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

Impact Assessment

D7.7

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Distribution Level	Public
Responsible Partner	ONE
Checked by WP leader **Daniela Bernardo (EUI)**	Date: 21/06/2019
Approved by Project Coordinator **Gianluigi Migliavacca (RSE)**	Date: 21/06/2019

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691405

Issue Record

Planned delivery date	M36
Actual date of delivery	21/06/19
Status and version	1.0

Version	Date	Author(s)	Notes
0.0	10/06/19	RSE, Terna, DTU, ONE	First draft
0.1	17/06/19	RSE, ONE	Text revision
0.2	20/06/19	Endesa	Text addition
1.0	21/06/19	ONE	Final version

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 in 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 analyze 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 in frequency and voltage regulation,
- capability of flexible demand to provide ancillary services for the system (thermal inertia of indoor swimming pools and distributed storage of base stations for telecommunication).

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List of Abbreviations and Acronyms

Acronym	Meaning
aFRR	automatic Frequency Restoration Reserves
AS	Ancillary Services
AWS	Amazon Web Services
BCM	Balancing and congestion management
CAPEX	Capital Expenditure
CS	Coordination Scheme
CS-A	Centralized ancillary services market model
CS-B	Local ancillary services market model
CS-C	Shared balancing responsibility market model
CS-D	Common TSO-DSO ancillary services market model
DCS	Distributed Control System
DER	Distributed Energy Resources
DSO	Distribution System Operator
FRR	Frequency Restoration Reserves
HV	High Voltage
HVRS	High Voltage Regulation System
ICT	Information and Communications Technology
IoT	Internet of Things
LV	Low Voltage
MO	Market Operator
MPC	Model Predictive Control
MV	Medium Voltage
MVRS	Medium Voltage Regulation System
OLTC	On Load Tap Changers
PV	Photovoltaic
RES	Renewable Energy Sources
SO	System Operators
TOTEX	Total Expenditure
TSO	Transmission System Operator

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Executive Summary

This deliverable describes the impact that the solutions proposed by the SmartNet project can have on the power system should they be deployed by 2030. The emphasis is made on the three benchmark countries – Italy, Denmark and Spain – while a generalized EU-level assessment is also performed.

The growing share of distributed energy resources (DER) in the distribution grid provides opportunities to use these resources for the provision of services not limited to the distribution grid, but for the overall benefit of the entire power system. To that end, the resources should be aggregated effectively and an appropriate coordination between transmission system operators (TSOs), distribution system operators (DSOs) and aggregators is necessary.

The SmartNet project compares four different TSO-DSO coordination schemes (CSs) and different real-time market architectures with the aim of assessing which one could deliver the best compromise between costs and benefits for the system. The simulations were carried out with reference to Italy, Denmark and Spain in the 2030 scenarios. In parallel, three national pilots were implemented in the mentioned countries to test specific technological solutions to enable monitoring, control and participation in ancillary services (AS) provision of flexible entities located in distribution networks.

The different coordination schemes and national pilots tested in the project have identified positive aspects, drawbacks and obstacles related to the TSO, the DSO, other market participants involved and the market operation in general. The table below summarizes the main impact, possible enablers and recommendations for each scheme and pilot.

TSO-DSO Coordination Schemes		
CS-A: Centralized AS market model		
Key Impact	**Enablers**	**Recommendations**
▪ Implies DSOs' investment in network reinforcement (fit-and-forget policy) and/or in ICT (monitoring) ▪ The most cost-efficient scheme in case of low congestion in distribution networks (Danish case)	▪ Regulatory framework should be modified to incentivize DSOs' remuneration to give more importance to investment in ICT (TOTEX) rather than in grid reinforcement (CAPEX) ▪ Local network planning should cover the whole distribution network, in coordination with the transmission network	▪ The most aligned with current policy and likely an optimal scheme in the very near-future scenarios ▪ Less efficient in future case of increasing flexible resources at distribution with more local congestions
CS-B: Local AS market model		
Key Impact	**Enablers**	**Recommendations**
▪ DSOs have more options to solve grid congestion ▪ Possibly beneficial in rare cases of severe congestion at transmission level by preventing high prices to spread between distribution and	▪ TSOs could be allowed to revoke an accepted bid at distribution level (as in Italy) to avoid global imbalance ▪ Local market perimeter could be enlarged to allow small DSOs to group together and operate a single	▪ CS-B performs well in case of high congestions in distribution networks (Italian case) ▪ Poorer economic performance unless the

transmission systems ▪ As a two-step market, less efficient economically and technically, with risk of causing more imbalance at transmission level ▪ Risk of scarcity/illiquidity of resources and market power exercise ▪ Need for detailed and complete network models for each local distribution network ▪ Implies DSOs' investment in ICT ▪ Implies TSO-DSO market compatibility issues *e.g.* minimum bid size, clearing frequencies, market timing	local market ▪ More flexibility resources could be incentivized to participate by introducing new market products of resources with lower flexibility (a trade-off evaluation needed between ICT cost and liquidity benefit) ▪ DSOs' remuneration should be incentivized to give more importance to investment in ICT (TOTEX) rather than in grid reinforcement (CAPEX) ▪ A form of common TSO-DSO sequenced market could be implemented to harmonize the market setups, in particular the bidding procedures	suggested enablers are extensively implemented
CS-C: Shared balancing responsibility model		
Key Impact	**Enablers**	**Recommendations**
▪ DSOs have more options to solve grid congestions ▪ Possibly beneficial in rare cases of severe congestion at transmission level by preventing high prices to spread between distribution and transmission systems ▪ Interaction between different energy carriers could make available more resources for local network ▪ As a two-step market with fixed active power exchange in TSO-DSO interconnection, it is less efficient economically and technically with high risk of imbalance especially at distribution level ▪ Risk of scarcity/illiquidity of resources and market power exercise ▪ Implies DSOs' high investment in ICT	▪ Flexibility margins should be introduced in the fixed power exchange profile as in cross border exchanges between countries ▪ Local market perimeter could be enlarged to allow small DSOs to group together and operate a single local market ▪ More flexibility resources could be incentivized to participate by introduction of new market products of resources with lower flexibility (a trade-off evaluation needed between ICT cost and liquidity benefit) ▪ DSOs' remuneration should be incentivized to give more importance to investment in ICT (TOTEX) rather than in grid reinforcement (CAPEX) ▪ Frequency restoration and cross-border balancing should remain under TSOs	▪ CS-C is in contrast with the common vision embraced by the European Commission and TSO-DSO associations, and thus should be avoided
CS-D: Common TSO-DSO AS market model		
Key Impact	**Enablers**	**Recommendations**
▪ DSOs have more options to solve grid congestion	▪ DSOs' remuneration should be incentivized to give more importance to investment in ICT	▪ CS-D could be a good scheme to consider for future scenarios. It is the most

▪ The most cost-efficient scheme in case of frequent congestion in distribution networks (Italian case) ▪ Low risk of scarcity/illiquidity of resources and market power exercise ▪ A common TSO-DSO market clearing algorithm implies high investment in ICT, especially for DSOs, and data property issues ▪ Sensitive to forecasting error in relation to distribution network congestion	(TOTEX) rather than in grid reinforcement (CAPEX) ▪ Forecasting error could be reduced by pushing the AS market gate closure as close as possible to real time taking into account the market clearing algorithm running time, ICT cost and time needed by DER to activate and/or ramp-up/down	efficient scheme when a significant amount of congestions is expected at distribution level (Italian case) and performs acceptably when congestions at distribution level are less frequent (Danish case)

National Pilots		
Pilot A (Italy)		
Key Impact	**Enablers**	**Recommendations**
▪ First step for definitive requirements for real-time observability and controllability of distribution grid by TSO through the implementation of two newly developed technological devices to integrate DER (hydro power plants) in power grid <u>Observability</u> ▪ Need for high number of measurements to estimate DER's active power ▪ Limitation in data update frequency of 20 seconds when DER are providing active power service like aFRR ▪ Including grid constraints in power availability calculation has provided safe and secure management of DER for distribution grid ▪ Need for improvement of capability and performance of power plant controllers for both active and reactive power <u>Voltage regulation</u> ▪ Technical feasibility of controlling power exchange by renewable power plants to regulate reactive power flow at interconnection point ▪ Important benefit of voltage regulation service provided by DER	▪ Provision of voltage regulation should be extended to allow participation of DER and open possibility for existing power plants to modernize their performance ▪ DER owners should be made ready and aware of business opportunities in providing AS	▪ Further experimentation is needed for an extended period of continuous operation to improve performance and reliability of behaviour of DER ▪ Proper algorithm based on probabilistic approach should be designed and developed for TSO to be able to estimate coherent and feasible real time system operation

