UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE
ELECTRIC POWER INDUSTRY

Master's Thesis

DSO – TSO COORDINATION

Author: **Pedro L Dueñas**

Supervisor: **David Trebolle Trebolle**

Supervisor: **Jorge Tello Guijarro**

Madrid, July 2015

Master's Thesis Presentation Authorization

THE STUDENT:

Pedro Luis Dueñas Cañas

Pedro Mnñ
....

THE SUPERVISOR

David Trebolle Trebolle

Signed: .... Date: 08/ 07/2015

THE SUPERVISOR

Jorge Tello Guijarro

Signed: .... Date: 08/07/2015

Authorization of the Master's Thesis Coordinator

Dr. Javier García González

Signed: .... Date: ....../ ....../ ......

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Summary

Distributed energy resources (DER) are bringing connection problems, generation uncertainty, bidirectional flows... However, they may also provide services to the system operators. Improvements of information and communication technologies (ICT) are bringing new possibilities for the monitoring of the low voltage grid levels. In this thesis it will be studied how DER and ICT affects to the European system operators roles.

It has been identified the roles, objectives and tools that system operators (DSO and TSO) have nowadays and which ones they will have in the future. In future, roles will remain but DER will bring new tools that will be useful for both DSO and TSO.

Since both system operators (SOs) are willing to act over DER, it is necessary to establish coordination so that both SO are be able to use DER services increasing the efficiency of the system: it is necessary to decide who is going to act over DER and how the other SO will be able to consider DER services.

In order to solve this coordination issue, it has been proposed a methodology that analyses how different coordination models fit in a country. The methodology is based on three different steps:

1. Analysis of current country boundary conditions
2. Evaluation of the transition costs if this model is implemented using technical, regulatory and economical approaches
3. Assessment of the decision variables for the long term looking at the whole country.

In order to see the robustness of the methodology it has been applied the methodology for 3 different models in three different countries. The three countries considered for this master thesis are three different representative countries after studding 12 European countries .Then, it has been applied the methodology nine times: one per each one of the couples country-model that this master thesis consider in order to study the European representative countries.

The different models that have been considered are based on state of the arts reviewed within this project. Furthermore, those models have been deeply defined during this master thesis.

By doing this, this work has studied the different possibilities on how Europe regulation may evolve for solving the TSO-DSO coordination issue. Comparing the results of the different case studies, it is possible to see that there is not one model that fits better for all the countries. Transition costs are different depending on the current situations of the countries nowadays. Furthermore, the long run efficiency is different depending on the DER penetration of each country and the market power/competition of the DSOs.

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1 INTRODUCTION

European network grid is divided in two different parts depending on voltage level: Transport grid includes the grid elements that are at higher voltages (the exact voltage value depends on the country but always include 220kV and 400KV). On the other hand, lowest voltages levels are considered distribution grid (which finds more differences among the European countries varying between 132kV and 400V).

In a previous situation, the management of the distribution grid was very predictable since generation was located at upper levels (transmission) and consumption was located downwards (distribution). Furthermore, generation that was being considered was firm and predictable.

However, this scenario is changing with the appearance of new connections at the distribution level: distributed energy resources (DER), concept which includes distributed generation, electric storage and demand flexibility. These new agents are changing the layout of the distribution grid and challenging the operation of the network: for example, generation depends on renewable sources which bring uncertainty for the generation forecast. Now generation is not concentrated in big nodes at transmission grid. Now there is generation spread out along the distribution grid. Furthermore, electrical flows cannot be considered unidirectional anymore; complexity of flows requires new considerations to ensure quality and security of the grid.

This is already a reality: Levels of solar PV panels have increased a lot during the last years in Europe. One meaningful example is the German case that is installing high amounts of PV panels during the last year. Similar situation had wind energy sources in Europe, there have been a huge increment during the last years, and the trend is to continue in this direction.

Looking at the future, power installed and energy injected due to distributed energy resources will increase in the future. The entry of the Electric Vehicle has almost not started and it should be considered in future scenarios. The widespread growth of this vehicle and the connection of a big amount of electric cars will challenge the distribution grid with new necessities. The use of batteries that make possible to storage energy in order to be used later for self-consumption or to be injected in the grid later on will be a possibility that should be also considered in future managements of the grids.

Furthermore, the appearance of the demand side response (DSR) gives the possibility to the users to control their consumption and offer different services to the system depending on their necessities and prices.

Distribution System Operators are at the core of this transformation since it is in their grids where most of the new elements are being connected. Furthermore, since both distribution and transmission grids are connected, TSO will be also affected with the new agents connected in the system.

The monitoring level at HV is very high. This do not happens for lower voltage levels. As the voltage level decrease, the monitoring information and the actions that can be done over the grid decreases as well. The low monitoring of MV and LV has not been a real problem since the flows of these networks were very predictable because of the behaviour of the loads and generators connected in that voltage levels. Flows were going from high levels –where generation plants were located- to the consumers allocated at lowest voltages. For this reason, flows were considered unidirectional. However, this situation is changing because of the improvements in the information and communication technologies.

In a traditional scenario the management of the generation has being done by the TSO while DSO has had a passive role. Technically speaking, network monitoring decreases as long as the voltage decreases. However, new possibilities for monitoring are coming due to the improvements of the information and technology communications.

With all these changes, a more dynamic system based on distributed and variable generation may replace the traditional static system based on predictable and centralized power generation. This new situation makes new challenges for both TSO and DSO in order to accomplish with the quality and security of the grid.

Furthermore, it should be considered that transmission and distribution system operators are regulated entities and their operation is determinated by Network Codes. System Operators can no act freely and should follow procedures established by the regulator. Regulation is a key aspect in this sense.

1.1 MOTIVATION

This Master Thesis under the title "New coordination needed between the DSO and the TSO", was supervised by Jorge Tello Guijarro with the co-supervision of David Trebolle Trebolle and done by Pedro Luis Dueñas Cañas with the aim of conclude the Official Master`s Degree in the Electric Power Industry at University of Comillas in Madrid throughout the academic year 2014-2015.

Distributed generation, electric vehicles and demand side participation are needed to be integrated within the electrical system. With this new scenario, the way both DSO and TSO work may need to evolve. Roles, objectives and tools to manage the grid may be different in the future. Typically, the operational tools of the electricity system have been managed by the TSO, but the high presence of distributed energy resources at the distribution side is challenging the business as usual paradigm.

Therefore, this master thesis tries to analyse the current and future state of operational procedures in the electric system. Furthermore, it will be analysed the necessities of the system operators and will be discuss what could be the most effective mode that ensures an effective coordination needed in the future between the DSO and the TSO within the European electric system.

1.2 OBJECTIVES

The global outcome of this thesis is to identify how to improve the coordination among DSO and TSO in order to make possible the full, secure and efficient integration of distributed energy resources.

In order to identify the coordination needed in future between DSO and TSO, five different objectives are going to be considered in this thesis.

a) Analysis of the TSO and DSO actual roles in the European countries.

b) Analysis of the TSO and DSO future roles in the European countries.
c) Identify the areas that require coordination among DSO and TSO.
d) Propose a methodology to address this issue.
e) Case study: Application of the methodology in representative countries.

1.3 STRUCTURE OF THE DOCUMENT

During this first chapter it is possible to see what is the motivation and objectives of this thesis.

Second chapter makes a review of the European regulation, papers, reports published by academia or electricity companies associations. Furthermore it has been analysed raw data of a survey from Eurelectric which gives information of what DSOs and national associations are requesting for future situations regarding DSO-TSO coordination.

Third chapter analyses the current, the transition and the future roles of the grid system operators (both DSO and TSO).

Forth chapter analyses if it is needed any overlapped area among DSO and TSO and which type of coordination it is necessary to define. This chapter also define in detail the different models that are considered in this thesis in order to solve DSO-TSO coordination issue.

Sixth chapter defines the methodology that is proposed in order to analyse how a coordination model fits in a country.

Seventh chapter consider the nine case studies in which the methodology has been applied for each of the couples country-model.

Eight chapter do a comparison of the different results of the cases studies trying to get an overall idea and conclusions of the case studies.

Finally, chapter nine consider the conclusions and limitations of this thesis as well as future research that have to be done in future.

2 STATE OF THE ART

2.1 LITERATURE REVISION

In this section, it is going to be reviewed literature that has relation with the DSO-TSO coordination: research papers, reports of different electrical associations, network codes, regulation and R&D projects. In this section, those documents have been summarised. Here are presented the most important points that deal with the objectives of this thesis.

