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SmartNet: H2020 project analysing TSO–DSO interaction to enable ancillary services provision from distribution networks

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Abstract: This study presents an overview of the results obtained during the first year of the SmartNet project, which aims at comparing possible architectures for optimised interaction between transmission system operator (TSOs) and distribution system operator (DSOs), including exchange of information for monitoring as well as acquisition of ancillary services (reserve and balancing, voltage regulation, congestion management), both for local needs and for the entire power system. The results concerning TSO–DSO coordination schemes, market design and information and communication technology (ICT) architectures are shown along with the layout of the three technological pilot projects.

1 Introduction

In the future, it is expected that distributed generation, together with demand response and storage connected to distribution grids, would be managed to provide services to the whole power system. Operation of these distributed energy resources (DERs) requires coordinated interfacing between TSOs and DSOs for efficient transmission and distribution (T&D) grid management. On one hand, DSOs could activate DERs for the provision of local services (e.g. voltage support, congestion management), while on the other, they could operate as facilitators for the provision of services for the whole system, in coordination with the adjoining TSO. Therefore, effective real-time coordination is necessary among the different resources participating in the provision of ancillary services (AS) at any level.

The three-year-long Horizon 2020 project SmartNet (http:// smartnet-project.eu/) aims at comparing possible architectures for optimised interaction between TSOs and DSOs, including exchange of information for monitoring and acquisition of AS (reserve and balancing, voltage regulation, congestion management), both for local needs and for the entire power system. Different coordination schemes for the interaction between TSO and DSO are compared on the basis of three national cases (Denmark, Italy and Spain) in order to analyse the impact of DERs' operation on the dispatching, market layout and sequencing, signals exchanged between TSO and DSO, ICT requirements and regulatory implications. The objective is to develop an *ad hoc* simulation platform, which models all three layers, i.e. physical network, market and ICT, in order to analyse three national cases (Italy, Denmark and Spain). Subsequently, this simulation platform (see Fig. 1) will be scaled to a full replica laboratory, where the performance of real controller devices will be tested.

In addition, SmartNet will implement three technological pilots physically located in the same countries that are object of the simulations.

Finally, policy provisions necessary to enable needed TSO–DSO interaction will be assessed and compared with present national and European regulation.

The consortium, under technical and administrative management by RSE, consists of 22 partners from nine European countries, including TSOs (Energinet.dk, TERNA), DSO (ENDESA, SE, Edyna), manufacturers (SELTA, SIEMENS) and telecommunication companies (VODAFONE).

This paper shows an overview of the results obtained during the first year of the SmartNet project, which aims at establishing the functional specifications upon which the simulation platform is then built:

- Coordination schemes enabling AS provision from distribution grids;
- Layout of smart AS markets where flexibility services are purchased by TSO/DSO;
- Modelling of the DER providing system flexibility and of their aggregation;
- Efficient reformulation of distribution networks models, with particular attention to realise a good trade-off between computational tractability and exactness (second-order cone convex models are implemented);
- Identification of critical communication and security requirements related to TSO–DSO coordination and design of an interdependent communication architecture taking into account the different coordination schemes.

Additionally, this paper provides insight on the three physical pilots.

2 Five TSO–DSO coordination schemes

The need for increased cooperation between TSOs and DSOs is widely recognised by regulators [1, 2]. Within SmartNet, five

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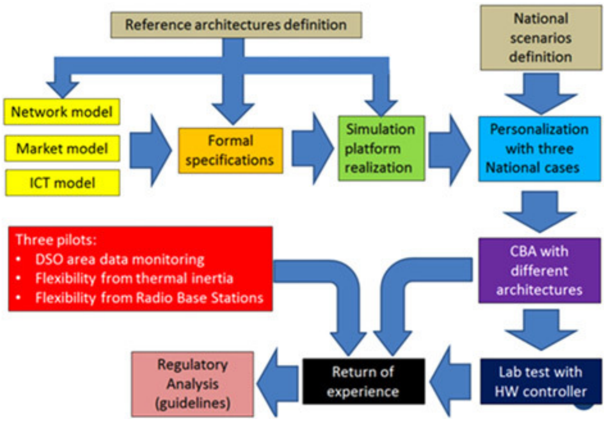

Fig. 1 *Architecture of the SmartNet project*

TSO–DSO coordination schemes are proposed and analysed from a conceptual point of view. Processes taken into consideration during the analysis relate to the prequalification, procurement, activation and settlement of the AS.

