



Smart TSO-DSO interaction schemes, market architectures and ICT Solutions for the integration of ancillary services from demand side management and distributed generation

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About SmartNet

The project SmartNet (<http://smartnet-project.eu>) aims at providing architectures for optimized interaction between TSOs and DSOs in managing the exchange of information for monitoring, acquiring and operating ancillary services (frequency control, frequency restoration, congestion management and voltage regulation) both at local and national level, taking into account the European context. Local needs for ancillary services in distribution systems should be able to co-exist with system needs for balancing and congestion management. Resources located in distribution systems, like demand side management and distributed generation, are supposed to participate to the provision of ancillary services both locally and for the entire power system in the context of competitive ancillary services markets.

Within SmartNet, answers are sought for to the following questions:

- Which ancillary services could be provided from distribution grid level to the whole power system?
- How should the coordination between TSOs and DSOs be organized to optimize the processes of procurement and activation of flexibility by system operators?
- How should the architectures of the real time markets (in particular the markets for frequency restoration and congestion management) be consequently revised?
- What information has to be exchanged between system operators and how should the communication (ICT) be organized to guarantee observability and control of distributed generation, flexible demand and storage systems?

The objective is to develop an ad hoc simulation platform able to model physical network, market and ICT in order to analyse three national cases (Italy, Denmark, Spain). Different TSO-DSO coordination schemes are compared with reference to three selected national cases (Italian, Danish, Spanish).

The simulation platform is then scaled up to a full replica lab, where the performance of real controller devices is tested.

In addition, three physical pilots are developed for the same national cases testing specific technological solutions regarding:

- monitoring of generators in distribution networks while enabling them to participate to frequency and voltage regulation,
- capability of flexible demand to provide ancillary services for the system (thermal inertia of indoor swimming pools, distributed storage of base stations for telecommunication).

Partners



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List of Abbreviations and Acronyms

Acronym	Meaning
CIRED	International Conference on Electricity Distribution
TSO	Transmission System Operator
DSO	Distribution System Operator
DER	Distributed Energy Resources
AS	Ancillary Services
IoT	Internet-of-Things
NFV	Network Function Virtualisation
SDN	Software Defined Networking
BRP	Balancing Responsible Party
RES	
T&D	transmission and distribution
MO	Market Operator
CMs	Commercial Market Parties

Executive Summary

The paper “SmartNet: a H2020 project analysing TSO-DSO interaction to enable ancillary services provision from distribution networks” was published as a joint effort of all WP leaders to present an overview of the results obtained during the first year of the project.

1 Paper

This paper reflects only the author's view and the Innovation and Networks Executive Agency (INEA) is not responsible for any use that may be made of the information it contains.

SMARTNET: A H2020 PROJECT ANALYSING TSO-DSO INTERACTION TO ENABLE ANCILLARY SERVICES PROVISION FROM DISTRIBUTION NETWORKS

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ABSTRACT

This paper presents an overview of the results obtained during the first year of the SmartNet project, which aims at comparing possible architectures for optimized interaction between TSOs and 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 ICT architectures are shown along with the layout of the three technological pilot projects.

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 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 amongst the different resources participating in the provision of ancillary services at any level.

The three-year-long Horizon 2020 project SmartNet (<http://smartnet-project.eu/>) aims at comparing possible architectures for optimized interaction between TSOs and DSOs, including exchange of information for monitoring and acquisition of ancillary services (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, 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, Spain). Subsequently, this simulation platform (see Fig 1) will be scaled to a full replica lab, 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.

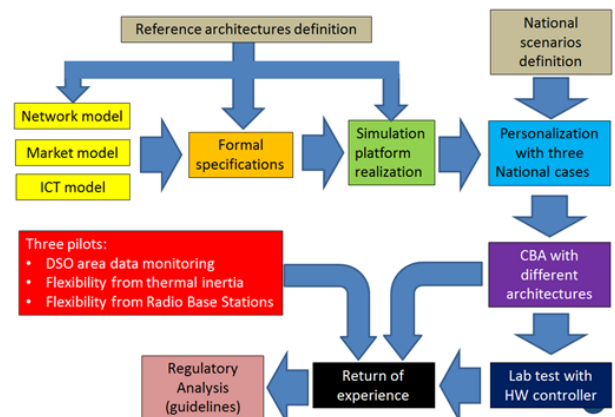


Figure 1. Architecture of the SmartNet project

The consortium, under technical and administrative management by RSE, consists of 22 partners from 9 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 ancillary services provision from distribution grids
- layout of smart ancillary services markets where flexibility services are purchased by TSO/DSO

- Modeling of the DER providing system flexibility and of their aggregation
- Efficient reformulation of distribution networks models, with particular attention to realize 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.

FIVE TSO-DSO COORDINATION SCHEMES

The need for increased cooperation between TSOs and DSOs is widely recognized by regulators [1]. Within SmartNet, five 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 Ancillary Services (AS).

The coordination schemes present different possibilities to organize the interaction between system operators. Each coordination scheme is characterized 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 Centralized 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 Centralized 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 organizes 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 organizes 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 realized by the joint operation of a common market (centralized variant), or the dynamic integration of a local market, operated by the DSO, and a central market, operated by the TSO (decentralized variant). Finally, in the Integrated flexibility market model, the market is open for both regulated (TSOs, DSOs) and non-regulated market parties (BRPs, CMPs),

requiring an independent market operator to guarantee neutrality.