This section has been divided in six different parts: First one consider network codes in a European stage as well as some local country network codes. Second part considers European electric associations' reports that have dealt this coordination issue before. Third part considers academicals research papers related with DSO-TSO coordination. Forth part consider documents and reports regarding the European regulation. It has been considered R&D projects that have already been developed and have considered coordination among both system operators in the fifth part. Finally it has been highlighted in the last part some issues of the German and the Netherlands electric system.

2.1.1 European Regulation

CEER reports: Future role of the DSOs. (CEER - Future role of DSOs. , 2014)

The Council of European Energy Regulators (CEER) is the voice of Europe's national regulators of electricity and gas at EU and international level. CEER principal objective is to facilitate the creation of a single, competitive, efficient and sustainable EU internal energy market that works for the public interest.

CEER published in 2014 a report (CEER - Future role of DSOs. , 2014), a document where it was studied the role of the DSO according to the future changes that are coming because of the appearance of DER. It sets that retail liberalisation, demand-side response arrangements, new technology and distributed electricity generation have meant that the role and culture of DSOs has changed over the last decade and will continue to change in the future.

This report explains that the role of the DSO is evolving since some DSOs should become active grid managers, much as TSOs already are today. This report also identify the needs for DSOs to become active grid managers. In order to actively manage their distribution grids, DSOs will require new system flexibility services to maintain a secure and high-quality costumer's service. This also implies that DSOs, especially larger ones, will need a stronger coordination with the TSO.

This report is mainly focused on ancillary services: the importance of those services and how should be provided. A procurement of system services (e.g. active power modulation, reactive power compensation, active voltage control, congestion management) may be required by both TSO and DSO in order to solve constraints located at both sides of the grid. An agreed operational procedure between the TSO and DSO for the use of these services as well as the coordination at the interface point is needed.

This report explains how the management of DG nowadays is. Normally, the DSO does not curtail DG to alleviate congestion. If curtailment it is required, it is usually requested by TSO for system security reasons. However, increased levels of DER and the increment of congestions on the distribution network may need to go one step further entailing the DSO to have an active role in temporary congestion management on the distribution network. The DSO should be informed when services of distribution networks are activated on the balancing market, as it may lead to subsequent constraints on the distribution network. DSO will face the challenge of power flow management in a much more dynamic way. Symmetrically, the TSO should be informed by the DSO in cases when local distribution ancillary services are activated because the changes may impact the TSO grid.

This report highlight that both SOs have to improve communications and data exchange in order to improve real-time operation for both the TSO and the DSOs. In many European countries still there is currently no consistent or systematic exchange of information between the DSO and TSO regarding distributed generation and other DERs. Furthermore it should be facilitated greater involvement of distributed energy resources -including storage and demand response from consumers– in system balancing.

Usually, DERs cannot offer their services to the system when needed. In some cases, energy production is lost due to necessary curtailment by network operators. In the future, there may be scenarios where the lack of DER coordination may negatively impact the efficiency of procuring balancing resources.

It is important to take into account that TSOs and DSOs might need to use the same DER service or services that are mutually exclusive (cases where the use of one service by one SO affects negatively to the other SO). In these cases it may be more efficient if one operator is prioritised over the other. It should be considered that some network services are locally managed (e.g. management of voltage constraints by reactive power provision), while others are for the system as a whole (e.g. frequency response through active power modulation). For this reason, different approaches should be considered depending on the different cases.

If distributed energy resources are called upon to provide a response in real time or close to real time, the TSOs ability to balance the system is impacted by the amount of actions undertaken on the DSO network. For this reason, an exchange information increment may be required in the future to ensure that distribution network operations are not in conflict with transmission network operation.

Traditionally, the TSO has forecasted the dispatch schedules. In the past, DERs were negligible and therefore were not considered by the TSO with sufficient detail in the forecast. However, with increased levels of both DG and active demand, the distributed users may be integrated into the TSO forecast. Furthermore those forecasts should be used by the DSO in order to know scheduling and dispatch of distributed resources, distribution network constraints...

Although the TSO is ultimately responsible for emergency operations, DSO must have a more active role informing the TSO or taking actions in the absence of an instruction from the TSO. Exchange of information in order to increase coordination among the agents is also needed. In some countries (especially those with higher DER penetration), DSOs are progressively carrying out forecasting activities. Accurate forecasting at local level would help DSOs to manage congestion and voltage constraints.

Improvements in infrastructure reinforcement and development data exchanged between DSOs and TSO could lead to efficiencies and cost savings to the end consumer since planned reinforcements on the transmission or distribution system are postponed or not needed anymore.

EG3 REPORT (EG3, 2015)

The European Expert Group 3 (EG3, 2015) recommends that both DSOs and TSOs must have constraint management procedures which include the right to purchase flexibility services in order to tackle constraints on their networks.

In this line, EG3 considers the new services (that may appear with DER) will be useful for DSOs and TSOs to have the possibility to optimise investment in networks through the use of smart grids, including demand side flexibility services. Flexible grid access and real-time flexibility can reduce or postpone investment need. DSOs should have the opportunity to use flexibility services where this provides a benefit to the network and hence to the consumer. Through proper regulation, DSO customers must have the possibility benefit from flexibility services.

To ensure safe, secure and cost-efficient distribution and transmission network operation and development, both DSOs and TSOs must have access to flexibility services and all technical relevant data needed to perform their activities.

EG3 recommends that DSOs and TSOs shall exchange relevant operational data with each other. However, EG3 do not specify what relevant operational data is. When congestion areas appear, DSOs and TSOs need to make available the appropriate information to all concerned parties (BRP, aggregators, suppliers etc.). Relevant purchases, activation of flexibility, or its modification done by DSOs or TSOs shall be exchanged in advance, before the activation is completed

This report considers that the link between DSO and TSOs should be used not only for information exchange but also for requesting actions on each other networks.

ACER published "The Bridge to 2025" (Acer - A Bridge to 2025, 2014)

ACER is a European organisation that was established following the entry into force of third energy liberalisation legislative package (3rd Package). Acer has regulatory responsibility tasks in relation to Europe's electricity and gas markets and is composed by national energy regulators.

In September 2014, ACER published “The Bridge to 2025” (Acer - A Bridge to 2025, 2014) describing recommendations on the development of the energy sector and the role of regulation over the next ten years. Based on extensive consultation, a number of regulatory measures are proposed. The publication includes a proposal of actions for the European Commission, Member States, regulators, and for energy market agents. The main proposed issues in the report are summarised below.

According to ACER, DSOs will need to adapt their networks to meet new demands, (e.g. distributed generation, users offering services of demand response, batteries issues or EV recharging stations). With all these connections, DSOs must be neutral market facilitators to enable the development of new market-based services to consumers while ensuring secure system operation.

DSOs will need to manage their networks actively through smart grid solutions, services and innovative investments. DSO and TSO coordination for operational network matters, but firstly it is necessary to clarify the distinct roles and responsibilities of TSOs and DSOs in order to clarify the bases. More coordination and info exchange among them will be required.

It is important to clearly define the core DSOs functions to facilitate the development of potentially competitive services. This report explains that is important to develop a toolbox through the regulation for DSOs that is flexible, adaptable to nationally conditions and includes a set of consistent options to ensure an adequate level of business separation.

In order to achieve investments in innovation and efficient management good practices regarding distribution it should be developed new network tariff structures and improve smart grids implementation. ACER sees smart meters as a key device in order to facilitate the operation of the system operators.

THINK Report (Florence School of Regulation, 2013)
THINK report is a document that advises the European Commission (DG Energy) on a diverse set of energy policy topics. Here are considered the most important issues of this report.

According to the project, DER can offer a range of products to (i) manage short-term problems in the grid, (ii) to optimize the cost of maintaining the desired quality of service, (iii) to reduce grid losses and (iv) to reduce or postpone future grid investment needs.

The report points out that one of the improvements needed nowadays is a clear regulatory definition for the use of DER flexibility by DSO and/or TSO operations. Wherever DSOs and TSOs in principle can procure the same service, more coordination among DSO and TSO is needed.

The author proposes to create a hierarchy of functions between TSO and DSOs due to the high complexity of the tasks and the large number of agents involved in the system. TSO is proposed as the agent responsible for system balancing. DSOs, after having undertaken their DER-related activities, should submit their protocols to the TSO (who is the final responsible system operator). These protocols are especially important for those DER that can provide services to both TSO and DSO.

According to this author, all DER have to be monitored with respect to what product they are offering and when. The data on dispatch should be given to DSOs as soon as possible, so that the DSO can react accordingly in an emergency situation and curtail the most appropriate DER. Moreover, any action on distribution network users requested by the TSO should be agreed with the respective DSO. A TSO should not act on any individual DER connected to distribution grid. An order from a TSO towards DER embedded in distribution systems should be passed through the DSO and never directly applied by the TSO.

