposed architecture, platforms and service design need to be suitable for a large scale roll-out. The implementation of the PC service proposed in SOGNO can be easily adapted to integrate requests for the tuning of the active and reactive power set points following an overvoltage problem occurring in a different portion of the grid. The data exchange between the different grid levels can be ensured via the data integration bus, which guarantees the interconnection among the different PC microservices associated to each grid area. Overall, therefore, the large scale roll-out of the PC service can be obtained in SOGNO with the implementation of multiple PC service instances that can be, when necessary, interconnected to jointly provide support for the solution of a possible grid problem.

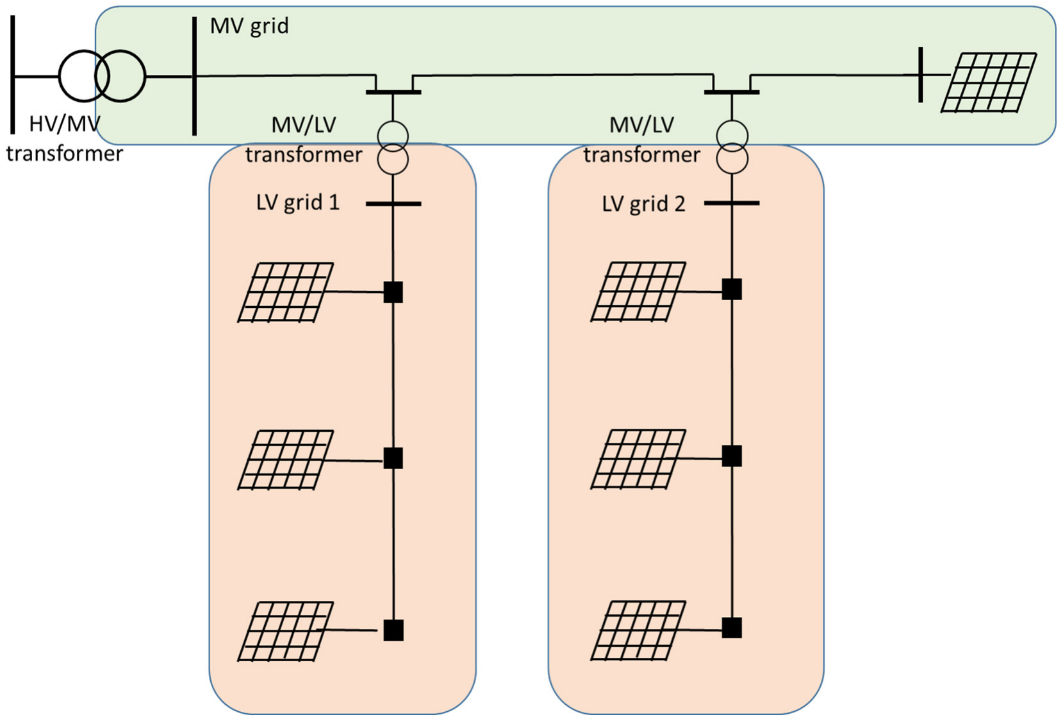

Figure 7: Partition of the PC service among MV and LV grids.

3.4 FLISR

The Fault Location Isolation and Service Restoration (FLISR) service provides fully automated procedures to detect the presence of a permanent fault, to localize where the fault occurred, to isolate the faulty section of the grid and, finally, to restore the power supply in those areas that are not directly affected by the fault and can be safely re-powered after the fault isolation. Since the isolation and service restoration process concerns the specific grid where the fault occurred, the FLISR problem is naturally decoupled between MV and LV grids and among different grids belonging to the same voltage level. Consequently, a large roll-out of the FLISR service can be done simply by deploying the service for each grid of interest, without any need of designing specific coordination procedures.

