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

Policy recommendations to implement and/or overcome barriers and enable TSO-ISO integration

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Distribution Level	
Responsible Partner	
Checked by WP leader [name surname]	Date:
Verified by the appointed Reviewers [name surname, name surname]	Date:
Approved by Project Coordinator	Date:

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	
Actual date of delivery	
Status and version	

Version	Date	Author(s)	Notes
1.0			

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).

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List of Abbreviations and Acronyms

Acronym	Meaning
aFRR	Automatic Frequency Restoration Reserve
AS	Ancillary Services
ASM	Ancillary Services Market
DN	Distribution Network
DSO	Distribution System Operator
ICT	Information and Communications Technology
IM	Intraday Market
mFRR	Manual Frequency Restoration Reserve
PV	Photovoltaic
RES	Renewable Energy Sources
TN	Transmission Network
TSO	Transmission System Operator

Executive Summary

All the TSO-DSO coordination schemes that have been assessed within the SmartNet project imagine levels of DSO's involvement in the System Operation and so of DSO's responsibility by far larger than what happens today. Thus significant investments in monitoring and control systems and a higher level of expertise on DSO side are required (especially for what concerns smaller DSO). Additionally, the so called "fit-and-forget" reinforcement policy (oversizing of networks in order not to have to deal with network "problems", mainly congestions, at the operation level) that nowadays is the basis of DN "operation" must be surpassed. These policies, in fact, could not unlikely lead some DSOs to develop a resistance to consider flexibility as a value and to underestimate the needs to invest in implementing monitoring and control system, mainly during the first years, in which the DN monitoring systems have to be deployed and costs would probably overcome benefits.

Long term planning should be extended to cover the whole DN as it already happens for TN. Then, apart from all the technological improvement needed, this also implies that some DSOs should be able to improve their expertise: the effort needed may be considerable, even in the case of the sharing of the market operation responsibilities with TSOs.

If local congestion management markets are implemented, they would require a good level of coordination between TSOs and DSOs; furthermore, whatever level of separation between Transmission and Distribution is introduced at the market level, even the extreme case in which balancing responsibilities are given also to the DSOs, the overall economic efficiency could decrease, since the knowledge of what is happening globally in the System may lack at various degrees (for instance: rebalancing in DN subsequent to congestion management that increases global imbalance). This should be tackled at a regulatory level, e.g. introducing a mechanism of revocation of the bids accepted locally.

Furthermore, the local and global markets could be implemented with different clearing frequencies, with the possibility that a bid that is offered both at local and at transmission level is accepted twice. Thus it is recommended that the setup of the two markets, in particular of the bidding procedure, is carefully coordinated by TSO and DSOs, for instance by means of a common shared database of resources without time correlation.

Local markets could also be affected by scarcity of liquidity, with the two following major problems:

1) if only a small number of resources are reliable or at the DSO disposal, those resources could have potential to exercise market power;
2) the DSO may not be able to solve congestion in the DN by means of the market and thus be forced to activate unwanted measures, thus increasing the costs for the System.

The very high prices that would occur in the Ancillary Services market should encourage investments in new resources in the local networks, but the consequent boom-and-bust price cycles could not be

tolerable for the society, bringing to the necessity for the regulator to intervene and sterilize (part of the) price signals. Small DSOs may avoid scarcity of liquidity by joining up to create a single and sufficiently large local market; it will increase also economic efficiency, since many small local markets have surely higher ICT costs for they implementation than a few local market with a reasonable size.

However, there are some rare cases in which the separation between Transmission and Distribution could bring the positive side effect that high prices in one area are prevented to spread to the others.

All this being considered, the experience of SmartNet project suggests that DSOs should be responsible of local (voltage) regulation and at most only for the congestion management of their local networks, but, as said above, to the expense of the overall market clearing efficiency. Balancing should always remain a “global issue” under the responsibility of TSO.

On the other side, if a sharing of the Market Operation responsibility between TSOs and DSOs is implemented (so that distribution constraints are managed together with transmission constraints), issues related to data and information sharing may arise, with the need of investments in ICT which, however, prove not so consistent if compared with the baseline expected in 2030 (the Centralized Ancillary Services Market model). Furthermore, although this is not a topic of SmartNet project, we highlight that it will become necessary to tackle problems related to data property.

Given that it is expected that in 2030 and beyond resources at distribution level will likely be mainly composed by RES generation, forecasting errors could heavily affect market efficiency, mainly when a Common TSO-DSO AS Market is implemented. Improvements in forecasting reliability, even if it is not under regulators’ control and, mainly, even if they affect more some generation technologies (e.g. PV) than others (e.g. mini-hydro), should be encouraged. Furthermore, forecasting techniques can have better performances if applied to shorter time forecast horizons. So, another option is to shift the gate closure time of AS Market as close as possible to real time, keeping in mind that a certain number of “dead” times has in any case to be accounted for the clearing the market and the technological limits in the activation and ramping-up/down of the resources.