Due to all new connections located at distribution level, DSOs shall facilitate market functioning by providing non-discriminatory access to the grid users. Furthermore, grid users should have the correct signals for efficient grid access and operation. Moreover, Member States may require to the DSO to give priority commitments to RES generators or CHP units.

Regarding to short-term reliability and system stability, it is currently the TSO who is responsible for ‘ensuring a secure, reliable and efficient electricity system and it has to ensure the availability of the necessary ancillary services'. However, more active DSOs will play an increasing role and as a consequence, an increased cooperation among DSOs and TSOs becomes crucial in order to coordinate the ancillary services efficiently. From a regulatory perspective, tasks of the different network operators have to be clearly defined in order to achieve an efficient system operation and cooperation.

As discussed above, the potential of DER services provided can be used to perform short and long-term TSO and DSO duties. DSOs will likely become more similar to the functions that TSOs have now. While DSO network management has been until now not based on services management (with exception of emergency scenarios), TSOs have pursued tasks that, besides long-term grid planning, are more directly related to balancing the network. These tasks typically include frequency containment, frequency restoration and replacement of generation units.

Table 1 represents the DSO and TSO roles that are directly related to grid management. It is possible to see that both have to guarantee the connections to their grid and both have to consider the long term planning and grid development. The differences among them are the grid level where they are acting and the actions they should be focused on: DSO control voltages and loads/DG disconnections when emergency scenario appears while TSO controls frequency (both values control and restoration) and generation replacement. The TSO products where are considered these operations are primary, secondary and tertiary reserves

DSO	TSO
Long-term distribution grid planning and grid development (including the connection of load and DG and guaranteeing efficient access and use of the grid)	Long-term transmission grid planning and grid development (including the connection of bulk generation (and load) and guaranteeing efficient access and use of the grid)
Grid operation, in particular: • Voltage control • Load/DG curtailment in case of emergencies	Grid operation, in particular • Frequency containment • Frequency restoration • Replacement of generation

Table 1: A taxonomy of the system operators' task directly related to grid management

In the Think Report are pointed out four areas that need to be reviewed in the regulation if we want to move form Distribution Networks to the Smart Distribution Systems: the methods of determining the regulated remuneration of distribution companies, the design of distribution network charges, the functions and the level of unbundling of DSOs, and the relationship among distribution and transmission system operators.

2.1.2 Codes and procedures

Third Energy Package of the European Union (Directive 2009/72, 2009)
The European Union's Third Energy Package is a legislative package for an internal gas and electricity market in the European Union. Its purpose is to further open up the gas and electricity markets in the European Union ensuring unbundling of the regulated agents.

According to the directive, DSO responsibilities are to ensure the long-term ability of the system in order to meet reasonable demands for the electrical distribution, operating, maintaining and developing the actions under economic conditions.

The directive considers third-party issues. It declares that discrimination in investment is less significant at distribution level than at transmission level where congestion and the influence of generation or supply interests are generally greater than at distribution level. However, legal and functional unbundling is required also in distribution system operator level. Agents should be monitored so that they are prevented from taking advantage of their vertical integration as regards their competitive position on the market, in particular in relation to household and small non-household customers.

Following this directive, Members States should encourage the modernization of distribution networks, through the introduction of smart grids, which will be used in a way that improves decentralised generation and energy efficiency.

In terms of new investment and planning and the development of the distribution network the directive considers that energy efficiency/demand-side management measures or distributed generation might supplant the need to upgrade or replace electricity capacity. With this consideration, networks companies (both distribution and transmission) will have the possibility of using different services of the grid users in order to achieve higher flexibility of demand and generation, avoiding or postponing reinforcements of the grid.

Where a distribution system operator is responsible for balancing the distribution system, rules adopted for that purpose shall consider transparent and non-discriminatory access. Terms and conditions, including rules and tariffs, for the provision of such services by distribution system operators shall be established in accordance with Article 37(6) in a non-discriminatory and cost-reflective way.

As stated in Art. 12 and 25 of the Electricity Directive (Directive 2009/72/EC), both TSO and DSO are deemed responsible for ensuring the long-term ability of the system to meet reasonable demands in their grids.

Regarding new connections, Member States shall impose on distribution companies an obligation to connect customers to their network meeting third party access. In the case of DG, Member States shall ensure that specific authorisation procedures exist for small distributed generation connections.

In terms of information that the distribution company should consider, the directive sets that the distribution system operator shall provide to system users with the information they need for efficient access. Information is considered as a general issue and it is not specified any particular information term that should be considered regarding distribution companies.

Spanish Network Codes (Ministerio de Industria energía y turismo, 2013), (Ministerio de Industria, Comercio y Turismo, 2006), (Ministerio de Industria y Energía, 2000), (Ministerio de Energía, Industria y Turismo, 2012), (Ministerio de Industria, Energía y Comercio, 2008)

This section contains the operating procedures, technical and instrumental data necessary for proper technical management of electricity system within the Spanish electrical system.

Spanish Network Code 3.2 deals with the procedures needed for solving technical constraints on the Distribution Network. In those cases where the DSO identifies the existence of a security problem on the network object to be managed. The central System

Operator (nowadays it is the TSO) must be request by DSO in order to introduce any amendments in generation scheduled to ensure security in the affected distribution network.

In the same network code, it appears that it is the TSO who should introduce the necessary modifications needed in the functioning base program and will inform to the distributor system operator with the information and the modifications that are created.

It is possible to see that almost all procedures consider the TSO as the central counterparty that can solve the problem. DSO have almost none possibilities to manage technical constraints on the Distribution network.

In the Spanish Network Code 3.5 it is approved that in cases where the distribution system operator identifies real time grid restrictions and the solution pass through the modification of the production planned programs, DSO can take all the distribution network measures at its disposal and then it shall inform the SO (TSO for this case), as soon as possible in order to do relevant changes. It is possible to say that currently DSO have almost none tools (just capacitors, tap changers…) but it has not the possibility to act over the users of the grid.

In the Network Code 7.4 it is set that the voltage control service is located at the transmission network voltage level. Nowadays, voltage control comprises actions on generation resources and absorption of reactive power (generators, chokes, capacitors, etc.) and other elements of voltage control, such as transformers changer of shots, aimed at keeping tensions at the nodes of the transport network within the margins specified to ensure compliance with safety and quality criteria. This code also fixes the consumption and the delivery of reactive power in the edge of both grids (transmission and distribution).

Information exchanged by the TSO is covered by the Network Code 9.0 where it is considered that distribution companies have to supply to the TSO with the information necessary of the elements of its network in order to keep the balance of energy updated.

Generators of the Spanish grid must send telemetric measurements to the TSO. These telemetric measurements shall be forwarded by the operators of generation installations or their representatives. This information may be transmitted also to the control centres of the distribution company if this is agreed by both parties. For generation with power installation lower than 10MW, TSO will send the data of those generators to the TSO if it is previously agreed by TSO and DSO.

Last Spanish network code that is going to be considered in this master thesis is the PO 15.1 which heed the interruptibility of the demand. DSOs can request to the TSO the emission of an order to reduce the power in the areas of the distribution when is required. Finally, it is the TSO who can accept or not the request.

In order to sum up this section, it is possible to see that TSO is the central counterparty in the grid operations. TSO is the system operator that can directly act over the grid users and it is the agent who has to receive the distribution grid information.

European Efficiency Directive (Directive 2012/27/EU, s.f.)

The 2012 Energy Efficiency Directive establishes a set of measures to help the EU in order to reach its 20% energy efficiency targets by 2020. Under the Directive, all EU countries are required to use energy more efficiently at all stages of the energy chain from its production to its final consumption.

Regarding the cogeneration, as explicitly stated (Directive 2012/27/EU, s.f.), Members states shall ensure that transmission system operators and distribution system operators: (i) guarantee the transmission and distribution of electricity from high-efficiency cogeneration, (ii) provide priority or guaranteed access to high-efficiency cogeneration (iii) when dispatching electricity generating installations, provide priority dispatch of electricity from high-efficiency cogeneration in so far as the secure operation of the national electricity system permits.

In the same directive it is declared the requirements related to the reliability and safety of the grid. It is specified that Member States shall take the appropriate steps to ensure that, it should be considered balancing services and other operational services at the level of transmission system operators or distribution system operators by cogeneration wherever it is technically and economically feasible.