The coordination schemes present different possibilities to organise the interaction between system operators. Each coordination scheme is characterised by a specific set of roles, taken up by system operators, and a detailed market design. A role is defined as 'an intended behaviour of a specific market party which is unique and cannot be shared' [1], implying a unique set of responsibilities.

The following coordination schemes are analysed: (1) the centralised AS market model, (2) the local AS market model, (3) the shared balancing responsibility AS market model, (4) the common TSO–DSO AS market model and (5) the integrated flexibility market model.

In the centralised AS market model, the TSO operates a market for resources connected both at TSO- and DSO-level, without extensive involvement of the DSO. In the local AS market model, the DSO organises a local market for resources connected at the DSO-grid and, after solving local grid constraints, aggregates and offers the remaining bids to the TSO. In the shared balancing responsibility model, balancing responsibilities are divided between TSO and DSO according to a predefined interaction schedule. The DSO organises a local market to respect the schedule agreed with the TSO, while the TSO has no access to resources connected at the distribution grid. In the common TSO–DSO AS market model, the TSO and the DSO have a common objective to decrease costs for system services. This common objective is realised by the joint operation of a common market (centralised variant), or the dynamic integration of a local market, operated by the DSO, and a central market, operated by the TSO (decentralised variant). Finally, in the integrated flexibility market model, the market is open for both regulated (TSOs and DSOs) and non-regulated market parties [balancing responsible parties (BRPs) and commercial market parties (CMPs)], requiring an independent market operator (MO) to guarantee neutrality.

All coordination schemes are analysed on their benefits and attention points and are illustrated by a conceptual visualisation. The analysis showed that the feasibility of the implementation of each coordination scheme is very dependent on the regulatory framework and the national organisation of TSOs and DSOs. Furthermore, the implementation of certain coordination schemes will have an impact on other markets, such as the intraday markets.

3 Market design considerations

Compared with conventional power generating units, DERs comprise a family of power sources with a wider variety of physical and economic characteristics. Actually, there are DERs whose power intake/production is not even fully predictable or controllable, such as electric vehicle (EVs) or wind turbines, or DERs whose primary energy service is not necessarily 'power', as in the case of combined heat-and-power units. However, the current design of TSO real-time markets is tailored to a very different reality: that of a power system comprising almost exclusively a limited range of controllable and dispatchable power generating units, the vast majority of which are located at the transmission grid. Consequently, these TSO real-time markets may fail to efficiently accommodate the potentially more dynamic and less controllable behaviour of DERs.

Against this background, the SmartNet project has identified which changes to current TSO real-time markets may serve to facilitate the effective utilisation of DERs. In this endeavour, the conclusions that are being drawn pertain to three different dimensions, namely:

- **Spatial** dimension: the market must allow for the *joint management* of T&D grids.
- **Time** dimension: the market must be able to react to the varying system conditions more quickly, *closer to real time and with some degree of anticipation* on the plausible evolution of the power system state variables.
- **Service** dimension: the market must enable the *coordinated provision* of power balancing, congestion management and voltage regulation.

In light of these conclusions, the SmartNet team is currently developing a framework for the nearly real-time management of T&D grid congestion and power balancing. This framework also accounts for voltage and reactive power constraints and is designed for a market for AS with a high-frequency clearing pace (the market can be cleared, e.g. every 5 min), with a short look-ahead horizon (of 1 h, for instance), and a fine time resolution (of 1 min for the first 5 min time slot of the market as an example). Furthermore, the market clearing can be carried out in a rolling-window fashion, so that it can benefit from updated system information as it comes closer to the point in time when the AS is to be provided. In addition, the market allows for a number of different complex bids, ranging from the basic energy-price bidding curves to the more sophisticated deferrable and exclusive bids.

Nevertheless, the framework that is being developed can be easily adapted to alternative market architectures that, albeit not so ambitious, may encounter less resistance on the way to actual implementation in the midterm (2030), among others in those countries where the pilots are being conducted, namely, Spain, Denmark and Italy.

4 Flexibility resources and distribution network modelling

One of the main goals of SmartNet is to demonstrate the possibility to leverage the flexibility from DERs, namely from energy storage (static and EVs), distributed generation (renewable energy source (RES), combined heat and power (CHP) and conventional units) and demand side management (shiftable and sheddable loads, as well as thermostatically controlled load (TCLs)). Mathematical models of DERs are set up such that the flexibility can be accurately determined and used for the provision of AS, while specifying the physical and dynamic behaviour of the resources. Depending on the type of AS to be provided (balancing, congestion or voltage control), the level of details needed in the model can change: e.g. detailed locational information is important for congestion/voltage control but sometimes less needed for balancing; reactive power modelling is optional, depending on whether the voltage constraints are taken account of. Flexibility costs are also needed for attributing a bidding price to individual DERs. Four cost components are considered: *discomfort cost*, *indirect cost*, *revenue change* and *operational cost*.