There is widespread agreement on the fact that Intraday Markets should bring gate closure as close as possible to real time (this would allow RES to recalculate their actual generation taking into account the most updated forecasts so to reduce imbalances). But if other markets are cleared too much close to real time TSO and DSOs could become no more able to evaluate in time the status of the System, calculate the needed reserve and arrange the AS market and, in any case, there are strong technological activation and ramp constraints could prevent some technologies from providing their services. Here, it could help to implement an Integrated Flexibility Market scheme, consisting of a mix of Intraday and Ancillary Services Markets, where flexibility resources would be available not only to System Operators but also to private operators to solve their own flexibility problems. However, times in which the commercial parties are allowed to change their own positions should be well distinguished from those in which DSO and TSO select resources in order to procure system, services: otherwise there would be high risk for TSOs and DSOs to assess system needs on the basis of a non-firm situation. In any case, further investigation on this subject is recommended.

As a final remark, to ensure level playing field in the participation of distributed resources, especially industrial loads, to the tertiary market, it will become necessary to introduce new bidding products, tailored on the technical and physical constraints of particular resources of the different technologies. This, yet considerably increasing the computational complexity of the problem to be solved, could bring to still acceptable performances if it is proven to bring real benefits to the System. Thus, a trade-off between these two aspects should be performed carefully.

1 Introduction

The present deliverable has reports the most important guidelines deriving from the results and the experience of the SmartNet project. Such guidelines are mainly (but not only) related to regulatory issues. All the statements that can be found here depend on the assumptions upon which the SmartNet project is based (e.g. the scenarios at the 2030 target year for the three studied countries.

Finally, It has to be remarked that the present deliverable will deliberately show no numerical results: who is interested in the numerical outcome of the simulations which allowed to get to the results discussed in this deliverable is prompted to look at the relevant deliverables, which are punctually referenced within the text.

2 Economic efficiency of the different coordination schemes

In this section of the deliverable we will go through all the five schemes of coordination that have been assessed within the SmatrtNet Project, both with numerical simulations and by means of three pilot projects. The present deliverable will draw some regulation guidance and recommendations from the main results of the project. A complete description of the coordination schemes considered by SmartNet can be found in deliverable [1].

In order to get complete information on the results of the simulations it is recommended to read the deliverable [2], while all the information and the results of the three pilots are available in deliverables [3], [4] and [5] for what concerns, respectively, Pilot A, Pilot B and Pilot C.

2.1 Centralized Ancillary Services Market model

The first coordination scheme (indicated in the following as Coordination Scheme A, or CS_A) considers a Centralized Ancillary Services (AS) Market Model, in which the AS market is operated by the TSO for resources connected at both transmission and distribution level. There is no separate local market and the TSO does not take DSO constraints actively into account. A separate process (system prequalification) could be implemented to guarantee that the activation of resources from the distribution grid by the TSO does not cause additional constraints (e.g. congestion) in the local Distribution Network (DN). Then, unless such system prequalification is implemented, the DSO is not involved in the procurement and activation process of AS by the TSO. By the SmartNet project point of view, this should be the baseline for the TSO-DSO coordination in 2030; thus, for evaluating the economic performances of all the other considered coordination schemes a comparison to CS_A is performed [2].

The prequalification of resources at DN level, that is under DSO's responsibility, can be implemented at various degrees:

a) System prequalification: the DSO assesses the impact of the delivery of a specific service by a certain resource on the grid. In case the delivery of the service in that specific area violates grid constraints, the DSO could forbid the delivery of the service by that specific resource (this differs from the technical prequalification, by means of which a certain resource is assessed to make it eligible to deliver a specific service);
b) In addition to system prequalification, the DSO has also the authority, after the clearing of the market, to block the activation of a flexible resource (if selected by the clearing of the market), in case DSO constraints might be violated.

All these degrees of DSO's responsibility needs investments, at a growing level from a) to b), in monitoring and control systems, and a higher level of expertise on DSO side (especially with respect to smaller DSO). But up to now, a great part of the Distribution Networks (DN) are operated under the so called “fit-and-forget” reinforcement policy, that is networks are usually oversized in order to avoid network “problems” (e.g. congestions). These policies could not unlikely lead to near-future scenarios in which DN will still not show significant congestions, with the following major side effects:

1) DSOs could underestimate the needs to invest in implementing monitoring and control system, mainly during the first years, in which the DN monitoring systems have to be deployed and costs would probably overcome the benefits;
2) a resistance to consider flexibility as a value could arise in some DSOs;
3) as a consequence of 1) and 2), CS_A, which is expected to be the standard in 2030, could appear to be optimal also for long term, so that the implementation of other (potentially more efficient) market schemes could not be even taken into account for the decades after 2030.