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to the DSO ▪ Need for appropriate data exchange and telecommunication to guarantee IT security and reduction of delays of voltage regulation Frequency/power regulation ▪ Technical feasibility of frequency/power regulation by DER but with unreliable contribution		
Pilot B (Denmark)		
Key Impact	**Enablers**	**Recommendations**
▪ Technical feasibility of delivery of flexibility using thermal capacity of summer houses deploying hardware, bespoke software, cloud services and control models ▪ Use of unidirectional communication and decentralized control to allow broadcasting of signals from millions of DER in a secure manner ▪ Reduction of CO_2 emission at least by 10% and cost savings for consumers ▪ Significant number of flexibility resources are needed to participate in AS ▪ Need for hardware and software in the set-up to be interoperable and harmonized ▪ Need for robust ICT infrastructure with centralized data centers and AI facilities	▪ Power market restructuring should be undertaken to allow aggregators to have a profitable business case (control approaches rather than bidding-clearing approaches) ▪ Reward, incentivization or new tax schemes should be implemented in addition to market savings to encourage significantly more consumers to provide flexibility to the grid	▪ Similar set-up can be undertaken for the district heating sector
Pilot C (Spain)		
Key Impact	**Enablers**	**Recommendations**
▪ Implies big effort for DSO to model the network in a real time 5-min resolution ▪ Technical feasibility of the tested AS market and DSO's shared balancing responsibility role ▪ Significant number of flexibility resources are needed to participate	▪ DSO should be remunerated for its new role as local market operator and for fostering the use of flexibility instead of grid reinforcement ▪ DER owners should be made aware of business opportunities, the role of aggregator and be incentivized to provide AS	▪ More research to deploy real implementation involving TSO is needed to allow real interaction between TSO and DSO

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in AS to achieve balance ▪ Aggregator assumes a novel central risk-taking role to allow scalability, specialization and exhaustivity	▪ Flexibility market should be designed to facilitate non-traditional, non-standard flexibility	

As a summary, while the centralized AS market model (CS-A) is the most efficient scheme for the power system when there are low congestions at distribution level and likely an optimal scheme to be implemented in the next years, the common TSO-DSO AS market model (CS-D) is the most efficient scheme for future scenarios when congestions in distribution networks are more frequent, given that it is expected that in 2030 and beyond, resources at distribution level will be mainly composed of variable renewable energy resources (RES) generation and the fit-and-forget policy will be abandoned. The implementation of CS-D implies significant investment in ICT especially for the DSO. Thus, the DSO's remuneration should be incentivized to give more importance to investment in intelligence rather than in grid reinforcement.

Forecasting errors could heavily affect market efficiency under the CS-D. Hence, improvements in forecasting reliability should be encouraged while forecasting errors could be reduced be shifting the AS market gate closure time as close as possible to real time.

To avoid scarcity/illiquidity of resources and market power exercise, DER owners should be made aware of opportunities and be incentivized to participate in the AS market including *e.g.* by means of reward, tax schemes and introduction of new market products with lower flexibility. In addition, local market perimeter could be enlarged to allow small DSOs to group together and operate a single local market. As for aggregators, significant ICT cost is expected in their operation and, thus, it is important that aggregators be able to have a high enough return to have a profitable business case.

Overall, long term local network planning should be extended to cover the whole distribution network and in coordination with the transmission network.

1 Introduction

The SmartNet project aims at providing optimized architectures for the coordination between the Transmission System Operator (TSO) and the Distribution System Operator (DSO) in the provision of network services, assuming the 2030 scenarios with high penetration of distributed energy resources (DER) in distribution networks.

The main objective of this deliverable is to identify the gaps between the current status quo and the desired optimized solutions proposed by the SmartNet project. The deliverable appraises the potential of the tested solutions for the power system should they be adopted. The assessment takes into account the economic impact, i.e. financial implications for TSOs, DSOs and commercial market actors (aggregators) as well as the system-level impact and regulatory recommendations, with the focus on the three benchmark countries - Italy, Denmark and Spain - where the coordination schemes and the pilots are referenced. In addition, based on the three national cases, a generalized EU-level assessment is also performed.

The compilation and synthesis is based on the SmartNet deliverables, most notably Deliverable 4.3 Cost-benefit analysis of the selected national cases [1], Deliverable 5.1 – 5.3 Results of the pilots [2-4], and Deliverable 6.3 Policy recommendations to implement and/or overcome barriers and enable TSO-DSO integration [5].

The followings are the four TSO-DSO coordination schemes (CSs) and three physical pilots covered by the deliverable:

- CS-A: Centralized ancillary services market model
- CS-B: Local ancillary services market model
- CS-C: Shared balancing responsibility market model
- CS-D: Common TSO-DSO ancillary services market model
- Pilot A (Italy)
- Pilot B (Denmark)
- Pilot C (Spain)

The deliverable is divided into eight main chapters. Chapter 2 to Chapter 8 provide an overview of the coordination schemes and national pilots, their advantages and disadvantages, the barriers to implement them as well as possible enablers to overcome such barriers. At the end of each chapter, recommendations are given to provide conclusive remarks as to whether such solution should be implemented and under what conditions. Finally, Chapter 9 summarizes the main conclusions.

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2 Coordination Scheme A – Centralized Ancillary Services Market Model

2.1 Overview

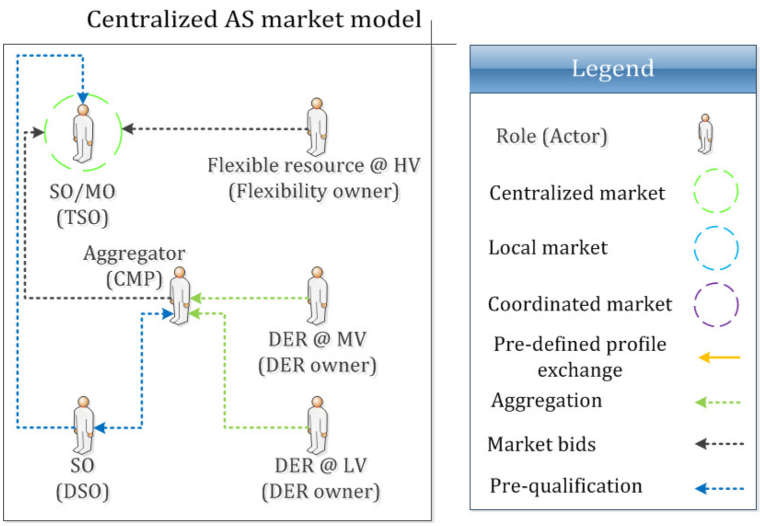

Figure 1 - Centralized Ancillary Services Market Model

The first coordination scheme presented (Coordination Scheme A – CS-A; see Figure 1 for its schematic representation and [6] for a detailed description) contemplates a market model in which the ancillary services (AS) market is operated by the TSO who considers resources connected at distribution level in addition to the ones connected at the transmission level; however, it does not take actively into account the local network constraints.

The DSO is involved in the procurement and activation process of AS by the TSO only if a system prequalification scheme is implemented. In this case the DSO has the responsibility to guarantee that the activation by the TSO of resources connected to the distribution grid does not cause additional constraints (e.g. congestion) in the local distribution network.

2.2 Impact Assessment

CS-A allows flexibility resources to be included in the AS market without the risk of local network congestions, thanks to the monitoring activity of the DSOs.

In order to make this monitoring activity truly effective, it is necessary to invest in Information and Communication Technologies (ICT). We have to note that it is possible to avoid congestion in the local networks also by means of network reinforcement. These are more or less the present policies for local network operation: lines are oversized in order to be sure that no congestion will occur; when problems begin to display, the network is further enlarged ("fit-and-forget" approach). It appears clear that this

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may not always be an economically efficient approach, first of all, because it is performed only on a local basis, then, because it does not make available to DSOs other options than to install new lines.

Consequently, DSOs should be made able to compare investment in network reinforcement and investment in ICT, in order to choose the more efficient way to operate distribution networks. This could be promoted for instance by passing from a capital expenditure (CAPEX) perspective to a total expenditure (TOTEX) perspective in evaluation and remuneration of the investments.

Furthermore, local network planning should take into account the efficiency of the whole system and, also, in coordination with transmission planning.