According to the directive, Member States shall promote access and participation of demand response in balancing, reserves and other system services markets, inter alia by requiring transmission system operators and distribution system operators in close cooperation with demand service providers and consumers.

Different services being provided by distributed energy resources such as demand side response can be used for the necessities of the system within for the different markets that system operators are being run. With the use of these services, the system will have the opportunity to integrate the different agents instead of just connecting them.
Up to now, the agents connected to the distribution grid were very rigid (they were not able to offer services or change their consumption depending on signals). However, there is the possibility to use services of these agents in order to achieve a flexible generation/consumption at distribution grid.

German Case, German Network Code (VDN, 2007)
In Germany, all necessary measures are implemented in a cascading manner across all network voltage levels, starting at the transmission system. The DSO carries out backup measures by order of the TSO. DSOs are required to provide support to the TSO through their own grid users taken in accordance with the TSO's instructions. The TSO usually makes contractual arrangements with the DSOs that are downstream transmission level. Local load disconnection is carried out manually by the system operators (DSO and TSO) depending on the voltage level where the user is connected.

To obtain the necessary information for the assessment of the system state, DSOs, energy producers and suppliers are required to make available information to the TSO.

2.1.3 Electrical associations

The electrical associations are the voice of different electrical companies in a pan-European level. These associations are important to be considered since they represent a big number of companies of the four different electric stages (generation, transmission, distribution and retailing).

Eurelectric (Eurelectric- Active Distribution System Management, 2013) & (Eurelectric - Designing fair and equitable market , 2015)
Eurelectric is the sector association which represents the common interests of the electricity industry at pan-European level. Eurelectric have also affiliates and associates on several other continents outside of the European Union. They currently have over 30 full members which represent the electricity industry in 32 European countries. Eurelectric explains in its report (Eurelectric- Active Distribution System Management, 2013) many issues related with the TSO-DSO coordination. Most important points are explained bellow.

Nowadays, grid monitoring level decreases to very low levels when grid voltage is low. This situation should be changed in order to consider the advantage of renewable energy resources (RES) with the new improvements in information and communication technologies (ICT). Eurelectric gives a recommendation to the DSOs to leave aside the traditional passive distribution networks based on a “fit-and-forget” approach. This association expounds that a cost-effective integration of DER requires a rethink of how distribution grids are planned and operated. Coordination among all relevant stakeholders is key issue when this problem is addressed.

Eurelectric sees a lack of clarity on the system operators roles and responsibilities towards other market parties (i.e. customers, BRP/supplier and TSO/DSO), which could leave room for free-riding, thereby increasing costs for customers.

In terms of roles and responsibilities clarification, this association considers that DSOs must be allowed to conduct constraints management if the secure operation of the distribution system is threatened. In order to achieve this, DSOs should be allowed to access the relevant data of DER. DSOs should have access to information from DER such as services that are being offered, operation schedules (as early as possible) and activations of services by other SOs.

In a newer report from this association (Eurelectric -Designing fair and equitable market , 2015), Eurelectric explains that demand side response (DSR) will be one of the building blocks of future wholesale and retail markets, offering grid users the opportunity to reap the full benefits of their flexibility potential. The development of innovative demand response services will empower customers, giving them more choice and more control over their electricity consumption.

Eurelectric sees a lot of possibilities from services provided by aggregators and used by TSOs for balancing purposes. In order to ensure higher efficiency those services must be full available for the system operators. Grid users providing services should be considered by as much as market players possible. When specific resources are needed to be activated in order to solve local congestions on the distribution network, DSOs should guarantee a transparent and non-discriminatory selection.

This report proposes to have a traffic light system informing about the network stability (green/orange/red states) depending if there are no problems, congestions or an emergency scenario. This traffic light system would provide the relevant information to market parties as well as transparency.

With this traffic light concept, DSOs must ensure that the intervention of aggregators does not impact the security of DSO or TSO networks. DSOs should also have access to constraint management procedures in order to tackle constraints in their networks. Traffic light concept it is fully defined in the ‘BDEW Functional Interaction between the market and the regulated sphere’ in this chapter.

GEODE (GEODE, 2014)

GEODE is made up of European independent distribution companies of gas and electricity. The association represents more than 1200 companies in 15 countries, both private & public owned. The member companies serve a population of 100 million people. This association published a new report in 2014 (GEODE, 2014). In this report is promoted the possibility of use Demand Side Response (DSR) in order to take advantage of the flexibility.

The report sets out how Demand Side Response provides benefits to the whole energy system: it makes possible to optimise usage and balancing of networks and electricity production and consumption (it gives the possibility to consume less during peak hours or to facilitate the integration of variable renewable energy sources and micro-generation), lower network costs, lower prices, improvement of security of supply or overall system efficiency are just some of all the benefits that include DSR.

GEODE identifies the following main barriers for Demand Side Flexibility caused by the current DSO tariff structure across Europe:

- The current DSO tariffs structures focus on energy consumed do not provide viable financial incentives for the customer to adapt their electricity consumption depending on network capacity. If consumers pay just for the energy but not for the capacity, the consumer does not have any incentive to decrease his peak value (capacity).
- Current tariff structures do not reflect costs appropriately. If a customer varies consumption, his costs will change; however the DSO's cost may not change in the same proportion. A reduction of energy consumption without a reduction of the maximum demand will reduce the DSO's revenues but not the DSO's fixed grid costs.

Hence, the current tariff structure has to be developed further in order to address the absence of adequate cost reflectivity. It is essential that DSOs are empowered with a satisfactory regulatory framework so they can play an active role in technology innovation.

GEODE proposes as a general rule that market players can act freely as long as the distribution grid is not put at risk. They propose a traffic light status system (as well as it has been proposed by Eurelectric).

Regarding to the Distributed generation, GEODE believes that distributed generators can contribute towards balancing the local distribution grid. In this sense, GEODE enhances the figure of DSO saying that in situations where flexibility services appear, DSOs are a key element in order to ensure grid stability and secure grid operation. The report explains that if the DSO needs to run a market it will be necessary to increase the real time monitoring ability and controllability in the distribution grid.

Since the complexity of the future energy system is increasing, new arrangements between the different market players are needed. The future challenge for the DSO will be to create dynamic databases bringing together consumption and de-centralised production.

EDSO (EDSO, Flexibility: The role of DSOs in tomorrow's electricity market, 2014)**.**
EDSO for Smart Grids gathers European distribution system operators (DSOs) for electricity, cooperating to bring smart grids into the European electric system. Within this section, it has been considered the principal points of the report that this association published in 2014 (EDSO, Flexibility: The role of DSOs in tomorrow's electricity market, 2014).

Today, the main tool used by DSOs to overcome increases of electricity consumption or generation in their network is to reinforce the grid by laying down more electricity cables, upgrading transformers, substations, etc., but there is an alternative approach that makes use of the flexibility offered by grid users. This new approach is gaining importance.

The report declares that with the rise of DER, flexibility services provided by users connected to the distribution grid will grow. These products might be sold or purchased without consideration of the physical grid state. This solution could lead to inefficiencies to the system since grid state is not being considered. Furthermore, DER connections will bring to the distribution grids less predictable energy flows. If this issue is not properly addressed, distribution companies will have to reinforce and extend their grids.

According with this report, the development of DER is heavily impacting in low and medium voltage networks. DER requires high level of control over the service level parameters. Monitoring networks and use of available meter data is essential for the operation of DSOs. Nowadays, the lower voltage in the infrastructure, the lower monitoring is being done. This situation is limiting the quantity and quality of available system flexibility services.

EDSO promote that DSOs can be allowed to procure flexibility services in all timescales. With this possibility, the DSO has the chance to decide if new investment is required or it is better to postpone the investment using a market solution (DSR). DSOs should be able to decide which situations call for a market based solution and which situations call for grid development, while maintaining a high quality of service. European Network Codes, such as Demand Connection, Operational Security and Electricity Balancing should not hinder the use of system flexibility services at distribution level.

This report also addresses the problematic that can appear if the roles of the operators are not clarified. Using system flexibility services it will be required an extensive cooperation and clear boundaries between TSOs and DSOs rights and duties.

According with the report, direct orders from the TSO to distribution grid users should not be authorised. The DSO should always be the interface and agree with the TSO the system management practices in order not to create subsequent constraints in the DSO network. Coordination of the obligations should be introduced.

System flexibility services are complementary to traditional grid reinforcement. New regulatory frameworks should include mechanisms that allow DSOs to implement system flexibility services and to recover their cost, also taking into account the shift from CAPEX to OPEX. This last approach will bring more incentives to the DSOs for the use of users services instead of using a ‘fit and forget’ approach.