Also locally, the execution of the FLISR algorithm does not pose significant challenges in terms of scalability. The complete procedure for the FLISR service and for the local coordination of the commands towards the remotely controllable switches usually relies on the information provided by the Remote Terminal Units (RTUs) connected to the switches and reclosers in the grid. Since the number of switches and reclosers available in the grids is generally limited, also in case of large grids, the FLISR algorithm can be designed without any particular concern for its scalability. Moreover, it is worth noting that the FLISR algorithm is triggered only when a fault occurs in the grid. As a consequence, this service does not put severe challenges also for the amount of data communication (the main challenges from a communication perspective are latency and reliability of the communication channel, not the size/amount of the data messages to be delivered).

3.5 Load & Generation forecasting

The Load and Generation Forecasting (LF & GF) services aim at providing an accurate prediction of the expected levels of power consumption and generation, respectively, at specific points of the grid of interest for the DSO. The operation of the LF and GF is exclusively based on the use of historical data available in the databases of the DSO. Each point (node, substation, generation plant, group of customers) for which the DSO desires to have a forecast will only rely on the historical data associated to that same point of the grid. As a consequence, the implementation of the LF and GF can imply the execution of the same service multiple times using different data or the deployment of a microservice for each of the desired forecasts. As a matter of fact, the main issue for the full roll-out of the service does not lie in the design of the underlying algorithms used to perform the forecast, but only on the way the service is deployed in the platform. From this perspective, the SOGNO approach allows large flexibility in the implementation of the service. Considering also that this service does not need to run in real-time, a potential solution is to have the service implemented in a container (or virtual machine) that sequentially scans all the points for which a forecast is needed. If a too large number of points need to be forecasted, multiple services can be deployed to run in parallel, each one taking care of a specific point or of a set of points in the network.

To avoid congesting the data integration bus with too many requests of large sets of historical data (needed for the prediction, but in particular when the training of the prediction models has to be updated), dedicated instances of the message broker can be installed in the available servers. This is particularly important also to avoid that a large request of data from the LF and GF services interferes with critical applications that should run in real-time.

4. Scalability of the SOGNO platform

The last developments in the field of Information and Communication Technologies (ICT) and Internet of Things (IoT) can both play a key role for the fast and effective transition towards the so-called "smart grids". The SOGNO solution devised for the deployment of the system awareness and self-healing services relies on a general definition of the SOGNO architecture that allows abstracting the implementation details of the software platform used to host the above mentioned services. Figure 8 shows a simplified and schematic view of the main components that are needed within the platform and that create the backbone of the SOGNO architecture.