2.3 Recommendations

Cost benefit analyses performed on the results of the scenarios for 2030 considered for Italy, Denmark and Spain [1] showed that when local network congestion is negligible (as in the Danish scenario), CS-A has very good economic performances, but when the congestion increases, this efficiency decreases since not considering local network constraints forces the DSO to block or limit some flexibility activations. This increases the residual imbalance which can be managed by means of FRR, which is more expensive than the originally selected resources. From this behavior, it is possible to conclude that CS-A is the natural evolution for the next years of the present situation in which, as said, local networks are usually over-dimensioned and local congestions rarely occur. However, as the amount of flexible resources connected to the distribution level increases, congestions will occur more and more frequently. In these cases, the other coordination schemes show better economic performances (see the Italian scenario results in [1]).

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3 Coordination Scheme B – Local Ancillary Services Market Model

3.1 Overview

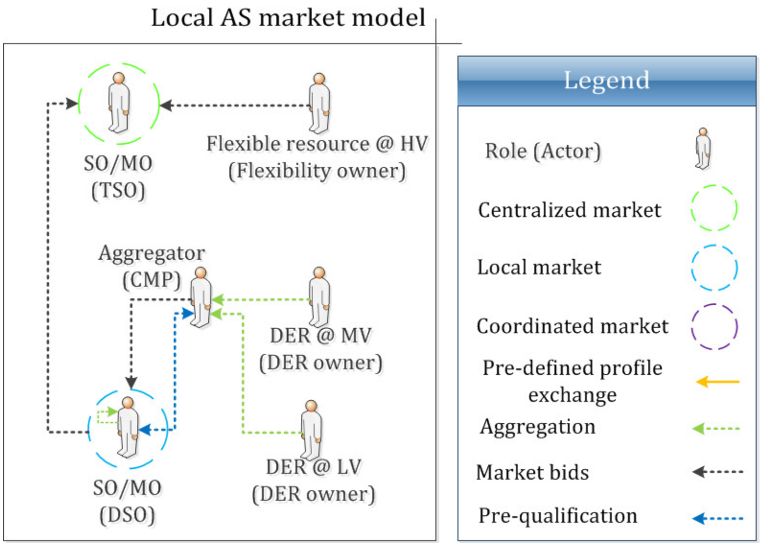

Figure 2 - Local Ancillary Services Market Model

The second coordination scheme presented (Coordination Scheme B – CS-B; see Figure 2 for its schematic representation and [6] for a detailed description) considers the case of a local AS market operated by the DSO to select the resources needed to solve the local congestions. After that, it also locally compensates the selected activations in order not to cause imbalances which may interfere with the services requested by the TSO. After having cleared the local market, the DSO transfers the remaining resources to the AS market operated by the TSO; the DSO must also assure that only bids respecting the DSO grid constraints can take part in the AS market.

Thus, CS-B is based on a two-step procedure:

(1) solution of the local markets: all local resources are at disposal of the DSOs (which will choose the cheapest ones to solve their network problems);

(2) solution of the AS market: the TSOs solve imbalances and congestions in the system with all the resources at the transmission network level and the resources not used by DSOs at distribution network level.

3.2 Impact Assessment

3.2.1 Positive Aspects

Under CS-B, the possibility to directly operate a congestion management market is given to DSOs. As highlighted by the experience of the three pilots, in particular of the Spanish pilot [4], this has the positive effect to largely increase the options at DSOs' disposal to solve grid congestions, which, nowadays, are substantially limited to grid reconfiguration.

3.2.2 Drawbacks

Splitting the market into two steps introduces some significant drawbacks. First, from a mathematical viewpoint, this is likely going to result in suboptimal solutions for the market clearing model. Then, also from a technical point of view, the economic efficiency may be reduced by possible need to counteract in the global AS market to activations made in the local markets. In fact, DSOs are not expected to be aware of the balancing needs of the whole system, and the activations operated by the local market in order to balance congestion management actions can be counterproductive at system level. This condition leads to a situation in which TSOs are forced to activate more (and less optimal) resources than ones theoretically needed for rebalancing the system.

Local markets are limited to each local distribution network, so, the smaller the amount of flexibility resources connected to the local network, the higher the risk that both market liquidity issues may arise and market power may be exercised. Both problems would result in very high prices in the local markets. These high prices should become significant signals for the investors that installing new flexibility resources could be profitable. But, if the solution of the scarcity of liquidity is left to market signals alone, it would probably result in the classic boom-and-bust cycle, a situation that usually is not tolerable neither for the society (due to the continuous changes in prices), neither for the system (reliability changes too frequently within the cycle) nor for investors (the high uncertainty in prices makes investment costs increase).

Obviously, these kinds of risk may affect any possible market schemes, even those that consider the system in its whole both for balancing and congestion management (the presence of systematic congestions tends to subdivide the system in smaller virtual areas characterized by different flexibility prices and, in some circumstances, these areas can be so small to be subject to market illiquidity, with all the related issues).

3.2.3 Technical Issues and Barriers

It is evident that in order to clear the local markets the detailed and complete network models for different local distribution networks have to be available, along with the implementation of ICT devices for the control over the local networks.

There may be issues of compatibility, e.g. minimum size allowed between the two markets, when bids that have not been accepted in the local markets are made available to the global markets. In addition, if the local and global markets implement different clearing frequencies, it could lead to the possibility that a bid that is offered both at local and at transmission level is accepted twice. The different timing between

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the local and global market could also bring along the need to operate a second rebalancing after the congestion management, significantly increasing the complexity of the TSO-DSO coordination.

3.2.4 Possible Enablers

Even if the two-step nature of CS-B is a peculiar and unavoidable condition, it is possible to tackle some of the consequent drawbacks at a regulatory level. For example, TSOs could be allowed to revoke an accepted bid at the local level, in a way similar to what happens in the Italian AS market (Mercato dei Servizi di Dispacciamento – MSD) where the market is, in fact, subdivided into different sessions and each session decides the activation for the full remaining portion of the day (MSD1 considers activations from 00:00 to 24:00, MSD2 activations from 5:00 to 24:00, etc.). At each session, the TSO recalculates the demand of reserve: if bids accepted in the previous sessions are no longer needed, the TSO can revoke them.

Illiquidity and market power exercise are risks related to the "perimeter" of the considered market. As said, the smaller the market, the higher the risk. Thus, two possible ways to solve the problem are:

- enlarge the local market perimeter, for instance by allowing small DSO to group together and operate a single local market, which would also have a positive impact on the operation costs and on the ICT investment costs. This solution is obviously available only when there is (geographical and electrical) proximity among the distribution networks that want to join up;
- increase the number of resources participating in the local market, including favouring the participation into the market of a larger pool of flexibility resources. This could be accomplished, for instance, by the introduction of new market products that take into account the peculiarities and the technical limitations of resources with lower flexibility, in particular loads (industrial loads, thermostatically controlled loads, etc.). However, the more the market products are complex, the higher the market clearing computational cost for the clearing of the market is. As a result, a trade-off evaluation between computational cost and benefits brought to the System have to be performed.

Same as for CS-A, passing from a CAPEX perspective to a TOTEX perspective in evaluation and remuneration of the investments could favor the investment in ICT by the DSOs and so the implementation of CS-B.

Finally, when the timing of the local and global markets is different, the setup of the two markets, and in particular of the bidding procedure, should be carefully coordinated by TSOs and DSOs. For instance, a sort of "Common Sequenced Market" could be implemented, with a common database of resources shared between TSO and DSOs without time correlation, so that once a resource has been selected by one operator, it becomes unavailable for others (as also suggested in [7] by TSOs and DSOs associations).

3.3 Recommendations

The results of the cost benefit analysis performed on the numerical simulations of the 2030 scenarios for Italy, Denmark and Spain [1] show that the economic performances of CS-B are similar to those of the schemes that consider a global market. In particular, CS-B performs quite well when local congestions are high (e.g. for the Italian scenario [1]) while it is slightly less performing when congestions are low (e.g. for the Danish scenario). Anyway, it is worth noting that the numerical simulations performed in the SmartNet project did not consider the potential exercise of market power because it was not within the objectives of the project. Since this is a considerable risk for CS-B, it can be concluded that, unless the suggested solutions proposed in section 3.2.4 are extensively implemented, actual economical performances of CS-B may be poorer.