Well-structured systematic information exchange will be necessary among DSO and TSO to ensure that both system operators have all the relevant information in order to maintain network stability. In order to do so, system operators need to develop clear definitions of hierarchical procedures and grid management plans with regard to one another and also to the market. It may be necessary to define new SOs responsibilities and governance arrangements as TSO grid management decisions have an effect on the DSO grid and vice versa.

Depending on the level of DG penetration and RES integration of each Member State and according to the size of DSOs directly connected to transmission grid, the roles required by the DSO may differ and therefore interaction with the TSO may also differ.

Although significant work has been undertaken in the current Network Codes to outline the roles and responsibilities and interactions between the DSO and TSO, further regulatory guidelines may be required in light of the increments in intermittent DG. It is needed to adapt properly the existing legislation and adapt it to the new environment. The regulatory framework should enable the creation of new system services at distribution level. These services will bring the opportunity to be procured as ancillary services. The report considers the obligation of DSOs along the different operators to act as neutral market facilitators for other new emerging market based services.

SEDC report: A demand response action plan for Europe. Regulatory requirements and market models (SEDC - A demand reponse action plan for europe, 2013)
The SEDC is an industry group focused on promoting demand-centred programs within the areas of Demand Response, energy information usage, smart home from the heart of the Smart Grid.

SEDC has published a report that covers the demand response issue (SEDC - A demand reponse action plan for europe, 2013). This report points out in that it is essential to create market structures which reward and maximize flexibility and capacity.

Other important point in this report regarding ancillary services is that Demand Response resources can sell their capabilities as a service to modify consumption on call. This call can be done directly by the TSO and DSO through and aggregator or to other Balancing Responsible Parties.

ISGAN (ISGAN, 2014)
ISGAN creates a mechanism for multilateral government-to-government collaboration to advance the development and deployment of smarter electric grid technologies, practices, and systems. It aims to improve the understanding of smart grid technologies, practices, and systems and to promote adoption of related enabling government policies.

This association has published in September 2014 a report where it is considered coordination TSO-DSO issue. This document presents the necessity of a clear definition for the roles of TSO and DSO and sees the cooperation between both agents a key point to be studied. Changes in the model, coordination and roles appear due to the necessity to allocate all new distributed generation that is appearing at distribution level. The definition of the roles is necessary and independently if the regulation moves to a more open evolution or with stricter indications.

Regarding the coordination TSO-DSO, ISGAN looks for a model where DSO manages the distribution grid and TSO is in charge of the transmission network. The DSO-TSO coordination that ISGAN proposes is focused on the set values agreement of primary substation that connects both DSO and TSO grids. The document explains that depending who is the owner (DSO or TSO) of the transformer different procedures should be considered for operation.

The document analyses different countries actions depending on different issues: congestions, overloads, support grid voltage, balance of the grid, black start-resynchronisation and coordinated protection. Once analysed the different cases for the different countries, the association identifies that DSO needs to include two ways of communication: one with the flexible customers (that should be real time) and other with the TSO. DSO has to evolve more than the role of the TSO.

The report compares how are solved different network problems today and how can be done in the future. Congestions are solved during the planning considering n-1 criteria. In case of an emergency situation TSO usually disconnects feeders or do curtailment (sometimes it might be necessary to do it through a request to the DSO). The report considers that in future, grid monitoring and data exchange would use flexibility on the grid to reduce loads when needed. The report highlights that the requests for the distribution grid should be done through the DSO and it should be the distribution company who decides which users will provide the flexibility services.

Looking at the procedures to solve congestions, it is necessary to look also at the information exchanged among both SO. This association sees as a possible solution that the DSO provides to the TSO the cumulative services available at the distribution grid. Then, the TSO will use its information of the transmission grid and the one provided by the DSO in aggregated way.

Once seen the congestion, the report also deals voltage issues. Nowadays, voltage issues are supported by the TSO. Even the voltage issues located at DSO grid are TSO supported by means of the tap changer on the TSO-DSO transformer. Furthermore, DSO can use capacitor banks to support the transmission voltages. Looking at the future, DSO will use more actively capacitor banks and it will be possible to coordinate the use of reactive power from distributed generators to support the transmission system voltage.

Report suggests for this issue a model where both TSO and DSO agree set points at TSO-DSO connection.

Regarding the balancing issues, nowadays DSO is not involved in balancing. Distribution users may take part in the balancing processes, but DSO may not be necessarily involved.

The report also considers Islanding, re-synchronization, black-start. Nowadays islanding situations are avoided by using appropriate protection devices. In case of black-start procedures, there should be established a close cooperation among TSO and DSO. In future, distributed generation can be included in existing plans for grid restoration (for example distribution feeders with high amount of distributed generation could be reconnected earlier).

It is also analysed situations and procedures when a fault appears. The report sees that in future, it will be possible to act more effectively if protection measurements could be shared amongst both system operations.

This report also introduces some models to manage different constraints situations: when there is congestion in the primary substation. It should be considered the possibility of using the flexibility of the distribution users connected to the branch where it is located that connexion point. The requests sent to the flexibility markets should be launched by the DSO of the area.

In case of a line overloading it can be solved by either the TSO flexibility or DSO flexibility. The requests sent to the flexibility markets should be launched by the SO of the grid in which the overlanding appears.

Finally, in case of voltage issues, the report proposes a solution where the DSO must consider the set points agreed by both SOs at primary substation. In case of local voltage problem, DSO should use reactive and active power flexibility by distribution users as well as capacitor banks in order have normal conditions in the grid.

A clear idea is launch in this report, DSO will be always responsible for monitoring the distribution grid while TSO must monitor transmission grid. Furthermore, it should be implement communications solutions in order to facilitate the monitoring functions.

These technical requirements, which could be a challenge especially for smaller DSOs, should not be underestimated regarding the implementation or costs. It will bring huge advantages for the system in the long term run.

BDEW Functional Interaction between the Market and the Regulated Sphere (BDEW, 2014)

The German Association of Energy and Water is called BDEW. It published a report in May 2014 (BDEW, 2014) that explains the “traffic light concept”. This concept can be implemented due to the increment of smart grids in order to regulate the interaction between the liberalised market and the regulated part of the electricity system.

In order to guarantee a secured, good value and environmentally friendly energy supply in future, it should be aggregated distributed energy generation, control end consumption and harmonise both. This would require more interaction between market participants and regulated network operators.

It is defined the traffic light concept in order to regulate the continuous interaction among the different agents of the grid depending on the situation that the network has (normal, constraints, and emergency scenario). Depending on the colour of the traffic light, different interaction of market and network are allowed:

- In the green phase - aside from control power - demand and supply of flexibility takes place solely between non-regulated market participants. The system operator does not intervene in the market.
- In the amber traffic light phase, a potential danger to the grid exists, which the network operator can remedy through a targeted intervention in the market by demanding suitable flexibility for the benefit of the grid (DSO or TSO) and for the benefit of the system (TSO). There is an interaction between non-regulated and regulated market participants. In addition, the market can use remaining flexibility for the benefit of the system.

- In the red phase, an acute grid risk exists. The system operator can only remedy giving direct set points for the users of the grid. There is not possibility of free market interaction.

BDEW sets out different risks in the grid that require different actions and for this reason is important to have different flexibility products. This poses great challenges for energy services providers as well as for the flexibility market operators. Processes for the utilization of flexibility still have to be developed for the distribution network level.

A comprehensive use of the traffic light concept requires standardised contractual documents between energy service providers and network operators. Existing agreements have to be modified and amended accordingly to the new situations. Standardized contracts are the necessary basis for a targeted flexibility market.

2.1.4 Research Papers

A methodology for the redesign of frequency control in modern power systems in presence of renewable energy resources (Ahamdi, 2012)
The paper sees that for the DSO it is a key issue to have information and control over the set points of the primary substations (connection point among DSO and TSO information). The knowledge of the TSO network conditions close to the frontiers between transmission and the distribution networks, will allow to the DSOs to evaluate the necessity of reconfiguration actions in case of serious failures or contingencies occurring at TSO level.

Communication Interface Requirements during Critical Situations in a Smart Grid (Hauer, 2012)
In a paper published in 2012 (Hauer, 2012) it is studied the problematic of data exchange among both system operators. In the report it is set that smart grids and networks need a regular orientated information exchange. This is basic for a stable power grid operation. Specially, for critical system situations, coordination of distributed energy sources in daily system operation a regular data exchange between TSO and DSO is important for fast and effective reactions.