Since DERs are typically small in terms of the flexibility quantity they can individually provide, the aggregator's role is to gather the flexibility provided by many DERs, and forward it, in the form of complex price-quantity bids, to the AS market. The aggregator plays a key role, by reducing the amount of data passed onto the AS market, which could potentially congest the clearing algorithm. It also helps makes it possible for small DERs to participate in AS markets and obtain additional revenue streams.

Out of the three distinct aggregation approaches used in the electricity markets, i.e. *physical* [3], *hybrid* [4] and *data-driven* [5], the physical approach was found to be the most suitable one for SmartNet purposes. The eight abovementioned DERs categories are grouped, based on the modelling similarities, into five aggregation models [6]: *atomic loads*, *CHP*, *curtailable generation and sheddable loads*, *storages* and *TCLs*. Cost-optimal scheduling of DERs, i.e. clearing the AS market, should be performed while taking account of the distribution network's physics. However, the optimal power flow (OPF) is non-linear and non-convex [7] and the overall problem can be classified as Mixed Integer Non-Linear Programming, very hard to solve. Considering that the AS market clearing has to be carried out in a limited time while considering an accurate network model, a convex approximation is needed. Use of the power flow's convex approximation allows development of an overall model, which is mixed-integer convex, and which has superior tractability. The numerical comparison of OPF formulations shows that *second-order cone programming branch flow model* offers the best accuracy and very high computational tractability. However, it requires the tuning of a penalty, which should not be too low/high.

5 ICT and security requirements

The presented five TSO–DSO coordination schemes revealed new challenges and opportunities for ICT with respect to communication cost, quality, availability, response time and security. In order to fully exploit potentials offered by ICT, we analysed the TSO–DSO coordination schemes and respective use case descriptions from ICT's viewpoint. We also studied existing and future ICT technologies to assess their abilities to fulfil the recognised communications and security requirements. The study of new technologies included next-generation wireless networks (5G) and Internet-of-Things to enable a flexible way of collecting information also from edges of the network. Network Function Virtualisation, Software Defined Networking and network slicing were investigated to offer flexible AS to stakeholders without dedicated communications networks. DataHub and Blockchain implementations were investigated in order to provide easy access to data storage, to enable cross-border data exchange, and to improve security and privacy in communications. The use case descriptions of TSO–DSO coordination schemes were translated into networking components, interfaces and exchanged data objects. Core operations were divided into four functional stages: prequalification, procurement, activation and settlement. Each data exchange belonging to a specific stage was described with communications and security requirements.

Capturing of ICT and security requirements was done by using an iterative and incremental procedure involving several refinement and harmonisation stages. As a result, a generic ICT architecture containing a core set of system actors, components and services was created.

The modelling follows smart grid architecture model (SGAM) reference architecture [8] model principals describing the structure of the architecture and interactions between entities from the business layer down to the component layer.

In addition to the common architecture design, we also created more detailed SGAM models for pilots and simulation platform. These derived models are called profiles, and they map the ICT architecture and communication requirements of specific coordination schemes to the pilot specifications.

6 Three project pilots

SmartNet includes three physical pilots for testing specific technological solutions:

- Technical feasibility of key communication processes (monitoring of generators in distribution networks while enabling them to participate to frequency and voltage regulation): Italian Pilot;
- Capability of flexible demand to provide AS for the system:
  - o Thermal inertia of indoor swimming pools: Danish Pilot,
  - o Distributed storage of base stations for telecommunication: Spanish Pilot.

An overview of each pilot is provided next.

6.1 Italian Pilot

The Italian power system is in a dynamic evolution process, where the large increase of RES penetration in the last 10 years is leading to a number of challenges, including a rise of active power from medium voltage (MV)/LV to high voltage (HV) and the difficulty to integrate unpredictable RES with traditional generation units.

In order to address these challenges, an improved monitoring of the grid at MV and LV levels, as well as a smarter operation of the grid and a deeper coordination between the TSO and local DSOs can be envisaged. In this context, the Italian SmartNet pilot is implemented in Ahrntal, an alpine region in northern Italy characterised by high penetration of hydro generation, to demonstrate:

- Aggregation of information in real time at the TSO–DSO interconnection point: total power installed per source, total load and gross load compensated by DER and real-time data for *P* and *Q* for all sources. Where real-time information is not fully available, updated forecast and reference production will be used to extrapolate and estimate missing data.
- Voltage regulation by generators connected at HV and MV.
- Power–frequency regulation (Frequency Restoration) by generators connected at MV.