To overcome this scenario, long term planning should be extended to cover the whole DN as it already happens for TN. Furthermore, this long term planning should be coordinated between the DSO responsible for the DN and the TSO responsible for the AS Market operation.

2.2 Local Ancillary Services Market Model

The Local AS Market scheme (Coordination Scheme B – CS_B) considers the case of the operation of a local market by the DSO. The DSO runs the local market so that at first it selects the resources needed to solve local congestion. After that it also locally rebalances the system compensating the extra activations done in order to solve congestion, so that the TSO will not see the total system imbalance modified; After clearing the local market, the DSO transfers the remaining resources to the AS market run by the TSO, but only after being opportunely aggregated by the DSO. The DSO assures that only bids respecting the DSO grid constraints can take part in the AS market.

In practice, this scheme is based on a two-step procedure: in the first step, that solves the local markets, all local resources are at disposal of the DSOs, which will choose the cheapest ones to solve their network problems; in the second step, the TSO solves imbalances and congestions in the System with all the resources at TN level and the resources not used by DSOs at DN level. CS-B is then affected by the following issues:

1) CS-B splits the optimization that clears the market into two steps, which, by a mathematical viewpoint, is likely to result in suboptimal solutions;
2) there are potential issues with market liquidity if limited resources are connected to DN: sometimes, mFRR market can’t close and aFRR, which is usually more expensive, has to intervene instead; this issue is also discussed in the results of Pilot C [5];
3) for the same reasons of 2), local DSO market could also be subject to important potential for the exercise of market power, difficult to detect and to contrast by the regulator;

4) in order to avoid global balancing market counteractions (second step, operated by TSO) to local market activations (first step, operated by DSOs), it becomes necessary to introduce a few extra constraints; as in 1), this likely results in suboptimal solutions;
5) the former market locally rebalances the subsystem by nominating extra bids opposite to what is needed to solve congestion; this is done, by principle, in order to avoid DSO to affect TSO needs in the global balancing market; but since this action is carried out disregarding the system global balancing needs, it could bring to inefficiencies when the imbalance introduced by the local congestion management were of the opposite sign of, and so it would contribute to reduce, the System total imbalance.

As a consequence of these five issues, if compared with the operation of market scheme in which the action is centrally coordinated, (for instance the so called CS_D, dealt in par. 2.4) CS_B is likely to have worse economic performances, as it is shown in [2].

How it is possible to overtake the above issues? 1) Is a peculiar characteristic due to the particular nature of this coordination scheme, so it cannot be removed unless the coordination scheme is changed.

2) and 3) are shared with other possible coordination schemes, although their impact may likely be stronger when the local DN are treated separately from the rest of the system, as it happens in CS_B and in the Shared Balancing Responsibility Market Model (dealt with below, in par. 2.3). Since is a common issue, illiquidity of local networks is treated separately in chapter 3.

4) and 5) could be tackled at a regulatory level imposing further constraints that prevent double activation or, better, allowing the TSO to revoke an accepted bid at the local level, in a way similar to what happens in the Italian Ancillary Services Market (Mercato dei Servizi di Dispacciamento – MSD). This market is divided in 6 different session (the first taking place the day before the delivery, the others in the day of delivery) related to different hours of the day of delivery (MSD1 considers h1 to h24, MSD2 h5 to h24 and so on); at each session the TSO recalculates the demand of reserve and then, if bids accepted in the previous sessions are no more needed, it revokes them.

Another issue has to be considered along with the previous five: due to the fact that the local and global markets could be implemented with different clearing frequencies, there is the possibility that a bid that is offered both at local and at transmission level is accepted twice. In order to avoid this circumstance, the setup of the two markets, in particular of the bidding procedure, should be carefully coordinated by TSO and DSOs, for instance by implementing a sort of "Common Sequenced Market", where a common database of resources is 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 by TSOs and DSOs associations in [6].

On the other hand, anyway, the possibility to directly operate a congestion management market offers the DSOs more options to solve grid congestions (other than, for instance, grid reconfiguration), as underlined by the experience of Pilot C [5].