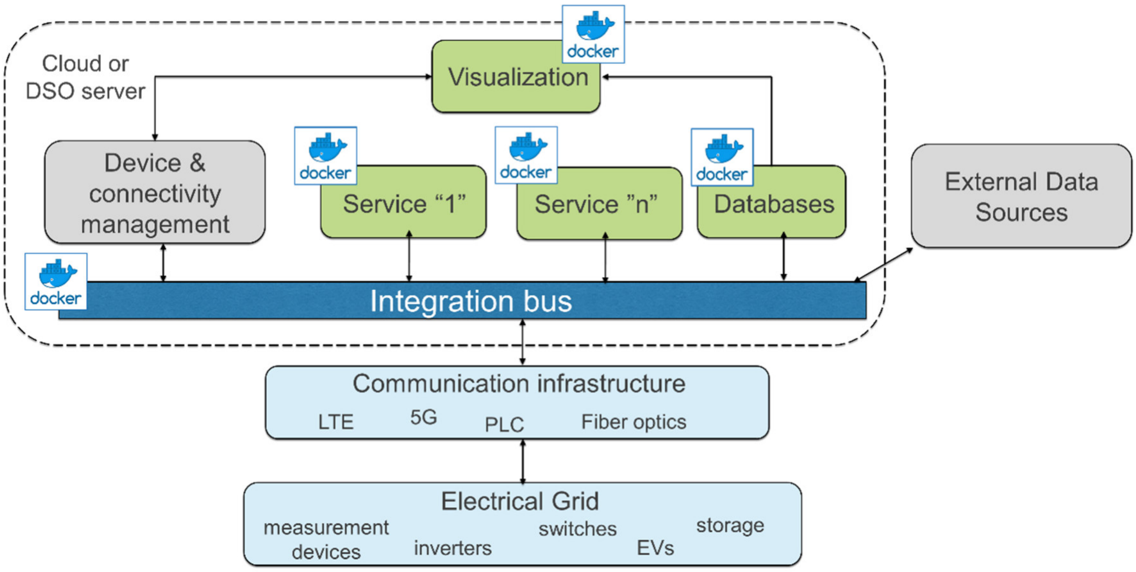

Figure 8: SOGNO platform backbone components.

The general requirements considered for the definition of the SOGNO architecture and, accordingly, for the implementation of the software platform used to run the SOGNO services are:

- **Modularity**: the platform need to be able to easily allow the integration of new services, new software components, new visualization interfaces, new data analytic tools, etc., without requiring modifications to the already existing components. This in SOGNO is obtained by adopting the microservices and containerization approaches, which are the most advanced solutions in the IoT domain. According to this philosophy, each power system service or platform component can be seen as a completely independent module that interacts with the rest of the platform only by exposing its input/output interfaces to the data integration bus. The data integration bus relies on a publish/subscribe mechanism for the data communication that allows fully decoupling the producers and users of the data, thus leading to the full modularity of the proposed architecture.

- **Bi-directional and near real-time communication**: the data flow in the platform need to move from the field devices to the power system services and vice versa, thus implying that a bi-directional communication channel is needed. For most of the automation services, the data have to be received or sent as soon as generated. To this purpose, the SOGNO communication relies on the use of message brokers and publish/subscribe mechanisms, which enable both bi-directional communication and the immediate re-routing of all the published messages to the subscribers.

- **Hardware interoperability**: the proposed architecture must allow the easy integration of hardware components installed in the field regardless of the used low-level communication protocol. This is obtained in SOGNO by using ad-hoc protocol adapters in the communication gateway and adopting commonly used light-weight IoT protocols with flexible data format definition within the platform.

- **Software independence**: the SOGNO platform must not be software dependent, meaning that it should not require the use of specific software or programming languages for any of its components. Different implementations of the SOGNO platform that comply with the general view and requirements of the high-level architecture can be possibly obtained. The same services can be implemented in any programming language thanks to the use of the microservices and containers approach: the only constraint for them is to expose the needed input and output interfaces to the integration data bus.

- **Scalability**: the platform need to be able to: i) host all the microservices that can be needed for the management of the grid or for the provision of auxiliary functionalities both at power system and ICT level; ii) allow the real-time communication of a large number of devices and resources in the field as well as the interconnection of the services running in the platform; iii) store large amounts of data produced both by the measurement devices and power system components available in the field and by the different services running in the platform. All these aspects of scalability will be further discussed in the following subsections.

4.1 Modularity via microservices and containerization

Microservices and containerization are the latest developments in the ICT and IoT domain towards greater modularity. As previously mentioned, one of the most important features to be provided within the SOGNO platform has to be the possibility to easily integrate, deploy, upgrade or replace a large number of services in order to flexibly accommodate the DSO needs. Such a requirement comes from the fact that, in the next future, DSOs will increasingly need to promptly react to the quickly evolving scenarios and to the changes occurring in their grid, possibly by installing new management services or by adapting the existing ones to account for the changed scenario. This requirement is achieved in the SOGNO platform by adopting a microservice-based architecture and using the last generation container technology to build isolated, robust and lightweight microservices.