4 Coordination Scheme C – Shared Balancing Responsibility Market Model

4.1 Overview

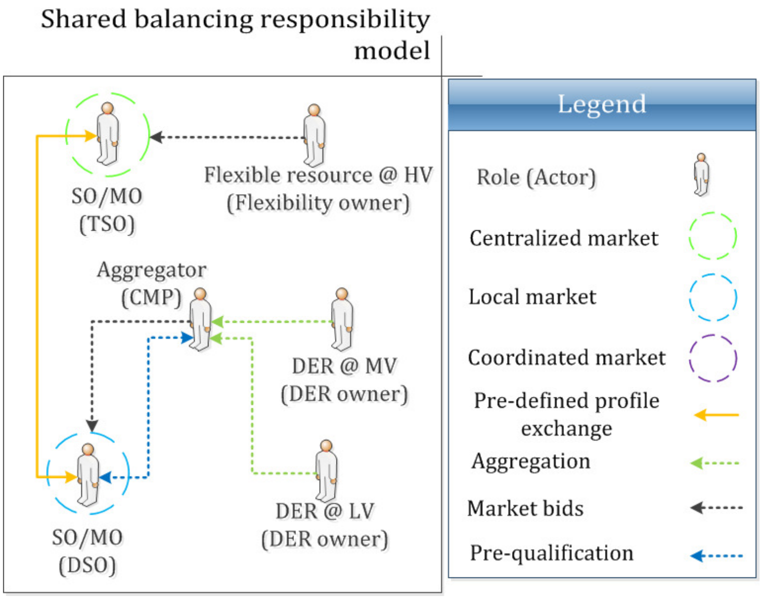

Figure 3 – Shared Balancing Responsibility Market Model

The third coordination scheme presented (Coordination Scheme C – CS-C; see Figure 3 for its schematic representation and [6] for a detailed description) considers the case in which the DSOs have complete balancing responsibility on their distribution grids, along with the congestion management responsibility. DSOs then operate a local market in order to obtain local resources both for balancing the distribution network and congestion management. The balancing requirement consists of a pre-defined power exchange schedule at the interconnection node between the distribution network and the transmission network that the DSOs must respect.

4.2 Impact Assessment

4.2.1 Positive Aspects

Under CS-C, the possibility to directly operate the local AS market and congestion management market is given to DSOs. As highlighted by the experience of the three pilots, and in particular of the Spanish pilot

[4], this has the positive effect to largely increase the options at DSOs' disposal to solve grid congestions, which, nowadays, are substantially limited to grid reconfiguration.

Furthermore, the mathematical separation between transmission and distribution could, in rare circumstances, prevent high prices to spread from a local network to the others.

Also, the interaction between different, and mainly to-be-developed, energy carriers (district heating, hydrogen [8]), could make available new resources which could be more easily selected by the local market.

4.2.2 Drawbacks

The need to respect a scheduled exchange between the transmission network and the distribution network introduces a very strong constraint with important consequences. From the mathematical point of view, the space of the available solutions is reduced in such a way that the clearing solution found will likely be suboptimal. i.e. low economic efficiency, with respect to other schemes in which only technical constraints are considered (e.g. network capacities, generators' flexibility, etc.). From a technical point of view, sometimes this constraint is so binding that it becomes impossible to find a feasible solution. In this case, there is a concrete risk of creating imbalance at the interconnection between the distribution network and transmission network, bringing the necessity of activating large volumes of expensive aFRR [1].

The complete separation between transmission and distribution introduces many remarkable consequences. From a strictly mathematical point of view, the separation of a problem into two separate subproblems may likely result in suboptimal solutions. But mainly, they are the technical drawbacks that are significant. First, the cross use of cheaper resources at both levels is prevented. Then, balancing performed locally may request activations that are increasing the imbalance of the whole system, which is not visible to the single local markets. This separation also obstructs TSOs in revoking decision made at distribution level, significantly decreasing the degrees of freedom for the management of the whole system imbalance.

Furthermore, single local markets could likely be illiquid, especially when distribution networks are small and/or only few flexibility resources are connected at distribution level. As a consequence, it may not be possible to clear those local markets on the majority of the time steps. Some examples of this behaviour can be found in the simulations [1], forcing activation of unwanted measures and, as a consequence, higher use of aFRR. At the same time, small local markets may be subject to significant risks in terms of market power exercise.

4.2.3 Technical Issues and Barriers

To implement local AS markets, DSOs must have a complete control on the networks and on the resources under their responsibility. To this aim, remarkable investments on ICT are needed.

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Secondary reserve is used for frequency restoration and cross border exchange restoration. Nowadays the TSO sends to all the interested resources a single signal, sum of the resulting signals to fulfil those two different services. In the case of complete separation of distribution networks, this mechanism would likely be subject to modifications.

It is commonly expected that in 2030 and beyond resources at distribution level will be mainly composed of Renewable Energy Sources (RES) generation (e.g. PV power plants, mini-hydro, etc.). But these technologies are affected by uncertainty in production and can provide flexibility only downward or, in any case, with highly asymmetric bands. In fact, the main source of imbalance for the power system are precisely RES, so we may expect that the largest share of imbalance will occur in distribution networks. These issues affect obviously all possible market schemes, but are particularly relevant for CS-C since distribution networks here are completely separated from the rest of the system.

4.2.4 Possible Enablers

The fixed power exchange profile between the distribution network and transmission network may be regulated in a way that introduces flexibility margins in their fulfillment, as it happens (happened) for cross border exchanges between different countries. On the other hand, the definition of the rules behind these flexibility margins would not be expected to be very straightforward. However, relaxing the strictness of the distribution network balancing constraint (which is a fundamental peculiarity of this coordination scheme) would result in a completely new TSO-DSO interaction scheme.

Illiquidity and market power exercise are risks related to the "perimeter" of the considered market. As said above, the smaller the market, the higher the risk. Thus, two possible ways to solve the problem are:

- enlarge the local market perimeter, for instance by allowing small DSO to group together and operate a single local market, which would also have a positive impact on the operation costs and on the ICT investment costs. This solution is obviously available only when there is (geographical and electrical) proximity among the distribution networks that want to join up;
- increase the number of resources participating in the local market, including favouring the participation into the market of a larger pool of flexibility resources. This could be accomplished, for instance, by the introduction of new market products that take into account the peculiarities and the technical limitations of more flexible resources. However, the more the market products are complex, the higher the market clearing computational burden is. As a result, a trade-off evaluation between market clearing latency and benefits brought to the System have to be performed.

Like CS-A and CS-B, again passing from a CAPEX perspective to a TOTEX perspective in evaluation and remuneration of the investments could favor the investment in ICT by the DSOs and so the implementation of such a market scheme.

Concerning aFRR management, it is unlikely that it could pass under DSO responsibility even when local AS markets are operated. Frequency restoration and cross-border balancing requirements are related to the whole System so it should remain under TSOs' responsibility.

4.3 Recommendations

From the regulatory point of view, this model is in contrast with the common vision embraced also in [9] and art. 32 in [10] that the DSO could assume at most responsibility for local (loading/voltage) congestion management in distribution. On the contrary, balancing should remain a system-wide centralized service procured by the TSO or another subject on behalf of the total system, who can resort to many more and cheaper resources. Furthermore, large effort has been made to couple markets of different countries at all levels, from the day-ahead market (Price Coupling of Regions [11]) to the intraday market (Xbid [12]) to the AS market (MARI project [13]; TERRE project [14]). So, it seems a contradiction to separate markets internally.

Certainly, the results of the cost benefit analysis performed on the numerical simulations of the three national 2030 scenarios (Italy, Denmark and Spain) [1] show that CS-C is always affected by a very high economic inefficiency in comparison with all the other schemes studied in the SmartNet project. Furthermore, even though exercise of market power was not simulated, its presence would further increase economic inefficiency.

For all these reasons, the implementation of CS-C should be avoided.

5 Coordination Scheme D - Common TSO-DSO Ancillary Services Market Model

5.1 Overview

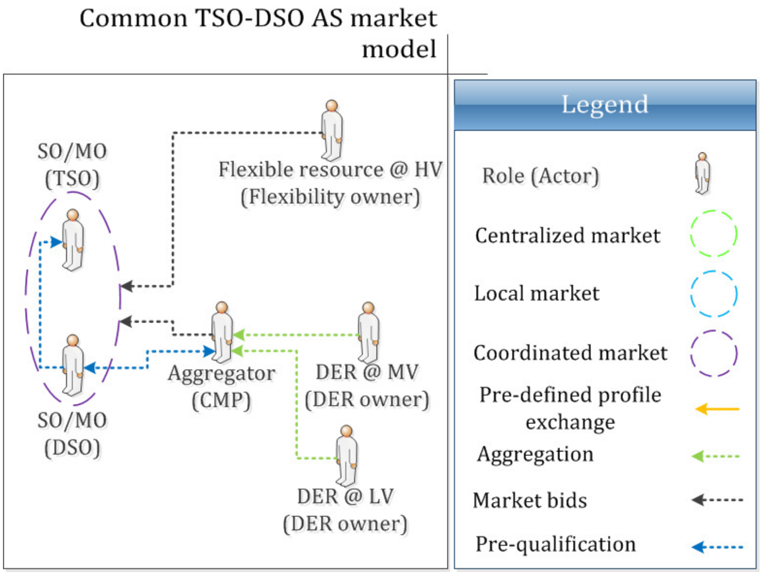

Figure 4 - Common TSO-DSO AS Market Model

The fourth coordination scheme presented (Coordination Scheme D – CS-D; see Figure 4 for its schematic representation and [6] for a detailed description) considers the case in which a common flexibility market is commonly operated by all System Operators (SO) in order to minimize total flexibilities procurement costs. The distribution network constraints are directly integrated within the market clearing algorithm together with the transmission network constraints.