The data flow chart for the Italian Pilot is shown in Fig. 2.

After the implementations at the TSO and DSO systems are completed and the on-site equipment is installed, the field experimentation is planned to start in summer 2017 and last till autumn 2018.

6.2 Danish Pilot

The Danish system is characterised by a high penetration of RES (mainly wind, but, increasingly, also photovoltaic (PV)) and other

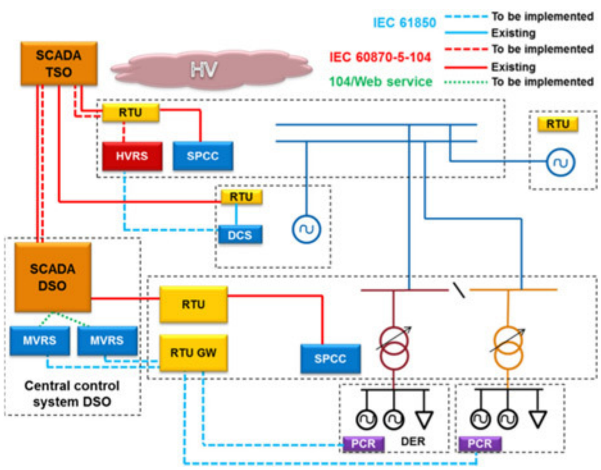

Fig. 2 *Data flow in the Italian Pilot project*

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highly flexible DER (CHP, waste treatment plants and other technologies such as EVs and heat pumps, which are expected to have a significant role in the mid-term).

Aim of the pilot is to demonstrate the opportunities for making use of predictable demand to contribute to T&D grid operation. In particular, it is aimed at demonstrating the use of price signals to control the set points of thermostats of swimming pools in rental summer houses. Such price-based control is expected to be able to handle many of the issues arising in both T&D grids, as well as to balance wind power generation. The setup of the Danish Pilot is show in Fig. 3.

The figure shows the main signals exchanged between the actors defined in the project (red lines). The pilot focuses on balancing and is characterised by a bidding and clearing procedure operated by the MO. The MO receives grid status from the TSO and the DSO and interacts with CMPs to gather the required flexibility. Based on a flexibility model that predicts the electricity demand as a function of prices, the CMP sends out both prices and price forecasts, which aim at creating a balanced situation for the relevant BRP for the next hours. Prices and price forecasts are received by the technical aggregator, who then calculates the optimal set point for the thermostats of all the summerhouses, based on price forecasts, weather forecasts and booking information. Measurements from the summerhouses are collected. These data are used, among other, to feed price-responsiveness information in the flexibility model. The implementation of the pilot has been made in a stepwise manner: the laboratory tests and the first implementations were completed in late 2016 and a full demo of 10 summer houses is ongoing since early 2017, while additional 10 houses will be included in summer 2017. Finally, the performance of 30 summer houses will be demonstrated between early 2018 and summer 2018.

6.3 Spanish Pilot

The Iberian Peninsula is still weakly connected to the rest of the European power system. Additionally, in the last years, there was an increased contribution of both wind power and PV to the electricity supply in Spain. Under these conditions, the use of flexible demand looks a very promising tool for Spanish grid operators.

The Spanish Pilot is demonstrating the prospects for the DSO of using the flexibility of mobile phone base stations to reduce congestion in distribution grids, and to help the TSO maintain system balance by fixing an exchange schedule at the TSO–DSO connection point. With that purpose, the DSO organises a local