Information about current feed-in, load and forecasts in all distribution networks will allow DSOs to have a better adaptation of the real time grid requirements, so that the adjustments needed can be done to the greatest extent possible and oriented to system stability. A standardized information exchange between all system operators is necessary to ensure a long-term security of supply.

Authors of the report also propose a list of information to be transferred from DSO to TSO and/or vice versa:

- Generation schedules of conventional generating units.
- On-line monitoring of power feed in, including forecasts,
- Feed in power time series of the last year (or other periods)
- On-line monitoring of active and reactive power for generating units and connected distribution systems.
- Basic data and state monitoring of connected distribution systems and their assets.
- Configuration of frequency relays.

The paper makes distinguish two different types of data: on-line monitoring data should be transmitted instantaneously, while other data, like forecasts, should be transmitted one day ahead. Further data such as unit base characteristics and historical time series of measured values should be communicated in longer intervals can be exchanged once a year or every three months, depending on their use.

Evolution of DSO control centre tool in order to maximize the value of aggregated distributed generation in smart grid (Sebatian, 2008)
This paper tackles the new activities that could be done by DSOs. The paper shows that new DSO activities may be much more intimately integrated in market mechanisms than what they are today.

This paper predicts that the participation of DER on electricity markets needs to be considered for monitoring and control of the distribution grid. Transmission and distribution operators will have to perform new activities such as the real-time voltage control using aggregated DER services. However, the diversity and the complexity of new critical situations will require to be anticipated considering two different approaches at least:

- A day-ahead of time: The participation of DER into electricity markets needs to be considered when planning the next day operation (normal grid configuration, backup configuration, generation schedule). Operational planning tools need to be adapted or developed for that purpose.
- A few minutes ahead of time: Critical situations need to be detected before they occur. Operational control centres need to be warned, in an appropriate manner, in order to request appropriate aggregated DER reserves.

Results of the studies shows that the DSO's traditional tasks will have to be extended to include new functions managing the new constraints or controlling DER. DSO will be greatly aided with increased visibility of DER and analysis tools to forecast and assess the power system management risks.

This author recommends that the generation schedule changes and possibility to activate flexibility services downwards the connection point between transmission and distribution network should be managed by DSO and sent to the TSO for technical validation.

This report also considers that every country is different and there are many situations depending on the different moment. For this reason, it should be considered the idea where '*One-size-does-not-fit-all'*.

Melo et al (2012) "Network active management for load balancing based in a intelligent multi agent system " (Melo, 2012)

The main point of this paper is that both DSO and TSO must integrate their Supervisory Control and Data Acquisition (SCADA) systems with an interface that handles data and information exchange in real-time. The authors of this report highlight that, in the future distribution management system, information exchange is a crucial aspect in order to make possible the energy flow coordination among DSO and TSO.

The integration between DSO and TSO to increase DG penetration – The Portuguese example (Silva et al., 2012)

In Portugal, researchers have studied data exchange problem among TSO and DSO. Their main conclusions are that the interaction between TSO and DSO is essential to increment the penetration levels of DG. In order to achieve a full integration with system operation, a direct interaction between DSO and DG units would be required.

In this research paper, it is recommended to increase the control of power flows at the distribution level. DSO needs more information from their assets and users. This is now possible to increase with the improvements in ICT. According with the report, nowadays it is possible to connect several DSR agents and avoid the tripping of the whole DG production when an operational problem occurs. This types of solutions were not possible in the past.

The new role of DSOs: Ancillary services from RES towards a local dispatch (Delfanti, 2014)

In this paper, it is declared that both SOs should have the opportunity to make efficient use of the services that distributed energy resources may offer by means of a new electrical grid management model.

This paper points out that if the Italian model is considered, there are no systems installed for acquiring data from DG (especially looking at DG). Just in some cases TSOs receive information from RES in real-time. When looking at the future, a well-structured and organised information exchange between relevant agents is necessary: the DSOs will need information about DG forecast, schedules and active dispatch to improve their visibility and to achieve a close to real-time management of the distribution network including local network constraints.

Three different approaches coordination models are proposed in this report depending on who is managing the different services. The first model proposed is an extension of a traditional coordination model. RES units connected to HV, MV and LV networks will have to submit a forecast of their injection into the grid the day before the day of delivery. DSO solves local constrains using that forecast. Regarding the real data, it should be given to DSO through the TSO (central counterparty), so that the DSO can eventually react accordingly in emergency situations and curtail the most appropriate DG. Moreover, any action on distribution network users requested by the TSO should be agreed upon with the relevant DSO in order to collect new dispatching resources; if the DSO finds out that some network limit is being overcome, it will have to report to the TSO in order to modify the production plan.

Second model brings the possibility to the DSO of running a flexibility operational market. DSO could both procure services to satisfy its own needs and also offer resources in a cumulative way on behalf of the TSO. DSOs can buy flexibility offered from different DGs or aggregators. The TSO accepts bids/offers from conventional plants and also from DSOs in order to operate the power system. TSO also solves residual transmission congestions and creates secondary and tertiary reserves at minimum costs.

In the last model proposed, DSO is responsible for maintaining the Scheduled Program at HV/MV interface. Differently from previous model, DSO is not incentivised to offer services to the TSO; but it will only maintain the adequate program profile by solving the unbalances produced by the DG units connected downstream. In order to reduce the unbalances at each primary substation, the DSO will have to use all balancing resources on the distribution network, while TSO will manage the system with a central dispatch including all users connected to the HV grid. System services will be managed by the TSO while the local services will be managed by DSOs separately, having as a unique common point the primary substations.

IIT Working Paper. REDEFINING THE NEW ROLE AND PROCEDURES OF POWER NETWORK OPERATORS FOR AN EFFICIENT EXPLOITATION OF DEMAND SIDE RESPONSE (Rivier, 2012)

In a working paper developed at IIT it has been considered that the appearance of a large amount of relatively small generation plants connected to the distribution grid worries TSOs since they are out of the scope of their monitoring and control areas and is not “visible” for them (since DSO and TSO just consider its own grid and the influence network information). It is impossible for the TSO manage to all the distributed generation that can be connected in a future to the grid.

The document explains that any process in which a DSO activity affects free market users must be subject to regulatory supervision. This regulation should be done in order to achieve and guarantee total transparency and equanimity of results at all times.

The report points out that the incentives provided to the DSOs must be attractive enough to encourage them to take advantage of the added value that DER services can provide to their operation and planning procedures, but at the same time it should be sufficiently moderate to ensure that under no circumstances DSOs may be induced to place their financial stability or service quality at risk.

FLECH - A Danish market solution for DSO congestion management through DER flexibility services. (Chunyu ZHANG, 2014)

Flech is a Danish solution proposed in order to solve future necessities due to the appearance of DER services. The solution considers a new parallel agent called Flech operator that runs a flexibility market and also is the channel for the DSO to speak with aggregators and DER. This solution is explained with a diagram in Figure 1.

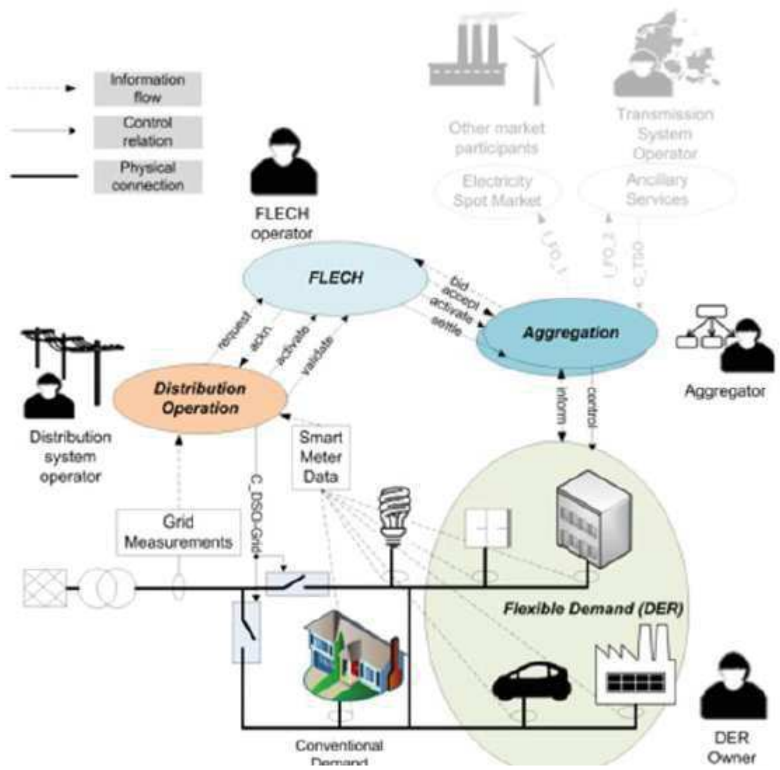


Figure 1: Flech solution diagram

The solution is more focused on giving a solution to the DSO. The Flech market is a parallel flexibility running market with the existing markets specializing in the distribution grid, in order to assist DSO to mitigate the congestions and revitalize the DER economy. Currently, the authors of this platform are in process of implementing specific services also for the TSO.