2.3 Shared Balancing Responsibility Market Model

In the Shared balancing responsibility coordination scheme (Coordination Scheme C – CS_C) the TSO completely transfers the balancing responsibility for the distribution grids to the DSOs, which uses local DER, obtained via a local market, to fulfil its balancing and congestion management responsibilities; the balancing requirement consists of a pre-defined power exchange schedule at the interconnection node between DN and TN that the DSOs must respect. All this brings to the following characteristics of such a coordination scheme:

1) DSOs must have a complete control on the networks and on the resources under their responsibility, that is remarkable investments on ICT are needed (especially considering that the state of the art for a large part of DN is based on the oversizing of the networks in order not to have the need to operate it – the "fit –and-forget" approach already introduced in paragraph 2.1);
2) the need to respect a scheduled exchange between TN and DN introduce a very strong constraint, with two important consequences:
    a. from the mathematical point of view, it will likely result in finding suboptimal clearing solutions (that is: lower economic efficiency), with respect to other CS where only technical constraints (e.g. network capacities, generators' flexibility…) are considered (such as the common TSO-DSO AS Market, treated below in par. 2.4); and
    b. it sometimes leads to the impossibility to find a feasible solution, that is an imbalance is present at the interconnection between DN and TN, as shown in simulations [2];
3) the complete separation between Transmission and Distribution has the following important consequences:
    a. it prevents the use of cheaper resources at both levels;
    b. balancing performed locally may bring to wrong decisions by not knowing the overall system balancing needs (e.g: when imbalance in DN is of the opposite sign of the one in TN: they cannot compensate each other), thus with further economic inefficiency;
    c. as like as 2)a it results in a suboptimal solution;
4) single DSO markets could result, in a way quite similar to what happens for CS_B, illiquid and it could not be possible to clear them in several time steps, forcing a higher usage of aFRR, which is more expensive; examples of this behaviour can be found in simulations [2];
5) again, as like as for CS_B, local DSO market could be subject to important potential for the exercise of market power, difficult to detect and to prevent by the regulator.

However, the mathematical separation between Transmission and Distribution could bring a positive side effect in rare circumstances: in this way high prices in one area are prevented to spread to the others. Furthermore, the interaction between different (and mainly to be developed) energy carriers (district heating, hydrogen), as for instances presented in [7], could make available new resources which use could be more easily optimized in a local market scheme.

From the regulatory point of view, this model is in contrast with the common vision (embraced also in [8], and art. 32 in [9]) that the DSO could assume at most responsibility for local regulation (e.g. voltage regulation) and congestion management in distribution; balancing should on the contrary 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.

For sure, as simulations show [2], CS_C is affected by a very high economic inefficiency with respect to all the other ones studied within the SmartNet project. Since this is the only scheme that allows DSOs to have direct balancing responsibilities on their network, this could be very likely be assumed as the cause of a large share of this inefficiency.

2.4 Common TSO-DSO Ancillary Services Market Model

The Common TSO-DSO AS market model (Coordination Scheme D – CS_D), promotes a common flexibility market for System Operators (SO) in order to minimize total flexibilities procurement costs. This can be seen as the evolution of CS_A in which the market is operated by TSO and DSOs altogether and DSO constraints are directly integrated in the market clearing algorithm, so that the outcome of the market clearing will not violate them. This scenario is operationally much easier than CS_A; nevertheless, integrating physical grid constraints in the market algorithm requires that the DSO provides the necessary data to the party responsible for the operation of the market.

Even taking into account ICT investment cost needed to make all the DNs under direct control, this scheme should show higher economic performances, since it incorporates all distribution constraints, as shown in [2].

Nevertheless, resources at distribution level will likely be mainly composed by RES generation (e.g. PV power plants, mini-hydro…), whose reliability strongly depends on forecast reliability. Simulations showed [2] that when forecasting error is non negligible and congestion low, the System could take false decisions on the basis of forecasted congestion which doesn't materialize. When compared with CS_A (the "baseline"), it could turn out that CS_D is more expensive, since the former doesn't consider distribution constraints and thus cannot be misled in decisions about DN congestions. How to deal with forecasting error is thus a key point for CS_D, but since it is also for the other coordination schemes (even if at a lower degree), it is treated in the dedicated chapter 3.

Another important aspect bound to CS_D is the fact that the market should be co-managed by the TSO along with all relevant DSOs. That could imply all DSO implement a monitoring/control system within their network. The market could be physically under responsibility of market operator representing all the involved SOs and having the right technical competence to manage clearing algorithms capable of considering network operational constraints (potential necessity of implementing experience-based decision-making processes).

2.5 Integrated Flexibility Market Model

The Integrated Flexibility Market scheme (Coordination Scheme E – CS_E), promotes the introduction of a market where regulated (TSO and DSO) and Commercial Market Parties (CMPs) procure flexibilities in a common market. This scheme was not simulated within the SmartNet Project due to its mathematical complexity and, in particular, to the need to consider game theory elements. However, such a scheme may create uncertainty among the operators (TSO and DSO) in charge of purchasing network services first because they would be no longer sure of how many resources are needed (i.e. the real amount of congestion and imbalance) and then because they could, in some scenarios, no longer be sure even to acquire the resources they need, since all the parties compete on equal terms to find the resources they need. Furthermore, the high level of competition between operators could increase market prices. All these issues are thoroughly treated in [1].