The microservices approach is a popular architectural style in which an overall business or technical goal is achieved via the parallel execution of a set of small and independent processes, each one performing a well-defined task. The microservices can interact with the other services or components deployed in the platform via their input/output interfaces and using lightweight communication mechanisms. In SOGNO, the microservices are coordinated using the data integration bus, which is composed of message brokers that route the messages to the right services on the basis of a publish/subscribe mechanism. Differently from the request/response communication paradigm, the publish/subscribe mechanism allows each data producer to publish the data only towards the broker. The sent data must be associated to a specific topic, which is used to identify the particular category or type of data being communicated. The producer of the data therefore does not have a direct link with the possible users/consumers of these data. In other terms, producers and users of the data are fully decoupled and they both interact only with the message broker. The data user can subscribe to receive the data communicated under a specific topic and, in this way, it will immediately receive the data once they are published. Routing the right data to all the subscribers (according to the topic subscriptions) is the task performed by the message broker within the data integration bus.

Among the different features of the microservices approach, those relevant for the SOGNO architecture and platform are:

- they are small and independent processing units performing well-defined tasks
- they can be connected and disconnected in a plug and play fashion
- they can be deployed independently and automatically
- they use light-weight communication mechanisms
- they can be implemented using different program languages

Microservices improve modularity by building complex control and management applications via the implementation of a network of small, light-weight services that may run independently and be easily combined with other applications. In the last years, the deployment of microservices is often done in combination with the so-called containers. Containers are an ideal deployment mechanism for microservices. Containers can be defined as lightweight environments that can be provisioned by integrating the only infrastructure and management tools that are needed to execute the service. They can be stored in a library, launched quickly and shut down easily when no longer needed. Containers enable each microservice to have exclusive access to resources such as processor, memory and libraries, which are essential for the microservice execution. The small size of container images makes it practical to deploy multiple individual application services in containers. From a scalability perspective, this is therefore the most suitable solution to design microservice-based systems that can scale quickly owing to a simple and light-weight deployment model.

Among the other benefits associated to the containerization of the microservices, it is worth highlighting that containers also guarantee the isolation for the environment where the microservice runs. Through the containers, each microservice is completely isolated from the physical platform via its host container. The completely isolated environment created to run the service ensures that the microservices running in different containers will never conflict with each other. An additional benefit of the use of containers is that they do not require any specific programming framework or server to run. In other words, developers can flexibly design the microservice using different languages, choosing the programming language that best fits their skills and the specific task to be implemented. Moreover, containers can be flexibly run on different operating systems (e.g. Windows or Linux), provided that the operating system supports that type of container. Exactly for this reason, containers are also portable. In fact, since there are no particular constraints on the servers and the operating systems to be adopted, the applications running in the containers can be easily ported to other computers, machines and operating systems. In this way, containers play a key role in facilitating the seamless transfer of the microservices from a platform to another, fostering portability and reusability.

Summarizing, the use of containers for the deployment of microservices leads to the following list of benefits:

- **Simplified and light deployment** of applications using container images (similar to the use of virtual machine, but with advantage to be much smaller)
- **Scalable deployment** of large number of microservices thanks to the small-size of the containers and of the embedded microservices
- **Ability to optimize hardware** usage, with consequent minimization of the hardware requirements needed to run the microservices
- **Provision of an isolated environment** for the execution of the microservice ensuring that different microservices will not conflict one each other
- **No requirements for the programming framework**, which allows the flexible choice of the most appropriate programming language for the design of the microservice
- **No requirements for the underlying operating system**, which allows wide portability and reusability of the created containers
- **Independent execution of small microservices**, which facilitates the deployment, use, maintenance and update of the applications running behind the microservices.

To safely run containers in a platform, some kind of container orchestrator is generally needed. In the implemented SOGNO platforms, Kubernetes is usually used to this purpose. Kubernetes introduces a high-level abstraction layer that enables multiple containers to run on a host machine and share resources without the risk of conflict. This simplifies the administration of large containerized environments, which is critical to ensure large scalability. Kubernetes also handles load balancing to ensure that each container gets the necessary resources. Kubernetes monitors container health and can automatically roll back changes or shut down containers that do not respond to pre-defined health checks. It automatically restarts failed containers, reschedules containers when some nodes die and can shift containers seamlessly between servers on premises and in the cloud. Altogether, this gives unprecedented productivity benefits, enabling a single administrator to manage thousands of containers running simultaneously and unlocking large scalability of the designed eco-system.