With this approach, the existing transmission grid market will balance energy and power through day-ahead and intraday markets while distribution congestions (overload and voltage issues) will be managed with through Flech market.

Once analysed the model, it is possible to see that one of the advantages is that there is no necessity to increase unbundling of the DSO. However, there are synergies among DSO and the flexibility market that are being lost if this model is used.

Wisconsin Institute (Wisconsing Energy Institute, 2014)
Wisconsin Energy Institute explains that since DER is participating in markets and contributes to grid ancillary services, the transmission/distribution boundary is being blurred. The report of this Institute studies the interface between DSO and TSO as a key aspect for the coordination among TSO and DSO.

The document details some advantages that the system operators can use from DER such as the possible reduction of the losses, increment of the reliability of the system, resiliency, minimize CO2 content...

In the report, it has been reviewed two different ways of controlling a system considering that there are big amounts of DER power installed. One is the ‘Expanded TSO Concept’ in which the TSO expands its roles to incorporate DER at distribution level. This model allows to the TSO to act directly over DER.

However, the report is more focused on the other model: ‘TSO/DSO Concept’ in which each SO acts over its grid with a unique common point the ‘P-Node’ (primary substation where both distribution and transmission grids merge). With this last model, the DSO is the balancing authority and marketplace for the grid users connected to its own network while TSO is the balance authority and marketplace at regional level for central generation and distribution regions. There are some benefits from this model that are highlight in the report:

- This approach is considered as scalable over wide range of grid sizes and configurations.

- Significant efficiency improvements such as higher renewable penetration or lower loses
- Significant long term improvements with a higher resilient grid due to the possibility of use user services along the whole grid.

Accordingly to the report, the implementation of this model needs more independent DSOs to incorporate the local balancing authority and marketplace as functions of distribution companies and ensure third party access and independence of their decisions.

California Independent System Operator and Caltech Resnick Institute (California Independent System Operator and Caltech Resnick Institute, 2014)

The report published by Caltech Resnik Institute and CAISO (California Independent System Operator) gives some recommendations regarding the DSO-TSO coordination and promotes a model where the DSO is able to manage the distribution grid meeting the Transmission-Distribution interface set-value.

Figure 2 represents the model in a conceptual diagram where it is possible to see that TSO balances the system and the DSO manages the users of the distribution grid in order to meet the set points of TD interface.

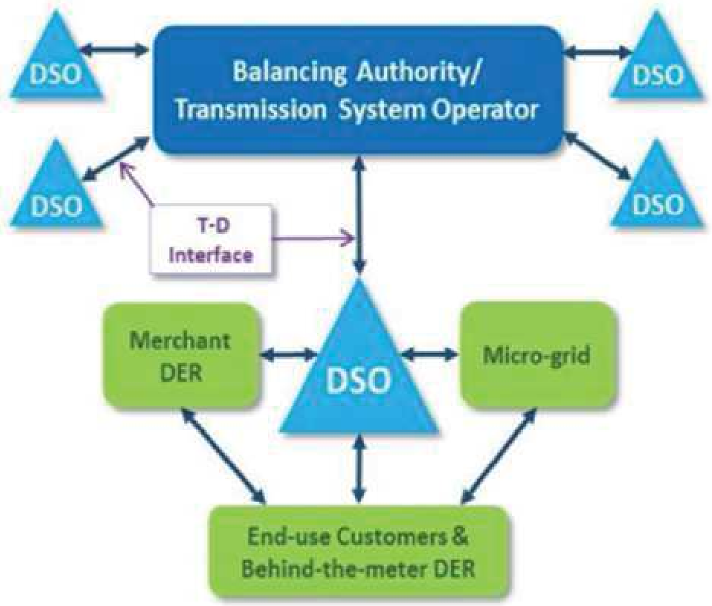


Figure 2: T-D interface model proposed by Caiso and Caltech Renisk Institute

Within the model proposed, the report sets the different distribution and transmission functions. DSO functions are the following:

- Safe and reliable distribution system operation which includes procurement and coordination of distributed reliability services.
- Delivery coordination of all active and reactive power flows across distribution grid.
- Market facilitation for active and reactive power transactions across distribution grid.
- Scheduling coordinator service for economic transactions with ISO and other parties.
- Transaction clearing at distribution level.

On the other hand, it appears the functions of the balance authority (TSO) has:

- Sale and reliable transmission system operation
- Markets for residual energy and reliability services
- Market coordination
- Transmission infrastructure planning coordinated with the distribution system planning.

2.1.5 R&D Projects

DRIP PROJECT (DRIP Project, 2014)

The Demand Response in Industrial Production project, also called DRIP is recent project (2014) that assesses the potential flexibility of the energy consumption processes of industrial customers. The project looks how is possible to use flexibility in order to contribute to grid efficiency and to increase the share of RES in the energy mix.

DRIP has developed and validated a procedure to determine, quantify and certify the demand flexibility in industrial facilities (DRIP Project, 2014). This project shows the handicaps that there are in order to broadly use DSR. The main drawbacks to be considered when using DSR services are: regulatory barriers, lack of DR-aggregator (or similar) and the lack of standards to facilitate the participation of the demand side among others.

IRISH CASE ESB (EDP Distribuicao & EDSO , 2015)

The Irish distribution company ESB is developing a pilot project where both the DSO and TSO have to act always through aggregators in case of requirements necessities from DER. Using this performance, all the agents should belong to one aggregator. The aggregator is who offer services to the DSO and TSO. It is a necessary counterparty to act over DER. Once any of the SO buys a service, it is the aggregator who decides which agents can be involved.

The advantage of this model is that both system operators have available all the services provided by the users of the grid. The drawback is that TSO and DSO can request for services that may produce new constraints on the other system operator grid.

PRICE Project (Universidad de Sevilla - Unión Fenosa Distribución, 2015)

Price project analyses the management of distribution network with distributed energy resources. The project considers the coordination needed among TSO and DSO at the frontier point.

Price sees as a barrier the lack of information that the DSOs have today. It is necessary that the DSO must have accessibility to the monitoring information of the distributed generation. Other barrier that has been identified is that nowadays DG has obligation to generate following a fixed set value of unitary power factor. With this regulation, those units cannot participate in voltage control services. If DER had not obligation to follow a fix set value, it would be possible for the DSO to improve the voltage services offered by them.

Other barrier identified is the lack of rights for the DSO to control distributes generation. In some countries like Spain, distribute generation follows the set values given by TSO while DSO is not allowed to control the elements of its gird.

It is considered that an improvement of communication among DSO and DER should be also considered. Furthermore, it should be eliminated the restrictions at the TSO/DSO frontier points, establishing a more flexible regulation.

REserviseS project (Fraunhofer IWES, ENEL Distribuzione, 3E, Union Fenosa Distribucion, EDP Distribuição, ACCIONA, 2014)
It has been studied German and Spanish countries. The document demonstrates that fixing reactive power flow requirements at TSO/DSO connection limit causes inefficiencies for the system. If DSOs were allowed to use ancillary services and managing its network in cooperation with the TSO, final outcome could be more efficient and less costly.

Other issue pointed out in this project is that integrating more distributed generation will also increase the costs (CAPEX and OPEX) incurred by distribution system operators due to the management of the system services. The case study shows that smart grid deployment can be cost-effective and cheaper than traditional grid reinforcements.

PRICE-GDI: A pilot experience for the integration of distributed generation in active distribution systems (Gonzalez et al, 2015)
This paper considers renewable energy resources for the management and operation of the network when DSO/TSO frontier point is located at low or medium voltage, and it is a result of part of the PRICE project mentioned before.

Regulation must guarantee the communications between the TSO and DSO in order to allow DSOs to monitor and control the DG connected to MV and LV networks.

Technical regulation must be adapted to facilitate the implementation of the ancillary services of voltage control with DG in distribution systems. The requirements for DG must be flexible enough to avoid unnecessary increments of grid reinforcements which will increment the system costs.

The economic regulation of the power distribution business should ensure a suitable distribution of the OPEX and CAPEX remuneration to incentivize a flexible operation of the distribution system.