As already said, due to the computational and mathematical complexity of such a coordination scheme, it has not been investigated as deeply as the other ones. We have underlined above two significant negative issues of this scheme, but it could as well reveal promising for certain kind of AS (for instance, it could perform very well for solving balancing issues) and also to eliminate gate closure issue (see ch. 6). Thus we suggest a further investigation on it in order to better compare pros and cons.

3 Evolution of DSO to Market Operators

Apart from CS_A, where the DSOs have a side role in the operation of the AS market consistent in bid prequalification for the resources located in their local networks, all the other coordination schemes considered within the SmartNet project imagine a role of Market Operator for them, either in a direct way (CS_B and CS_C) or in a shared way (CS_D).

Apart from all the technological improvement needed, furthermore this implies that DSOs should be able to develop a proper expertise, far more advanced than the one which would be needed for the implementation of CS_A, that, at least in SmartNet, is considered to be the baseline for 2030. The effort needed is considerable, also in the case of the sharing of the market operation responsibilities with TSOs (which is, in present days, the most agreed vision for the future TSO-DSO coordination, according for instance to [6], [8] and [9]).

4 Illiquidity of local networks

As said, local markets could also be affected by scarcity of liquidity. This could bring the two following major problems:

3) If only a small number of resources are reliable or at the DSO disposal, those resources may have potential to exercise market power, so to lead to an increase of the prices and, then, the costs for the system. In SmartNet project this issue has not been investigated, due to the mathematical complexity of its modelling, but Regulation Authorities should take this problem into account.
4) The DSO may not be able to solve congestion in the DN by means of the market and thus be forced to activate unwanted measures, thus increasing the costs for the System.

Both these problems should anyway lead to very high prices in the AS market and so investor should be pushed to invest in the installation of new resources in the local networks. Thus, the scarcity of liquidity should solve itself, but it could take a lot of time, whether due to technical (the time needed to build a new plant) or economical (return of investment) or bureaucratic (local and environmental laws, regulatory framework) problems. The consequent boom-and-bust cycles could not be tolerable for the society, bringing to the necessity for the regulator to intervene and sterilize (part of the) price signals.

Another possible solution that should be taken into account, especially for small DSOs, is the possibility for them to join up in a single local market sufficiently large to avoid scarcity of liquidity. This approach should be encouraged not only because a larger pool of resources would be available, thus increasing competition and reducing the chances of market failure, but also because it will increase economic efficiency, since many small local markets have surely higher ICT costs for they implementation than a few local market with a reasonable size.

Also, the introduction of proper market products, tailored on the technical needs of DER, should contribute to solve illiquidity issues, as discussed more widely in chapter 7.

5 Influence of forecasting error

We expect that in 2030 and beyond resources at distribution level will likely be mainly composed by RES generation (e.g. PV power plants, mini-hydro…), whose reliability strongly depends on forecast reliability. We have seen in paragraph 2.4 how forecast error could heavily affect efficiency when a Common TSO-DSO AS Market is implemented. However, even if in a lower degree, also the other coordination schemes are obviously influenced in their result by the accuracy of RES production forecast. Two are the possible ways to follow to reduce the influence of forecasting error:

1) to improve forecasting reliability, which, however, is not under regulators' control. Furthermore, forecasting techniques can have better performances if applied to some generation technologies (e.g. PV) but much worse if applied to others which are strongly influenced by local climate and weather factors (e.g. mini-hydro).
2) to put the gate closure of AS Market as close as possible to real time; this can be done only up to a certain extent because a certain number of "dead" times has in any case to be accounted for:
    a. by Market Operator(s) to clear the market (and this could be overcome by investments in computational power) and
    b. by the resources to activate themselves and to ramp-up/down to the requested level (technological constraint).

6 Gate closure of other markets

We have already discussed in chapter 5 how pushing AS market closure as close as possible to the real time should decrease the impact of forecasting error on the total costs for the System, provided that the computational power for the market clearing and the response capability of the resources are adequate to that task. For both of them, appropriate investments would probably be needed.

Another important issue is the gate closure of other markets with respect to AS market. There is widespread agreement on the fact that Intraday Markets should bring gate closure as close as possible to real time in order to allow, in particular but not only, RES to recalculate their actual generation taking into account the most updated forecasts. This will reduce imbalances, with an important cost reduction by the point of view of the System and by the point of view of producers as well, since they are called to pay for the activations needed to solve the imbalances they cause.

If other markets are cleared too much close to real time, two issues may arise, very similar to what was discussed above with respect to the reduction of the impact of forecasting error by putting AS market closure as close as possible to real time:

1) TSO and DSOs become no more able to evaluate the status of the System, calculate the needed reserve and arrange the AS market, unless strong investments both in ICT, to allow detailed control on DN, and computational power, to speed up the clearing of the market, are performed;
2) activation and ramp constraints could prevent some technologies from providing their services.