4.2 Scalability of the integration bus

Even if nowadays the measurement devices and the resources in the distribution grid that are connected to the control center are still in a limited number, it is reasonable to expect that in the next years these figures will quickly change, following the efforts of DSOs for digitalization and smartification of their grids. As a consequence, the platform used to host the SOGNO services has to be future-proof and needs to guarantee the possibility to connect to a potentially large number of devices or resources available in the field. Since the platform component handling the connection between the application layer (with the SOGNO services) and the measurement and communication layers in the field is the data integration bus, it is essential to ensure that the used integration bus can easily scale according to the changing (growing) needs. In particular, the key component within the data integration bus, which is responsible for the forwarding of the messages from the publishers (data producers) to the subscribers (data users or consumers), is the message broker. Therefore, the scalability of the data communication has to be analysed in close connection to the scalability features of the used message broker.

In general, the message broker can be defined as the distributor of the messages within the conceived architecture. As clear, having a unique message broker in the system can be critical for different reasons: i) it will represent a single point of failure: if the broker crashes or stops functioning, then the whole system would not work anymore and all the services and devices will lose their connection; ii) it represents the bottleneck for the data communication: if the amount of incoming data messages exceeds the capability of the broker, messages will be lost or not delivered in real-time as expected. To overcome this issue, clusters of message brokers can be created. A cluster of message brokers can be defined as a distributed system in which multiple brokers are installed in different physical machines connected over a network. This set-up is completely transparent from a device and application perspective, meaning that the cluster of brokers is seen from the publisher and subscribers still as a unique logical broker. In other words, publishers and subscribers cannot see any difference regardless of the number of brokers really implemented in the data integration bus, since they always “see” only a single broker. The cluster of message brokers usually requires the adoption of ad hoc load balancers to orchestrate the access to the different brokers and to manage possible faults or disruptions within the cluster.

Overall, the use of a distributed cluster of message brokers thus leads to the following benefits:

- **Elimination of single points of failure**: even in case a message broker gets disconnected or stops functioning, the reliability of the communication can be still ensured by the remaining brokers in the cluster.
- **Message distribution among the brokers**: since multiple brokers are available, the data communication can be intelligently divided among them to ensure the best possible performance.
- **Smooth upgrade of the brokers**: again, since multiple brokers are available, it is possible to upgrade the brokers step by step, keeping always a number of brokers active to ensure a reliable communication without any downtime.
- **Linear scalability**: using a cluster of distributed brokers, it is easy to scale according to the requirements by simply adding new nodes (brokers) to the cluster whenever it is needed.

4.3 Scalability for the databases

The last relevant aspect that the SOGNO platform must guarantee in order to ensure a large roll-out of the SOGNO services is the possibility to store very large amounts of data. This requirement comes not only from the need to store the measurement data produced by the instruments and components in the field, which can arrive from multiple measurement points and that, in future scenarios, can be provided also with very high reporting rates. But, it comes also from the necessity to save the results of each of the implemented services, since these can be important for a posteriori analyses and for performance verifications and validations.

The databases used to this purpose should be time-series databases that allow for large scalability. Similar to the case of the message broker within the data integration bus, a solution to achieve scalability is to implement distributed databases. A distributed database can be defined as an overall database system that consists of multiple physical nodes/machines connected over a network where several database instances are installed. Therefore, from a physical perspective the database is distributed among different nodes, but from a logical perspective all the applications will still “see” only one database. The implementation of a distributed database requires the use of ad-hoc orchestrators for the management of the database distribution and for handling the accesses of the applications to the data. Different types of distributed implementations of the database can be generally found, based on different architectures, fragmentation logics, and replication approaches. In general, however, regardless of the particular settings and architectures used to distribute the database, all these solutions allow tackling the issue of large storage requirements, shifting the problem on the hardware allocation and on the data retention policies applied by the DSO.