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

MARKET DESIGN CONSIDERATIONS

Compared to conventional power generating units, Distributed Energy Resources (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 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 utilization 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 transmission and distribution-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 transmission and distribution-grid congestion and power balancing. This framework also accounts for voltage and reactive power constraints and is designed for a market for ancillary services with a high-frequency clearing pace (the market can be cleared, for example, every five minutes), with a short look-ahead horizon (of one hour, for instance), and a fine time-resolution (of one minute 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 ancillary service 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.

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 (RES, CHP and conventional units) and demand side management (shiftable and sheddable loads, as well as 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. Also, it 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 nonlinear and non-convex [7] and the overall problem can be classified as Mixed Integer Non Linear Programming (MINLP), 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.

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 analyzed 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 recognized communications and security requirements. The study of new technologies included next generation wireless networks (5G) and Internet-of-Things (IoT) to enable a flexible way of collecting information also from edges of the network. Network Function Virtualisation (NFV), Software Defined Networking (SDN) and network slicing were investigated to offer flexible ancillary services 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 harmonization stages. As a result, a generic ICT architecture containing a core set of system actors, components, and services was created.

The modelling follows 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.

THE 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 ancillary services for the system:
 - thermal inertia of indoor swimming pools: Danish Pilot,
 - distributed storage of base stations for telecommunication: Spanish Pilot.

An overview of each pilot is provided next.

The 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 MV/LV to 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 characterized 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.

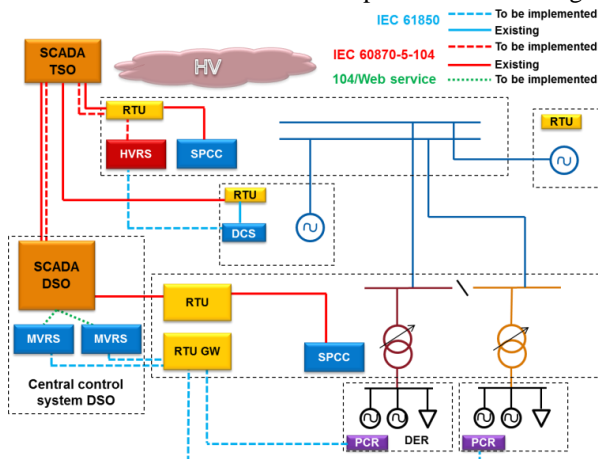


Figure 2. Data flow in the Italian pilot project

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.

The Danish Pilot

The Danish system is characterised by a high penetration of RES (mainly wind, but, increasingly, also PV) and other 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 transmission and distribution (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 shown in Fig 3.

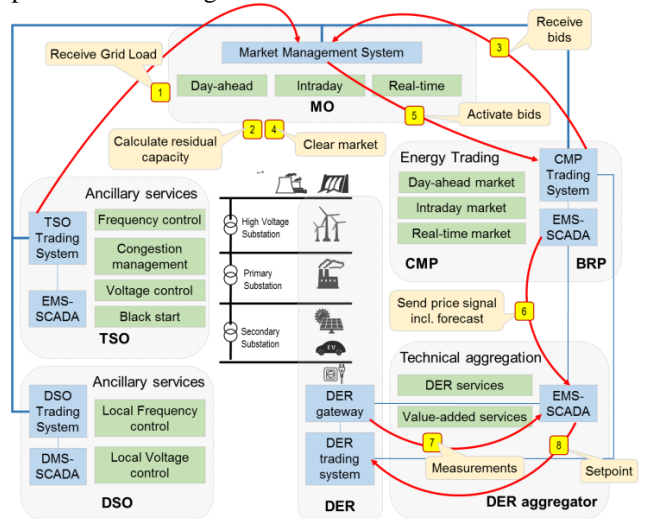


Figure 3. Architecture of the Danish pilot

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 Market Operator (MO). The MO receives grid status from the TSO and the DSO and interacts with Commercial Market Parties (CMPs) to gather the required flexibility. Based on a flexibility model which 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 Balancing Responsible Party (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.

The 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 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.

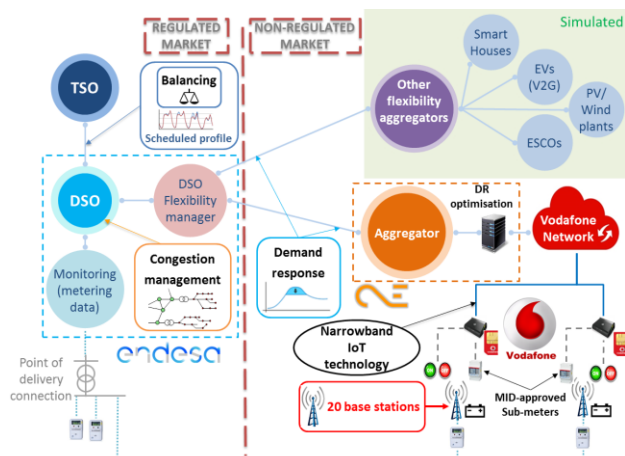


Figure 4. Architecture of the Spanish pilot project

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 characterized 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 ancillary services, 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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