5.2 Impact Assessment

5.2.1 Positive Aspects

Under CS-D, the market is operated by TSOs and DSOs together or by means of an independent market operator. Thus, DSOs, as buyers, have direct access to flexibility resources and so, as also underlined in CS-B and CS-C, this has a positive effect in increasing the options at their disposal to solve grid congestions.

Furthermore, distribution network constraints are directly integrated in the market clearing algorithm, so that the solutions found do not intrinsically violate them. Since neither additional strict constraints are introduced nor subdivision of the system is implemented, the market clearing algorithm likely returns the true optimal solution, guaranteeing the highest economic efficiency.

In addition, although liquidity issues and the risk of exercise of market power may affect CS-D too, the probability that they occur is likely lower than the one featured by local-market-based coordination schemes. This condition is achieved thanks to the fact that CS-D considers a market for the whole system, which guarantees the highest possible competition among bidding resources.

5.2.2 Drawbacks

It is commonly expected that in 2030 and beyond resources at distribution level will be mainly composed by RES generation (e.g. PV power plants, mini-hydro, etc.), whose reliability is strongly dependent on forecast uncertainty. Simulations showed [2] that when forecasting error is comparable to the probability of distribution network congestions, the system could take false decisions on the basis of forecasted congestion which does not actually materialize. This situation brings to the necessity of activating aFRR to perform counteraction against the "wrong decisions" taken. How to deal with forecasting error, especially when related to the occurrence of distribution network congestions, is thus a key point for CS-D.

5.2.3 Technical Issues and Barriers

Including all the local networks model into the market clearing algorithm increases largely the computational cost for its solution. Hence, consistent investment in computational power are needed.

Furthermore, the information about local networks must be shared by all the system operators (TSOs and DSOs) with the Market Operator, being an Independent Market Operator – IMO – or a consortium of the TSOs and DSOs involved. This may bring forth data property issues that were not treated in the SmartNet project but that will have to be tackled by the competent authorities. Technical aggregation strategies (i.e. combination of distribution network resources to a single bidding curve) can be adopted in order to limit the amount of shared data. In this latter case, concrete benefits in terms of market clearing computation burden can be achieved too.

Finally, DSOs should perform consistent investment in ICT to have the requested complete control and monitoring over their network and the flexibility resources connected to them.

5.2.4 Possible Enablers

Like the other CSs assessed in the SmartNet project, passing from a CAPEX perspective to a TOTEX perspective in evaluation and remuneration of the investments could favor the implementation of ICT by the DSOs and so the operation of such a market scheme.

Forecasting error impact could be reduced by pushing the gate closure of the AS market as close as possible to real time. One limitation to this approach is the fact that the market clearing algorithm needs a certain amount of time to run, and even if this time could be reduced by investments in computational power, it will always remain finite. Besides, the computational cost of CS-D is very high since it has to consider all the local networks model. Another limitation may depend on the time needed by flexibility resources to activate and/or to ramp-up/down to the requested level.

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5.3 Recommendations

The results of the cost benefit analyses performed on the numerical simulations of the 2030 scenarios for Italy, Denmark and Spain [1] show that the economic performances of CS-D are good when a significant amount of congestions is expected at distribution level (Italian scenario). In other circumstances, infrequent distribution network congestions (Danish scenario) tend to decrease its profitability but it still remains acceptable. It should also be noted that the numerical simulations did not consider the potential exercise of market power since it was not within the investigation goals of the SmartNet project. However, its impact on CS-D is expected to be low and less significant in terms of system economical performances.

Considering all aspects, we can say that CS-D could be a good scheme to consider for future scenarios.

6 Pilot A (Italy)

6.1 Overview

In Italy, the adoption of a policy that aims to encourage the development of new and renewable forms of energy and the fossil fuel replacement has resulted in a strong growth of renewable penetration. Already reached the 2020 objective, the targets set by the National Energy Strategy provide for renewable sources to reach a level of 28% of total consumption by 2030 (in particular a 55% share of renewables in electricity consumption) and for the complete phase-out from coal by 2025. The aleatory of primary energy sources and the spread of the distributed generation can affect the management of the electrical system.

The increase in the share of generation from renewable sources and the consequent reduction in the number of traditional units in service will lead to the need to propose new approaches to ensure the availability of ancillary services essential for the management of the grid that, at the moment, are provided by programmable traditional power plants.

In order to enable distributed generation to become active player in the electricity system to deal with the energy transition, it is necessary to identify innovative and effective technological solutions and to evaluate and improve the performance of renewable energy sources in the provision of services on an experimental basis.

Within this context, the Italian Pilot [2] is a technological pilot realized in a part of the grid located in northern Italy, at the border with Austria. This area is characterized by numerous hydro power plants of different sizes connected at different voltage levels. The spread of distributed generation leads often to reverse power flow and high voltage (HV) along the medium voltage (MV) feeders. In this context, the pilot aims to develop and implement in the field two kinds of device, realized by the technological partners of the consortium (Siemens and Selta), in order to implement different functionalities with the purpose to integrate the renewable energy sources in the power grid.

The High Voltage Regulation System (HVRS), implemented by Siemens and installed in HV substation, aims to manage the reactive power exchange of four generators connected at the subtransmission grid subtended at the substation in order to obtain a coordinated voltage regulation at the TSO HV station busbar.

Two models of Medium Voltage Regulation System (MVRS), realized by Siemens and Selta employing different approaches and algorithms, are installed in a control center of Edyna, an Italian DSO, to provide three functionalities:

- observability of the distribution grid to allow Terna, the Italian TSO, to have real-time data of the whole DSO grid in order to let the distributed generation provide ancillary services;
- voltage regulation provided by distributed generation by implementing the setpoint sent by the Terna;

- frequency/power regulation obtained controlling the active power production of distributed generation by implementing the level sent by Terna.

The management of the distributed generation in this pilot is based on a nodal representation of the aggregation of connected sources differentiated by type of source. This approach allows Terna to aggregate the real time measurements from the field and to operate considering the controllable power plants as a virtual power plant.

In order to allow real time management of the available resources, the devices calculate in real-time the dynamic capability that takes into account the capability at the operational point of each power plant and the distribution grid constraints (e.g. voltage and overload). Moreover, the devices give priority to the resolution of DSO's voltage violation: if a violation occurs it indicates the aggregate as not available to the telecontrolled regulation and operates to solve the violation.

6.2 Impact Assessment

6.2.1 Positive Aspects and Drawbacks

The solution adopted in the Italian pilot, in terms of performances and general requirements, is a first pragmatic step for definitive requirements for observability and controllability of the system.

The technological partners of the consortium have realized different devices, described above, in order to obtain:

- Observability of the distribution grid every 20 seconds: Since at the moment the control system of Terna receives net values of load and generation measured at the HV side of the transformer of the substation, it has been investigated the possibility to have an accurate estimation of the distributed generation in real time, in order to help enabling the provision of ancillary service from DER together with a secure operation of the HV network. In fact, having the possibility to measure almost all the generation installed at the DSO grid participating in the pilot project, it has been possible to have the measurement of the generation and load at the transformer interconnection every 20 seconds. Having access to all these measurements allowed to study how estimation algorithm shall work and how many measurements are needed to have an accurate estimation of the production (in case not all the generation plants would have been measured). Conclusions drive to: high number of measurements are needed to estimate hydro power plants' active power, where weather forecast cannot directly be related to the active power estimation (more than 60% of the installed power of power plants need to be measured to achieve the required accuracy); data update rate of 20 seconds shows its limits when DER are providing active power service like aFRR, since with aFRR provision the power production vary rather quickly (note: full activation of aFRR from DER acts in 100 seconds!).
- The calculation of the capability of the virtual power plant composed of the distributed generation involved in the project: In fact, in order to allow the TSO to manage resources

connected at the distribution grid, the devices calculate in real-time the available active and reactive power margin on DSO network considering the capability of each power plant and the operational limits of the distribution grid. In case of violation of grid constraints, the aggregation appears unavailable to the telecontrolled regulation and the devices try to solve the violation acting on the reactive production/absorption of the power plants and on the position of On Load Tap Changers (OLTC). By adopting this approach, i.e. including a priori the grid constraints in the calculation of the power availability, tests have provided positive results regarding the safe and secure management of the distributed generation for the DSO grid.