5. The role of 5G and edge cloud for scalability

Scalability and performance of the SOGNO services in the power networks supported with the cellular communications were topics of utmost importance for the project. In particular, scalability and performance of the SOGNO services in power networks supported by 5G and LTE communications were studied and tested in the field and laboratory trials during the project.

5.1 5G ICT possible requirements and solutions supporting scalability and performance of the SOGNO services

From the start of the project, the requirements for large-scale deployments of the SOGNO services in commercial power networks supported with cellular networks, existing LTE and the new 5G networks, were studied. A set of the energy requirement parameters considered as the most relevant for the SOGNO services from communication point of view was carefully selected. The selected requirements were the number of endpoints, the latency, the sampling rate, the message volume, the bandwidth, the reliability, the availability and the security for each SOGNO services. All these requirements are described in detail in the Deliverable 4.6.

Based on these requirements, the following 5G ICT solutions that support high performance and scalability of the SOGNO services in the commercial power networks were selected:

- **Low latency communications links** to new end points in the power networks 5G as a wireless communication system offers a cost-effective and easy to deploy solution to supply communication over a short distance connecting individual new assets which are part of the automation scenarios of SOGNO.
- **Network slicing** as a feature of 5G solutions for energy providers gives them control of QoS, reliability and security features. Network slicing, which is only possible with 5G, enables a maximum of reliability in the communications and the quality of the service on an end to end basis. It is possible to set its own priorities for communication resources connected to one slice and to use whatever communication reliability and security parameters it considers to be appropriate.
- **Edge Infrastructure** as a feature of 5G solutions for energy providers enables DSOs to reduce the latency of communications, increase the reliability and provide local hosting of algorithms increasing the resilience of communications of SOGNO services.
- **Non-public (private) 4G or 5G networks,** currently, there is a growing interest by Utilities in using private 4G and 5G networks in indoor and outdoor settings. A non-public network could be deployed by a DSO or TSO to provide a part or even all of the communication links needed for grid monitoring. The advantages are that the operator has full control of the priorities, security, configuration and access to the network. In some cases, also the public network could be utilized to connect remote locations to a non-public network.
- **5G Mobile networks for massive IoT communication,** when low latency is not a critical requirement for a service, 5G could be utilized and configured for massive IoT communications thus further fostering large scalability.

5.2 Analysis of the cloud-based solutions for large-scale deployment of the SOGNO services in the commercial power networks

Furthermore, a few cloud-based solution options for large-scale deployment of the SOGNO services in the commercial power networks supported with 5G were evaluated. The Power Quality Evaluation service was not evaluated in this context as the relevant indices are directly computed on the device. The focus was set on a practical full rollout cloud solution for the State Estimation service. Taking as a base the Edge Computing concepts [6], the following cloud-based solutions for deployment of the SOGNO services in the commercial power network were evaluated:

- Low-voltage State Estimation in the Access Edge deployment
- Low-voltage State Estimation in the Aggregation Edge deployment

The following service characteristics were taken into consideration during the evaluation of the options:

- service process cycle duration,
- number of nodes involved in the service execution,
- number of communications channels,
- service reliability,
- service availability, and
- service security.

The analysis showed that the option with deployment in the Access Edge is optimal. The evaluation details are provided in the Deliverable D2.1.

5.3 Performance test of the SOGNO services in the field and the laboratory trials

The requirements for large-scale deployments of the SOGNO services in the commercial power networks and the solutions that were available throughout the duration of the project were tested in the field and laboratory trials. In the field trials, LTE networks deployed in the field trials locations were utilised, whereas the new 5G networks were utilised in the laboratory for the performance test of the SOGNO services. In both field and laboratory trials, it was proved that the SOGNO services perform as required. Additionally, the tests showed that 5G network is able to support improved performance of the SOGNO services that offer higher services quality comparing to the initial service deployments in the commercial power networks.