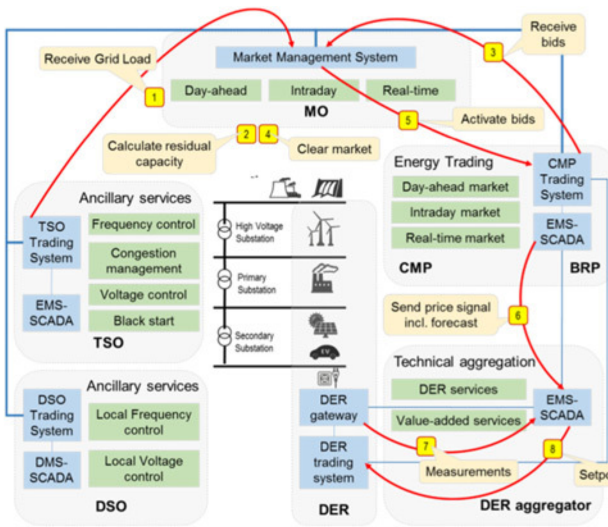

Fig. 3 *Architecture of the Danish Pilot*

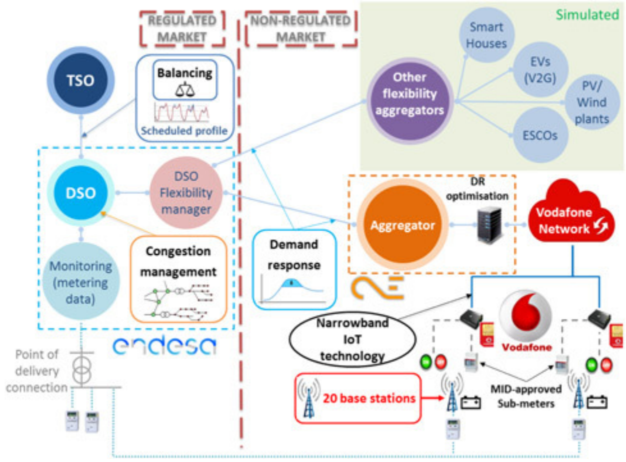

Fig. 4 *Architecture of the Spanish Pilot project*

market, where different aggregators offer their flexibility. Once cleared, the market aggregators perform direct control over the DER they manage, and the DSO checks the compliance with local market results (see Fig. 4).

The pilot has been running since spring 2017 and will continue until summer 2018.

7 Conclusions

As discussed above, the aim of the SmartNet project is to provide an extensive in-depth analysis of key issues affecting the operation of the future energy systems, which will be characterised by an increasing penetration of renewable generation and the need of additional real-time demand flexibility to compensate variability of the generation patterns. In order to enable participation of DERs (via aggregation), in the provision of AS, as well as making real-time markets more robust and liquid, the project is carrying out an in-depth analysis of TSO–DSO architectures, design of real-time markets and ICT requirements. The three pilot projects will also play an important role in demonstrating the technological feasibility of monitoring, aggregating and controlling DERs in the real system. These solutions will then be compared against the current and emerging regulatory frameworks, to evaluate policy implications of the proposed market arrangements for the DER integration in various markets. At the end of the three project years, when the full ‘puzzle’ is finally assembled, SmartNet will provide technical, market and regulatory analysis of different approaches and recommendations that can help TSOs, DSOs and regulators in deciding on the design of the future electricity system and related energy markets.

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9 References

1 CEER: ‘Position Paper on the Future DSO and TSO Relationship’, 2016 [Online]. Available: http://www.ceer.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/CEER_PAPERS/Cross-Sectoral/2016/C16-DS-26-04_DSO-TSOrelationship_PP_21-Sep-2016.pdf

2 Rivero, E., Six, D., Ramos, A., *et al.*: ‘Preliminary assessment of the future roles of DSOs, future market architectures and regulatory frameworks for network integration of DRES’, evolvDSO Project, Deliverable 1.3, 2014 [Online]. Available: http://www.evolvdso.eu

3 Parvania, M., Fotuhi-Firuzabad, M., Shahidehpour, M.: 'Optimal demand response aggregation in wholesale electricity markets', *IEEE Trans. Smart Grid*, 2013, **4**, (4), pp. 1957–1965
4 Saez-Gallego, J., Morales, J.M., Zugno, M., *et al*.: 'A data-driven bidding model for a cluster of price-responsive consumers of electricity', *IEEE Trans. Power Syst.*, 2016, **31**, (6), pp. 5001–5011
5 Ruiz, N., Claessens, B., Jimeno, J., *et al*.: 'Residential load forecasting under a demand response program based on economic incentives', *Int. Trans. Electr. Energ. Syst.*, 2015, **25**, (8), pp. 1436–1451
6 'Aggregation models: preliminary report', SmartNet project, Deliverable D2.3 – draft version, January 2017
7 Dent, C.J., Ochoa, L.F., Harrison, G.P., *et al*.: 'Efficient secure AC OPF for network generation capacity assessment', *IEEE Trans. Power Syst.*, 2010, **25**, (1), pp. 575–583
8 CEN-CENELEC-ETSI Smart Grid Coordination Group 'SG-CG/ M490/F – Overview of SG-CG Methodologies', November 2014 ftp://ftp.cencenelec.eu/EN/EuropeanStandardization/HotTopics/SmartGrids/SGCG_Methodology_Overview.pdf

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