In particular, for what concerns 2), an intervention from the regulator is needed, since, even if we could expect a technological improvement leading to remove those technical constraints for some resources, for others this is impossible (e.g. loads related to industrial processes).

Another possible solution could be to arrange an Integrated Flexibility Market scheme, as like as the one suggested in CS_E (see [1] and also par. 2.5). Such a market should be the result of the mix of IM and ASM, where flexibility resources would be available not only to System Operators but also to private operators to solve their own flexibility problems. Pros and cons of such a market were not assessed within SmartNet due to modelling complexity, so further investigation is recommended.

7 Market Products

Ensuring level playing field in the participation of distributed resources, especially industrial loads, to the tertiary market is a key feature. But these kinds of resources are in general smaller and less flexible than the ones connected at the transmission level. Let's consider as an example the case of a production line that is "flexible" in the sense that two possible consumption profiles, related to two different production lines, can be chosen alternatively; in this case the plant may present two different offers of flexibility, but once one of the two is chosen, the line cannot be changed anymore and for the following time intervals the plant has a fixed consumption profile. Another example is related to Thermostatically Controlled Loads (TCL), described in [10]: they are loads which have to fulfil a heating (or cooling) demand and are able to change (reduce or increase) their consumption profile for a few time intervals, but then they have to regain the energy in the following time intervals. We have to consider also that increasing the number of resources that are able participate to the AS market will help to solve liquidity issues (see chapter 4).

Thus, it will become necessary to introduce into the market brand-new bidding products, even sophisticated, tailored on the needs and peculiarities of the different technologies, since without this it would be nearly impossible for them to participate.

As a consequence of the introduction of this complex and even sophisticated products, with the aim of taking into account in a better way the technical (or physical) constraints of particular resources, an increase in the complexity of the mathematical representation of the markets and so in the costs for the computational power needed to clear the market, will be met. However, physical and technical constraints are always mathematically describable, even if not always in a simple way, and an increase, although considerable, in the complexity of the problem to solve could be accepted if it brings real benefits to the System. Thus, a trade-off between these two aspects should be performed carefully.

8 ICT findings and recommendations

Communications requirements of all coordination schemes were analysed in the SmartNet project and for them suitable current and emerging technologies and architectures were examined. The cost-benefit analysis of coordination schemes included the assessment of IT system costs when upgrading the baseline TSO-DSO coordination scheme to alternative coordination schemes proposed by SmartNet. Also the pilots had some data communication aspects. This chapter summarises the resulting ICT findings and recommendations.

The Spanish pilot (see [5]) indicated that markets and regulations should be developed further to grant access to the flexibility of backup power in the AS markets. There is significant and inexpensive flexibility potential offered by battery groups used in mobile networks' base stations to ensure backup power for telecommunications. See Deliverable 4.4 [11] for more information. The data communication findings from the Italian pilot [3], discussed later in the chapter 9, and the Danish pilot [4] are in line with the views in the analysis described next but less general and covering.

As the telecommunications technologies evolve fast, the regulator should not define technologies to be used, but functional requirements that applied technologies should fulfil. ICT services can be implemented by various technologies; the most economical and practical technology is hard to predict due the nature of modern ICT services and it may vary according to a geographic region. The analysis reported in SmartNet D3.2 [12] revealed that the most critical requirements, and also the most difficult ones, are related to response time (latency), security, and cost. Latency and security will significantly affect the cost and communication technology to be used. The analysis process and parametrized architecture model presented in [12] will support this kind of performance assessment. As the remote monitoring and control extends to the edges of the grid e.g. small or medium size DERs, more grid components without sufficient security will emerge and more emphasis must be put on dividing the grid in secure/reliable and unsecure/unreliable parts. See [12] for discussion on future flexible architectures using dynamic microservices and gateways to aggregate information from various devices and owners and to guarantee sufficient cyber security.

The technologies that enable data communication with small DER in provision of AS while meeting the identified requirements regarding cost, latency, security, availability, interfaces and permanency are available. But it is uncertain if they will be ubiquitously implemented and deployed by year 2030 without some appropriate regulatory measures. Well-defined open interface standards are needed to serve the variety of equipment and service providers. The regulatory requirements need to cover smart metering systems and the public telecommunication networks.

Regulation of private and public telecommunication networks should be considered as a whole and converge towards minimum requirements to all telecommunication networks. Services to the energy sector will increasingly utilise public networks and the decision of using private or public network is done case by case. Network Function Virtualisation and Software Defined Networking provide additional flexibility by offering means to move from hardware-centric architectures to software-centric ones as part of the telecommunications softwarisation. This needs to be taken into account when the future grid communication and related minimum requirements are designed. See [12] for more information. Furthermore, the energy sector is foreseen to buy ICT as a service, which should be taken into account in the regulation of the energy grids and markets.