- Coordinated voltage regulation by renewable power plants, in this application hydroelectric generators connected at the subtransmission grid (132 kV), that currently don't participate in hierarchical voltage regulation: The field tests carried out have shown the technical feasibility of controlling the reactive power exchange of the power plants involved to regulate the reactive power flow at the interconnection point or the voltage at the HV busbar. The potentiality of this feature is to expand reactive reserve available for the regulation. Although the effect on the voltage of the transmission grid and the performance of the power plants controller are not the same as the service provided by big-size programmable power plants connected at transmission grid, the system allows to coordinate the area of reactive power flow in order to avoid reactive loop that can be established between the groups.
- Voltage regulation service provided by distributed generation connected at the same primary substation: The functionality showed important benefit for the DSO in the control of the voltage rise effect along the feeders of the distribution grid and the device is then always in operation to regulate the voltage profiles within standard limits even when it is not operated by the TSO. From the point of view of the transmission system, the behavior of power plants connected at the transmission grid is more prevalent than the contribution of the distributed generation. At the moment, the involvement of distributed generation in this service does not provide evident advantages in the management of the HV grid because the voltage trend follows the performance of the HV power plants. Nevertheless, for the previous point, the coordination of the reactive power exchange of these power plants can contribute to avoid waste of sources that provide reactive power regulation.
- Frequency/power regulation provided by distributed generation: This functionality has been implemented to allow the TSO to control the power plants connected at the distribution level and involved in the project as a virtual power plant represented at the interconnection point between TSO and DSO. The pilot proved the technical feasibility of this kind of regulation, but it also showed issues in the performance of the contribution. The response clearly does not comply with the requirement of the aFRR (automatic Frequency Restoration Reserve) in terms of accuracy and delay. Moreover, the tests highlighted that the contribution is not reliable to guarantee a safe provision of the reserve, due to the aleatory nature of the primary source.

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6.2.2 Technical Issues and Barriers

The Italian Pilot is a purely technological project and, thus, the economic and regulatory analysis is out of scope.

From the technical point of view, the tests have highlighted the need to improve the capability and the performance of the power plant controllers both for the active and the reactive power control. In fact, upgrade and reconfigurations of the Distributed Control System (DCS) of the power plants are necessary to obtain the required performance in the actuation of the setpoints. The experimentation of HVRS had also included the involvement of the Automatic Voltage Regulator (AVR) manufacturer to optimize the control parameters in order to reduce the delay and the overshoot of reactive power response. This kind of improvements could not be implemented for the distributed generation because the owner of MV power plants participated in the experimentation on a voluntary basis.

Regarding the voltage regulation, it is also important to find the way to increase the reactive capability available for the activation of the regulation. Often the power plants that do not take part in this service at the moment have reduced capability, mainly in under-excitation operation that do not allow to provide enough reactive power to support the grid.

Another important aspect is the data exchange and the telecommunication among the systems involved in the communication chain in order to guarantee the necessary IT security and the reduction of delays of the full chain of regulation. The tests highlighted a response time which is not compatible with the real time management of the sources. The communication interface between devices of different manufactures has been an issue in the implementation of the pilot and the insertion of additional device in the communication chain led to a reduction of the accuracy and the delay of the tests.

6.2.3 Possible Enablers

Regarding the voltage regulation in Italy, the local voltage regulation (primary regulation) is provided by the relevant programmable power plants, i.e. thermic and programmable hydro power units which have nominal power greater than or equal to 10 MVA, while the so-called secondary voltage regulation is mandatory for traditional power plants with a generator with a size of more than 100MW.

With the national implementation of the new European Regulation (Requirement for Generators) in Italy, the ability to regulate the voltage has been extended. For this reason, new power plants shall be able to provide the voltage regulation and it could open to the possibility for existing power plants to undertake modernization to adapt its performance with new requirements and provide voltage regulation.

Another aspect to be taken into account in order to allow the dissemination of this kind of devices is the need to increase the readiness of the producers for the opportunities of the integration in the provision of services for grid management.

An economic recognition during the experimental phase of the production curtailment, mainly for the frequency/power regulation, would have supported active participation of a greater number of power

plants, with the prospect of both expanding its know-how and anticipating new business plans for the future.

From the TSO point of view, the requirement is to improve the reliability and the accuracy of the response provided, in order to ensure an acceptable level of safety in the management of the grid, of which the TSO is responsible, in particular considering the foreseen reduction of traditional resources with a high consolidated reliability of the service provision.

6.3 Recommendations

In conclusion, the Italian Pilot represents an important innovative testbed that allows, on one hand, the constructors, Siemens and Selta, to produce new technological products currently not available in the market and, on the other hand, the system operators (both TSO and DSO) to analyze how to exploit new resources available in grid and evaluate their response in the provision of ancillary services.

Due to the importance and complexity of grid operation and, in particular, the management of reserves and ancillary services, especially in the peculiar structure of the Italian system, the electrical system needs reliable, accurate and safe real time tools to manage the grid.

The main value of the project is the results of the tests and the detection of the aspects to be improved in order to integrate the renewable energy sources in the electrical grid. It is clear the need for further experimentation, some already in place, in order to improve the performance and the reliability of the behavior of renewable energy sources. Moreover, the tests highlight the importance of a continuous monitoring of the sources and of the actuation of the services in order to guarantee the efficiency, safety, adequacy and quality of the dispatching.

From TSO perspective, the main result from the project on observability is the confirmation that a deterministic approach is not sufficient to guarantee the desired observability level on the system; the TSO has to design and develop a proper algorithm based on probabilistic approach able to estimate globally a coherent and feasible operational real time snapshot of the system.

The experimentation with ancillary services from distributed generation provided promising results but which highlight the need for adjustments and, above all, for an extended period of continuous operation to identify difficulties that would otherwise not be identified. It should be necessary to deepen the characteristics and the performance of each element of the regulation chain: TSO, DSO, devices, telecommunications infrastructure, generator performance, reliability and availability of the service, etc.

7 Pilot B (Denmark)

7.1 Overview

Summer houses with swimming pools consume substantial amounts of electricity for heating water and humidity control. The electricity demand from summer houses is particularly flexible. For example, swimming pools have a large thermal capacity thus, the load to heat pool water can be disconnected or shifted with little consequences on the comfort of the occupants within given intervals that depend on the size of the heated environment and other factors. The Danish Pilot is aimed at assessing and demonstrating to which extent flexibility of summer houses can be exploited to provide both T-D grid levels with ancillary services.

NOVASOL is a rental company that operates about 900 summer houses with an indoor pool in Denmark, holding an average annual power consumption of about 30.000 kWh per house. They also do pool inspections 55.000 times a year – this includes heating adjustment tasks prior and after arrivals/departures. Although the summer houses are not occupied permanently, they have a year-round base load, e.g., to guarantee that the pool water temperature does not fall below a certain threshold, should a customer wish to rent the house with short notice. The location of the houses, coupled with their thermal inertia, make their load a suitable candidate for the provision of grid services. Indeed, many are in coastal areas of northern Jutland (in the DK1 control area of NordPool), where the distribution grid is weak. At the same time, a large capacity for wind power production is installed in the area, making summer houses a suitable candidate for the provision of congestion management services.

NOVASOL joined the SmartNet project in order to be able to offer lower energy cost for house owners with pool and thereby attract more owners, while at the same time ease their pool handling services. Exploiting a small but representative sample of the summer houses operated by the summer house rental company, the Danish Pilot demonstrates swimming pools' value in providing ancillary services both at local level to the DSO, and transmission level to the TSO. The Aggregator which is referred to as an Economical Aggregator acts as the aggregator of the summer houses and oversees their flexibility offering into the local or national markets, where relevant. The necessary ICT required to establish the coordination between the Economical Aggregator and other actors through the physical facilities is also provided falling under the responsibility of the automatic control algorithms which is also referred to as a Technical Aggregator in this document.