In the laboratory tests, the SOGNO services improved performance was shown when optimised radio access parameters of 5G network were applied. The laboratory tests results were shown in SOGNO Deliverable D4.6.

5.4 Conclusions

The energy requirements for large-scale deployments of the SOGNO services in the commercial power networks enabled with LTE and 5G communications were defined in the project. The potential 5G ICT requirements and solutions that support these requirements were defined. Several cloud-based solution options for large-scale deployment of the SOGNO services in the commercial power networks supported with 5G were evaluated and the optimal solution in the Access Edge was proposed.

The field and laboratory tests proved that LTE and 5G networks support high scalability and ensure high performance of the SOGNO services. Furthermore, the tests proved that 5G network ensures even better performance of the SOGNO services that will offer higher service quality. Based on the laboratory test results, the recommendations on how to optimize the performance of 5G in supporting the SOGNO services using a range of optimization parameters available in 5G networks were provided.

6. Conclusions

The SOGNO project promotes a highly innovative approach for the management and automation of the future distribution grids, based on the delivery of monitoring, management, control and automation algorithms as turnkey services for the DSOs. This type of philosophy can bring a drastic change also in the way the distribution management systems are implemented and operated, leading to a transition from a paradigm with monolithic SCADA systems to a more flexible framework with agile IoT platforms built upon a microservices architectural scheme.

During the SOGNO project, this vision has been refined, developed, deployed and validated in several field trials, by means of different system awareness and self-healing automation services implemented in pilot grids via IoT hosting platforms. The field trials proved that the proposed concepts can be successfully implemented and that the promoted ideas can bring a large set of benefits to the DSOs in terms of flexibility, upgradeability and functionalities offered with the proposed services as well as for the integration of auxiliary services and data analytics tools based on recent artificial intelligence and machine learning techniques.

This deliverables discussed and showed how the overall SOGNO eco-system can move beyond the project pilots and be scaled up to allow a full roll-out of the SOGNO services in the distribution system. In particular, three aspects have been considered as relevant for the large scale deployment of SOGNO services: i) the scalability of the same SOGNO services by design; ii) the scalability of the SOGNO platform; iii) the scalability of the communication channels.

For the first aspect (scalability by design of the SOGNO services), the focus in this deliverable has been on the specific services considered within the SOGNO project. In general, all the services can be distributed among the different voltage levels of the grid to facilitate their implementation in the whole distribution system. For some of the services, namely the State Estimation and the Power Control service, the possible drawbacks arising in case of distributed implementation of the algorithms are presented and discussed, providing also indications on how to coordinate the local instances of the services, through the adopted platform, in order to minimize the negative effects. Concerning the SOGNO platform, the deliverable provides the recommendations on the use of containerized microservices, distributed message brokers and distributed databases to tackle the problem of scalability. The use of these technologies allows a large set of benefits and, theoretically, does not put limits to the scalability of the deployable components and services. Last but not least, for the communication, the attention has been mainly focused on the possibilities opened by the upcoming deployment of the 5G mobile communication. In particular, the availability of edge cloud processing capabilities has been identified as the most interesting feature that can foster a distributed and decentralized implementation of the SOGNO automation services, thus paving the way for a large scale delivery of secure and reliable automation services to the DSOs.

7. List of Figures

8. References

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9. List of Abbreviations

DER	Distributed Energy Resource
DMS	Distribution Management System
DSO	Distribution System Operator
FLISR	Fault Location Isolation and Service Restoration
GF	Generation Forecasting
ICT	Information and Communication Technologies
IoT	Internet of Things
LF	Load Forecasting
LV	Low Voltage
MQTT	Message Queue Telemetry Transport
MV	Medium Voltage
OPEX	Operating Expense
PC	Power Control
PMU	Phasor Measurement Unit
PQE	Power Quality Evaluation
RTU	Remote Terminal Unit
SE	State Estimation
WLS	Weighted Least Squares
WP	Work Package