In the smart grids, the amount and data formats used for exchanging information between system components will change. This requires flexible and standardised virtual interfaces that diminish the role of the hardware allowing remote software updates and smooth aggregation of energy. It is anticipated that the costs of data communications and control of small DERs are dominated by installation and site visit costs. As part of this, cyber security must be adequate but affordable also for small stakeholders. Regulation and standardisation of the interfaces and minimum functionalities have a key role in reducing these costs and protecting future energy systems.

The ICT cost assessment compared costs to upgrade from the baseline coordination scheme, operational with all DER communications in 2030, to alternative schemes proposed by SmartNet, see deliverable D4.3 [2]. The upgrade cost differences between coordination schemes were small and there was only a minor variation in costs depending on the country. Depending on the country and grid conditions alternative schemes may provide benefits to grid operations that exceed the additional ICT costs. All coordination schemes analysed have similar last kilometer communications. It may be possible that DER communication/activation costs turn out to be too large for a profitable ancillary service aggregation of very small DERs. This applies to each coordination scheme equally and may make all considered coordination schemes unfeasible for very small DERs. The last kilometer DER control communication costs per unit flexibility depend on the size and amount of available flexible DER and the regulation regarding the communication interfaces, grid codes, smart metering and communication networks and their detailed analysis was outside the SmartNet scope. Lastly, the cost analysis indicated that aggregators will have a large share of ICT costs. They will most likely be responsible for DER control signal communications and their software needs are considerable. Thus the following aspects outside the scope of the SmartNet studies may significantly affect the ICT costs. 1) The market design details can have impact on the aggregation complexity needed. 2) Meeting the communication performance requirements in exceptional situations tends to be expensive.

9 Technological response limits

Some technologies may present delays, even very large, in the response to the activation signals sent by operators. This could happen more likely at DN level and is usually due to technological limitations on telecommunication availability and power plants that are aged and were not designed for the provision of specific AS. This has been particularly highlighted in the development of the Italian Pilot (Pilot A, which implemented CS_A in northern Italy, see [3]), where several DER (hydro power plants) performed significant delays (tens of seconds) in aFRR compared to the requirement of the response (less than 20 seconds and data update every 4 seconds). A good forecast is also essential when the requested AS is a power modulation around a fixed power profile (like in aFRR service).

This shows how important it is to setup appropriate testing procedures (prequalification process) in order to ensure compatibility with newly requested reaction times, if not even pilot projects. In particular, taking into account that technical limitations are mainly featured by old power plants, DER retrofitting and/or advanced aggregation processes (capable of optimally combining DER with different dynamics) can be promising solutions depending on level of criticality (and business attractiveness) of specific services.

The Italian experience also demonstrates how reactive power flexibility (provided by DER) can be a fundamental service for the management of local (distribution network) voltage issues. On the other side, the same flexibility has not provided significant benefits in the regulation of the TN voltage (where DN is connected), but it resulted in an improved power factor management in correspondence of the TSO/DSO interconnection point (where TN power plants are regulating the voltage concurrently and DN reactive power can negatively impact on it).

10 References

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11 Appendix – Comparison with other institutional views

11.1 The vision of System Operators

In this paragraph we are going to compare results and suggestions from the SmartNet project experience with the vision presented in the document "*TSO – DSO Report. An Integrated Approach to Active System Management with the Focus on TSO – DSO Coordination in Congestion Management and Balancing*", published in 2019 by Cedec, EDSO, ENTSO-E, Eurelectric and Geode [8].

The report deals with active power management from the perspective of a close collaboration of TSOs and DSOs for what concerns congestion management in both distribution and transmission grids and system balancing, in particular when they are provided in a market-based approach by third parties. This is inserted in the framework of the so called Active System Management (ASM), which in the vision of the institutions who authored the report is "a key set of strategies and tools performed and used by DSOs and TSOs for the cost-efficient and secure management of the electricity systems."

The document presents the main topic in an organic way under different aspects, organized in proper chapters: Congestion Management Process, Information Exchange, Products and Bids, Pre-qualification and Marketplace for Congestion Management. In particular, in this last chapter (chapter 7 in [8]), paragraph 7.2 discusses 3 market models for Balancing and Congestion Management, which is very close to the core of SmartNet project (that is to assess different TSO-DSO coordination schemes for Ancillary Services Market).

These 3 market models assessed are:

1. "SEPARATED TSO AND DSO CONGESTION MANAGEMENT"

DSO congestion management is separated from TSOs congestion management and balancing (which can be run both in a separate or in a merge way by TSOs). This is similar to CS_B in SmartNet and, in some ways, to CS_C (provided that CS_C gives balancing responsibilities also to DSOs, while in the framework of the report [8], balancing is only a TSOs' issue).