7.2 Impact Assessment

7.2.1 Positive Aspects and Drawbacks

The Danish pilot's aim has been to deliver flexibility using the thermal capacity of the summer houses as an ancillary service to the grid, and by the end of the pilot execution, it has managed to achieve its overall aim. In general, the pilot has succeeded in providing a set of innovations and achievements during

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the implementation phases. The achievements are categorized into four areas, hardware, bespoke software, cloud services and control models. During the initial investigation and requirement analysis of the pilot it was evident that the existing Gateways available in the market would not be efficient to handle and support the diverse set of instruction required and the IoT devices used in the pilot. Therefore, a dedicated Gateway system (SN-10) was developed that supports two-way communications with GSM connection. There was a need for bespoke software to act as a central platform of the pilot that various actors could connect and provide/get updates. This platform was developed as a web service that fetches the sensors data from the summer houses, receives different external forecast outputs (weather, price, temperature, etc.) to provide remote and autonomous control. For the software to function and work in a heterogeneous environment, a cloud service has been set up and hosted in Amazon Web Services (AWS) to facilitate the interactions among various actors and ensure the availability of services to each platform user. Finally, a predictive control model (MPC) with a flexibility function, which reacts on either price or CO2 emission, is developed. The MPC would take all the inputs from the summer houses, market prices and forecast data into account to provide set points to the heat pump in the swimming pool. The output data generated by the MPC would then be broadcasted to the SN-10 by the main platform. The innovative part of the pilot has been successfully coordinating and managing to run various components and software developed by different partners in the pilot in parallel with a common goal of providing the flexibility to the grid. Figure 5 is the simplified set up of the pilot and some of the partners involved. It must be noted that the market operator (MO) is also hosted in the AWS and send the price inputs to the software used by DTU/ENFOR to be used for the control model.

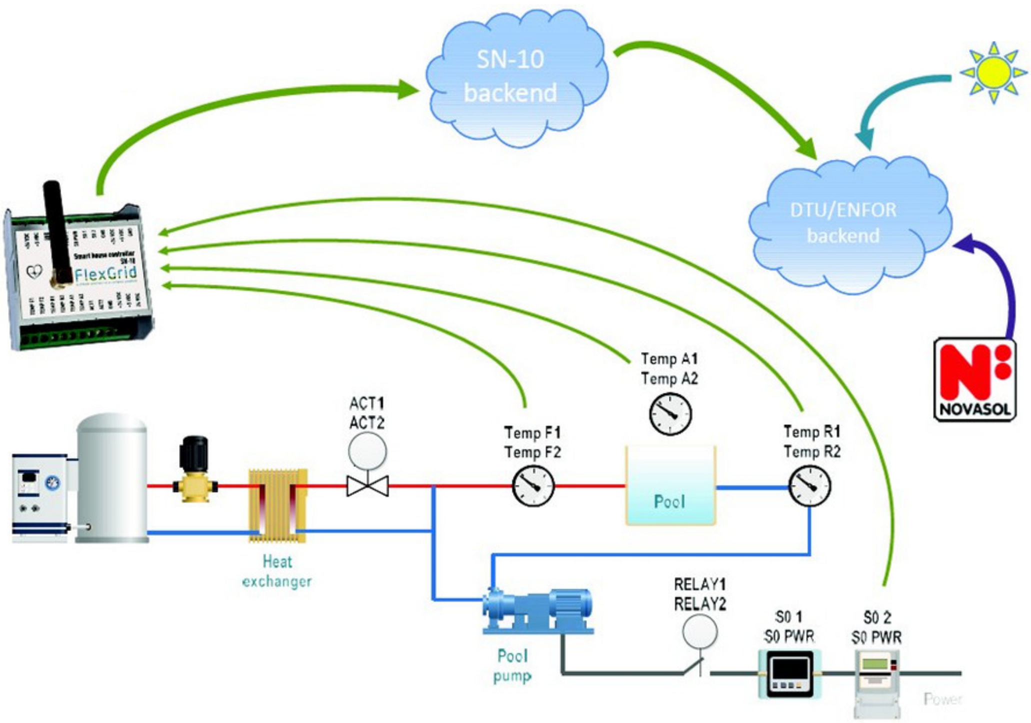

Figure 5 Danish Pilot setup

The results obtained from the experiments performed in the pilot show that using the control algorithm developed for the pilot could reduce the CO_2 emission by at least 10%.

7.2.2 Technical Issues and Barriers

During the implementation phases, the pilot faced several technical challenges, which were not foreseen. The most crucial problem was the lack of a stable communication between the summer house and the central platform server. This has resulted in various changes and installation amendments both in the summer houses and the SN-10 Gateways. This issue mainly because the SN-10 Gateways only support GSM connection and in the areas, with weak communication signal, the packets were constantly dropping or in some cases losing the links for several days until a technician manually visited the summer houses and rested the SN-10. To overcome the issue, an external antenna has been used outside of some of the summer houses to strengthen the signal. In general, this was the main obstacle in not been able to increase the number of summer houses to benefit and provide the flexibility to the grid. Although, one might suggest that SN-10 Gateways could have been equipped with WiFi or wired connections, however this would have required a completely new design and a different installation set up in the summer houses and additional costs that the pilot partners did not anticipate.

The Danish Pilot has been developed by using a unidirectional communication between the upper and lower levels of the Pilot. As a full real-time feedback is not required, the computational load and time declines considerably, thus allowing to broadcast signals from thousands or even millions of assets.

The control for this system is decentralized, as stochastic controllers perform the control duties. Also, this scheme is more secure in case of a certain intrusion, i.e. a hacking attempt into the system. The reason is because it does not allow interference from e.g. the hackers as the Economical Aggregator does not read the available flexibility or bids anywhere; eliminating a significant communication risk.

However, this system makes the Economical Aggregator implement a new way for the conjugation of the "deterministic" auction/bid/clearing mechanisms necessary at high level, for the "non-deterministic". The exact reaction of the assets is unknown, as just models have been used for this purpose.

7.2.3 Possible Enablers

Throughout the pilot, it has also become apparent that energy flexibility must be considered as a dynamic phenomenon. This contrasts with the classical problems related to production, transmission and distribution of power, where everything can be assumed static. Moreover, energy flexibility comes with stochasticity much more extensive than that experienced for power generators. The dynamics and stochasticity are especially pronounced when zooming in on few buildings and small time-scales, as was done in this pilot. This means that bidding-clearing approaches are inappropriate for activating energy flexibility, which leaves aggregators in a poor position to participate in the current power markets.

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Control approaches are currently the only known solution to stochastic and dynamic problems. A restructure of power markets should be undertaken to allow such solutions and the Danish pilot is a good example that has demonstrated the way forward in how the market operators can take the flexibility into account and retrofit the existing structure for more dynamic solutions.

The current policies and regulations in place should also account for such implementing and provide reward schemes for such set-ups for several reasons. For instance, when using the pilot set up based on the existing structure the consumer's saving solely depends on the electricity prices of the market operators, and if the price variation is marginal, it has a direct impact on the conservation the consumers can make. However, if there is a tax scheme reward or incentivization by the regulators in addition to the market savings, then this could encourage a more significant number of consumers to participate in such set-up and provide flexibility to the grid.

7.3 Recommendations

The Danish pilot has shown the way for new developments and the creation of new technologies that help in providing extra flexibility to the energy sector. The methodologies and models developed for the pilot have proven that savings can be made for the consumers and also the energy sector benefits from the unlocked flexibility of the summer house. The Danish pilot has successfully managed to achieve its objectives of how to apply new control algorithms, defining new technologies to provide flexibility and also in offering cost savings to consumers. A similar approach as the Danish pilot set-up can be undertaken for the district heating sector to gain extra flexibility and help in reducing overall CO2 emissions. During the implementation phases and data analysis stages, it was apparent that only having the set-up and having advanced technologies in place might not be enough to gain the full potential of flexibility. Therefore, there is a need to restructure the current tax schemes and provide incentives that are more significant to consumers to offer flexibility.

From the implementation point of view, it is essential that the hardware and software used in such set up are interoperable and harmonized. To roll out such set-up nationally then there is also a need for a robust ICT infrastructure with centralized data centres and AI facilities to aid the functionality of the services, provide low latency of communication and facilitate the smooth operation of the proposed solutions given by the pilot.

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8 Pilot C (Spain)

8.1 Overview

In the Iberian market, balancing and associated AS have become increasingly complex and costly because the share of highly-variable renewable energy in the Spanish generation mix is relatively large. In addition, insufficient interconnection capacity with the rest of Europe reflected in all 2030 network development scenarios means the expansion of balancing service providers and their competition to reduce costs is limited. At the same time, the increasing number of consumers and DER may lead to grid congestion issues. Under this circumstance, the need for a more flexible demand is expected in the near future in Spain, however, so far demand-side management has only been implemented at the transmission level and applied to large industrial loads.

To address these potential problems, the Spanish pilot aims to investigate the applicability of the shared balancing responsibility market model; demonstrate DSO's ability to procure AS from DER connected at distribution level; and demonstrate that small-scale flexibility providers connected at distribution level can be aggregated effectively.

In doing so, the pilot tested the provision of AS from an aggregation of radio base stations' backup batteries at distribution level in a newly designed AS market using 5-minute bidding and activation intervals. There are joint balancing responsibilities between the TSO (balancing) and the DSO (balancing and congestion management) according to a predefined schedule in the common border. The DSO organizes a local AS market to respect the schedule agreed with the TSO, while the TSO has no access to resources connected at the distribution grid. The DSO, as local market operator, operates a market platform where aggregators aggregate DER from different DER owners, sell the flexibility as well as dispatch and balance DER in their portfolios.

The pilot used the Optimal Power Flow (OPF) methodology to optimize the network management while allowing participation of as much diverse flexibility as possible. It implemented balancing and congestion management (BCM) services for the distribution network through direct bidirectional signals to the aggregator. At DSO level, one of the important points was the observability of the network in order to make better decisions as present metering systems have more relaxed time requirements than the 5-minute market time operation requirements defined in the pilot.

For the aggregator, the pilot has served to test the potential to develop services to intermediate between DER owners and the AS market while DER owners could focus on their core business and operational roles, leaving the technicalities of market access, bidding and settlements in the hands of a third party.

The demonstration of the benefits provided by flexible DER to the operation of power systems and to social welfare of European citizens may provide the hints to allow both DSOs and DER owners to exploit the value of small-scale flexibility.

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8.2 Impact Assessment

8.2.1 Positive Aspects and Drawbacks

Although the role of an aggregator as an intermediary between DER and the AS market is not entirely new to the European energy market and is quite active in some markets such as the UK, Germany and Denmark, it is not so in most European markets. By implementing BCM services from DER located at distribution level, the Spanish pilot tested the role of an aggregator with a new configuration in two perspectives:

Firstly, in contrast with traditional pass-through or market-access service propositions, the pilot's aggregator acts as a market expert and a route-to-market provider for untapped flexibility. The aggregator takes a novel central risk-taking role in the configuration, placing bids on the market and committing to acquire flexibility from its own interpretation and expectation of remaining flexibility in its portfolio. The main advantages of such exercise are:

- Scalability: As DER certainly outnumbers at least by thousands times market experts equipped with analytical tools and infrastructure to make sound market decisions.
- Specialization: The pilot divides the responsibility of owning and operating DER and extracting maximum market value from the newly designed AS market.
- Exhaustivity: In its risk aggregation and optimization role, aggregators are incentivized to combine complex flexibility from DER which most often might not meet the strict specifications of AS markets, thereby identifying and exploiting synergies amongst these DER (such as ramp times, pulse durations, etc.) to conform maximum value for DER which comes from maximum value delivered to the system BCM.

Secondly, from a functional point of view, the Spanish pilot served to test the design, implementation and running-time errors of an aggregator as well as to gain experience under real world conditions. The aggregation services were designed and hosted in a resource and cost-efficient manner in an Amazon Web Services (AWS) to minimize the coding and code-maintenance requirements.

8.2.2 Technical issues and Barriers

From an aggregator's perspective, some of the most relevant pending issues are:

- Market design: For the European internal energy market, the functioning of the energy market in opposition to the AS market has to be defined. Market design should favor transparent and efficient flexibility markets which are segregated from energy markets. In addition, it should allow for the redistribution of risks and responsibilities across the value-chain inviting specialization of certain roles. In line with this point, one of the main barriers/threats to efficient risk and responsibility distribution is the development and implementation of capacity markets which distort the market price signal and assign value, hence responsibility, directly to flexibility owners. Market price distortion would make it

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increasingly difficult to structure energy services around an efficient and innovative energy market.

- Awareness: Throughout the preparation, discussions and activities of SmartNet and particularly of WP5 and the Spanish Pilot, it has become evident that the untapped flexibility potential remains dormant due to the lack of awareness on a) the system and system value of such flexibility (not only value of real-time flexibility, but also downscaling of investments in long-term stand-by capacity) and b) the actual functioning of energy markets and grid hierarchy.

8.2.3 Possible Enablers

The main enablers of the experience tested by the Spanish Pilot are:

The awareness of the value of flexibility by DER to understand the role they could take in the energy market and potential to derive additional revenue streams. This could be done via providing incentives for the reduction of balancing requirements/costs (to be provided by the system operator) as well as awareness raising campaigns at three different categories: industrial, tertiary sector and household. Each of these three categories has specificities on the type of flexibility that lies in its process and non-process energy consumption.

The development of the current flexibility market design to make it more friendly for non-traditional, non-standard flexibility. Although it becomes the role of the aggregator to bridge the gaps and confirm 'standard' bids from 'non-standard' flexibility, the greater the space is given to DER and aggregators to participate and compose their offerings, the greater their participation would be and also the lower a risk premium aggregators would have to charge for taking risks in bridging the gaps.

We believe that direct participation of DER in flexibility markets represents a complex endeavor and the role of aggregators should be on the rise in the coming decade. In line with this trend, the aggregator could also benefit from a differentiation between the roles of energy suppliers and balancing responsible parties, so that consumers could have the choice to delegate their balancing and participation in flexibility markets to a counterpart which does not necessarily have to be the supplier of energy in the day-ahead (spot) market.

8.3 Recommendations

As a summary, the Spanish pilot allows to validate a possible solution to face the changes in the electrical generation model. It serves, on one hand, to validate the new role assigned to the DSO and, on the other hand, to prove the concept of flexible resources at distribution level in order to help in the balancing and the congestion management.

The DSO had the responsibility for the balancing agreed between DSO and TSO. Regarding the shared balancing responsibility model, DSO had to perform the role of TSO, because there was no TSO involved in

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the pilot. In future projects, it could be useful to involve a TSO, which would imply a real interaction between these two entities.

Due to the complexity of the distribution network, a big effort to model the network involved was necessary in the design of the market. Another issue to face was the real-time execution of the market, as one of the specifications of this pilot was to evaluate the market in a five-minute resolution. This restriction is important considering that the market needs time to solve all the restrictions.

The market developed in the pilot consists of a mathematical model looking for a feasible solution in terms of technical and economical restrictions, and this kind of problems needs time to be solved. The results of the tests prove the feasibility of using this kind of market, but more research to deploy a real implementation is needed.

For the monitoring of the grid during the tests, an issue on the power meters in low voltage grid was found. The problem was that, in the power meter configuration, there was not a prevision to change the sample rate of the meter. The issue was eventually solved, but it took a lot of time to change the configuration, because, at this level, there is the monetary transaction with the clients and the focus was to have an impact on them.

The tests have proved that the amount of flexibility available in the pilot was not enough to achieve the balance. The conclusion is that, to achieve the balancing, more flexibility is needed or should be combined with other ancillary services.

From DSO perspective, both the local market feasibility and the new role to share the responsibility for balancing have been proved. These are the first steps to fit with the coming changes on the generation and consumption electric model.

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9 Conclusions

This deliverable carries out an assessment on the potential of the solutions proposed by the SmartNet project. In conclusion, while the centralized AS market model (CS-A) is the most efficient scheme for the power system when there are low congestions at distribution level and likely an optimal scheme to be implemented in the next years, the common TSO-DSO AS market model (CS-D) is the most efficient scheme when congestions in distribution networks are more frequent and is the optimal solution to be implemented in future scenarios, given that it is expected that in 2030 and beyond, resources at distribution level will be mainly composed of variable renewable energy resources (RES) generation and the fit-and-forget policy will be replaced.

Although the local AS market model (CS-B) performs quite well when local congestions are high, being a two-step decentralized market makes it less efficient economically and technically with higher risk of system imbalance, scarcity/illiquidity of resources and TSO-DSO market incompatibility (e.g. clearing frequencies, bid sizes, etc.).

The implementation of the schemes and increasing responsibility of the DSO would imply significant investment in ICT especially for the DSO. As a consequence, the DSO's remuneration should be incentivized to give more importance to investment in intelligence rather than in grid reinforcement. In addition, it is worth highlighting that in the case of CS-D, there could be the issue relating to data property (sharing of information among different parties) that should be tackled by the competent authorities.

Under the CS-D, forecasting errors could heavily affect market efficiency. Hence, improvements in forecasting reliability should be encouraged while forecasting errors could be reduced be shifting the AS market gate closure time as close as possible to real time.

To avoid scarcity/illiquidity of resources and market power exercise, DER owners should be made aware of opportunities and be incentivized to participate in the AS market including *e.g.* by means of reward, tax schemes and introduction of new market products with lower flexibility. In addition, local market perimeter could be enlarged to allow small DSOs to group together and operate a single local market. As for aggregators, significant ICT cost is expected in their operation and, thus, it is important that aggregators be able to have a high enough return to have a profitable business case.

Overall, long term local network planning should be extended to cover the whole distribution network and in coordination with the transmission network.

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