For this market model, the document presents a series of pros and cons. The indicated pros are related to technical issues that were not tackled in SmartNet. On the contrary, among the cons indicated are

"Probably less liquidity in small markets, and probably higher prices", as also discussed in the present deliverable in Chapter 4.

"Market fragmentation", that is "flexibility resources may be 'locked' in local markets", also discussed in the present Deliverable in paragraphs 2.2 and 2.3.

"Coordination between TSO and DSO is more difficult", that is "double activation of the same asset bidding in two separated market processes", also discussed in the present deliverable in paragraph 2.3.

Thus, on this market model, the two visions are aligned.

2. "COMBINED TSO AND DSO CONGESTION MANAGEMENT, WITH SEPARATED BALANCING"

A common market for TSOs' and DSOs' congestion management is considered. For balancing, a separated market is arranged, since in this repost balancing responsibility is only a TSOS' issue. This is similar to what within SmartNet is called CS_D, although in CS_D also balancing responsibility is shared.

Among the pros considered it is possible to find:

"More flexibility and competition leading to lower costs", as it is highlighted also in section 2.2 of the present deliverable.

"Coordination between TSO and DSO is more efficient", even if in the cons we can read that this goes along with the need of more complex, and likely more expensive, ICTs.

"Clear division between the two processes of balancing and congestion management and clear congestion management costs"; we have to underline that in SmartNet a clear separation between congestion management costs (that should be paid by the Network Operators) and balancing costs (that should be paid by those resources that cause the imbalance) has not been highlighted, while in the report [8] it is a key issue.

Among the cons:

"Governance to be shared", which has been also dealt with in SmartNet more focused on the aspects of data sharing (see paragraph 2.4 in the present deliverable).

3. "COMBINED BALANCING AND CONGESTION MANAGEMENT FOR ALL SYSTEM OPERATORS TOGETHER"

All balancing and congestion management bids and actions are combined in an integrated market-based process to allow TSOs and DSOs to access all bids from market parties and mutually coordinate activations. This market scheme is quite similar to the CS_D in SmartNet.

According to the report [8] this option could ensure liquidity, build a level playing field for different service providers and allow the coordination of different market processes such as balancing and congestion management. Furthermore "because congestion management bids can be merged with a well-established balancing market, the costs for congestion management bids are likely to be low". It is underlined that locational information is a key issue in order to develop such a market scheme; similar considerations have been drawn in SmartNet (see paragraph 2.4 in the present deliverable).

On the other hand, again the complexity of interaction between TSOs DSOs and other market parties is underlined along with the complexity of the implementation which “would require an overall optimization and bid selection system that may be very cumbersome to achieve starting from scratch”.

A final consideration on this market scheme the definition of proper market products, that here is presented by the System Operators viewpoint while in SmartNet is posed by resources viewpoint (see chapter 7 in the present deliverable).

11.2 ETIP-SNET Vision 2050

The European Technology and Innovation Platform of Smart Networks for Energy Transition (ETIP-SNET) launched in 2018 its "Vision 2050" for the future power system, which was coined "System of Systems" [7]. The vision covers a gradual transition to a new energy system, which will pave the way for fully CO2 neutral and circular economy, while maintaining and extending the European industrial leadership.

There are several key principles, composing the system together. The present key role of the electricity sector will be further enhanced, so the electrification of the Europe's energy system will be the backbone of its societies and markets. In addition to this, it will be introduced an incremental coupling of electricity and gas networks, via production of carbon-neutral synthetic gases ensuring security of supply by using seasonal storages. The low carbon European economy will also include coupling across several other energy systems, including electricity, heating and cooling systems as well as electricity and biofuels. The system will in addition mobilize all available flexibility solutions in order to optimize the grid capacity uses.

It is pointed out the deployment of such system will require major investment into integrated technical infrastructure, including conversion, transmission and distribution of energy as well as digital solutions. More importantly it will require development of markets allowing interplay across different energy carriers, where imbalances between energy generation and demand will be handled automatically using market-based mechanisms.

Due to the physical nature of some of the energy carriers e.g. district heating, considerable share of optimisation involving different energy carriers will happen locally. The vision therefore encourages decentralisation of several processes within the power system operation and applies the principle of subsidiarity, meaning that actions will have to be optimised locally first (at the most immediate level) and then things, which cannot be optimised locally, will be handled at the next level.

Increased decentralisation of the existing operation is one of the main elements embedded into the new system. Implementation of the vision will therefore require a thorough revision of the existing organisational architecture and accordingly redistribution of the roles and responsibilities between different actors.

Having slightly shorter timer horizon, the SmartNet coordination schemes deal with more specific challenges and do not include different energy carriers due to several reasons. There is however a different level of centralisation, which is implemented in the schemes. Introduction of interplay among different energy carriers, which has to be optimised on the local level, favours the coordination scheme (-s) presuming higher decentralisation and even balancing on the local level.

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