Reactive power flow and voltage control requirements of the primary substation fixed by ENTSO-E Networks Codes should be more flexible in order to avoid extra costs for the power system.

Netherlands Case (EDP Distribuicao & EDSO , 2015)

TenneT is the national electricity transmission system operator of the Netherlands which is also responsible for system balancing. Below 110 kV the DSO is responsible for maintaining and management of the network. TenneT is responsible for maintaining system balancing, also on the local distribution level.

According to TenneT, interaction with small customer load, storage, and EV, is a matter of DSOs and distribution smart grids. Accordingly to TenneT, each system operator should interact with the resources connected to their networks.

For future developments, Tennet asks for stronger connections among TSO-DSO and the DSR agents. TSOs relays on the flexibility provided from large generation and big loads, while DSOs are more concerned with local resources.

GERMAN CASE (50Hertz, 2012)

50Hertz, the German TSO, proposes new responsibilities and requirements for DSOs and TSOs due to the Smart Grids appearance.

The document defines the responsibilities of both system operators in its country. TSO is the inter-area system operator that grants the security of supply while DSOs are the regional system operators that receives and offer local system services.

The report shows the inter-market player cooperation is a key issue for the future scenarios of the grid. In regulatory terms, the document sees lack of terms and rules for the collection, offers and use of smart grid data.

2.2 EURELECTRIC SURVIEW

Eurelectric has done a survey for DSOs and National Associations in Europe about the DSO-TSO coordination which is a very hot topic in European discussions. Raw data of the survey was obtained from Eurelectric for the use in this Master Thesis.

A total of 18 DSO companies and 3 National Associations filled out this survey representing Austria, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Portugal, Spain, Switzerland, and United Kingdom. Although Norway and Switzerland are not members of the UE28, they work intensively with the rest of European countries in terms of electrical issues due to the geographical position that they have and for this reason both countries were also considered for this survey.

This is a semi-informal survey. Conclusions from precise countries cannot be drawn due to possible interpretation errors of the questions depending on the particular situation. However, what it is possible to get from this survey is a general overview of electric power sector along Europe by means of aggregating the information.

This section will be divided in different parts: Firstly, it will be done a general overview of the countries that have answered this survey. Then, it will be reviewed the actual and future information that DER is sending to the system operators. Third part reviews who is able to act over DER and under which conditions it is possible to act. Following part reviews where it is considered the coordination among TSO and DSO in order to act over DER. Afterwards, there is a part in which is considered the data exchanged among both system operators.

Finally, as contribution of this Master Thesis, results are analysed and countries have been grouped according procedures that are used to act over DER

2.2.1 General Overview

All distribution companies that have answered are big distribution companies (more than 100.000 customers). The information used by the companies to fill out this survey comes from 2013 with exception of three cases: German and Ireland and Irish association that used data from 2012.

If it is compared the peaks of the demand and the generation power installed at the distribution level it is obtained a significant value. This value has an average of 79.7% along Europe. This clarifies that distributed generation be not negligible. Looking at the energy that is covered by the generation located at distribution level, 39.36% of the energy in the demand is already being covered by generation connected at the same network. If both ratios of energy are considered, it is possible to see that distributed energy resources that are considered nowadays are not negligible. Country by country results are published in Table 2. Data of Table 2 consider the average information of the companies that have filled out the survey, not the country as a whole.

	MW of peak is of the demand	MW peak generation	Ratio peak generation / peak demand	%Energy covered by own generation
Austria	7728	10056	1,301	41
Finland	2500	845	0,338	40
France	70000	1650	0,024	12
Germany	81800	160100	1,957	n.a.
Ireland	4768	3150	0,661	18
Italy	473	266	0,562	28
Netherlands	6500	1600	0,246	15
Portugal	8322	n.a	n.a.	60
Spain	44603	44300	0,993	42
UK	23957	26115	1,090	42
Norway	23969	29600	1,235	100
Switzerland	3046	1080	0,355	35
	277666	278762	0,797	39,36

Table 2: MW of peak generation and peak demand for the networks considered in each country

Since the situation in each country differs in terms of generation, it is important to analyse the penetration of the wind and the photovoltaic energy in the countries. Table 3 shows the average perception of the distribution companies and national associations regarding the penetration of PV panels and wind. It has been considered just wind and solar since both are two of the most present technologies in the distribution networks.

	Wind	PV
Austria	Low	Low
Finland	Low	Low
France	Low	Low
Germany	n.a.	n.a.
Ireland	High	Low
Italy	n.a.	n.a.
Netherlands	n.a.	n.a.
Portugal	High	Low
Spain	Intermediate	Low
UK	Intermediate	Low
Norway	Low	Low
Switzerland	Low	Low

Table 3: Penetration of wind and PV

Analysing Table 3 it is possible to see that the amounts of PV and wind is still low in most of the countries analysed. With this situation, it could be possible to have increments of power installed due to the free room that still there is. If we wait to implement new tools when DER penetration is higher, system may have to address further important problems.

Looking at the new problems that can arise, it has been considered the voltage, quality, and power (both active and reactive power) represented in Table 4 as possible problems to be considered in future. It was asked to the distribution companies their perception considering if those issues will be stable, will be more problematic (tighter) or will be easier to cope with it (looser).

	Active Power	Reactive Power	Voltage Value	Quality of signal
Austria	Stable	Tighter	Tighter	Stable
Finland	Stable	Tighter	Tighter	Tighter
France	Stable	Tighter	Tighter	Stable
Germany	Tighter	Tighter	Tighter	Stable
Ireland	Tighter	Tighter	Tighter	Stable
Italy	Stable	Stable	Stable	n.a.
Netherlands	Stable	Stable	Stable	n.a.
Portugal	Tighter	Stable	Stable	Stable
Spain	Stable	Tighter/Stable	Tighter/Stable	Tighter
UK	Stable	Stable	Stable	Stable
Norway	Tighter	Tighter	Tighter	Stable
Switzerland	Looser	Looser	Looser	Tighter

Table 4: How the obligations of the DSO are going to change in future

It is possible to see trends analysing the data of the Table 4:

- Active powers issues seem to be stable for most of the countries.
- Reactive power issues seem to be more difficult to control in a future.
- Voltage issues trends to become an important problem for most of the countries.
- Quality of signal seems to stay stable or become a tighter problem for DSOs.

With a general overview, reactive power, voltage and quality issues will be more difficult to manage in the future from the perspective of the DSO.

Although active power seems to be stable or tighter for most of the countries, some DSOs agree that it is particularly important to control the active power for effective voltage control in weak LV networks (with predominantly resistive cables). Comments about this issue request appropriate regulations that should enable the DSO to manage independently owned DG resources (either through a market mechanism for voluntary participation of DG owners or through regulatory obligations imposed as grid connection requirements for DG).

One important point that has appeared in the comments is that DER penetration increments leads to a "stronger" utilization of the available voltage band. Generally speaking, DSOs see that grid operation is ‘using’ more and more towards the allowed limits since DER are being connected to the grid.

Regarding the information of the generation schedules, just Austria receives this information in advance in order to check the information and verify if there is any congestion in real time from large generators (>50MW). Within this information there are two special cases in two countries:

- One case is in UK, where DSO is entitled to receive only if DSOs ask for it.
- The other case is in Germany where the DSO do a forecast for wind and PV at the control centre of the DSO to avoid congestions in real time. For conventional generation (only at 110 kV), the DSO can request the generation forecast from the TSO.

	Highest voltage level	
Austria	HV	110 kV
Finland	HV	110 kV
France	MV	20 kV
Germany	HV	150 kV
Ireland	HV	110 kV
Italy	HV	150 kV
Netherlands	HV	66 kV
Portugal	HV	60 kV
Spain	HV	132 kV
UK	HV	132 kV
Norway	HV	132 kV
Switzerland	HV	110 kV

Table 5: Highest voltage level owned by the distribution companies depending on the country (Eurelectric, 2013)

In order to see the whole picture of the differences among the European countries, it is necessary to see a comparison of the different voltage levels that each distribution company operates along Europe.

2.2.2 DG information

This module is going to consider the information that is sent by DER (DG, DSR, EV...) to the system operators.

Quality and quantity of DG information

Two different terms are going to be assessed from the information that goes from the DG to the system operators: quality and quantity. First one assesses the amount of information that DG sends. The other checks how good this information is.

Figure 3 represents the quantity of information from DG. For each country there are three different bars, one for each voltage level (HV, MV, and LV). Data showed in following charts consider 'value 1' as 'very low' and 5 as 'very high'. For some cases, there are no bars because there is not information from this survey.

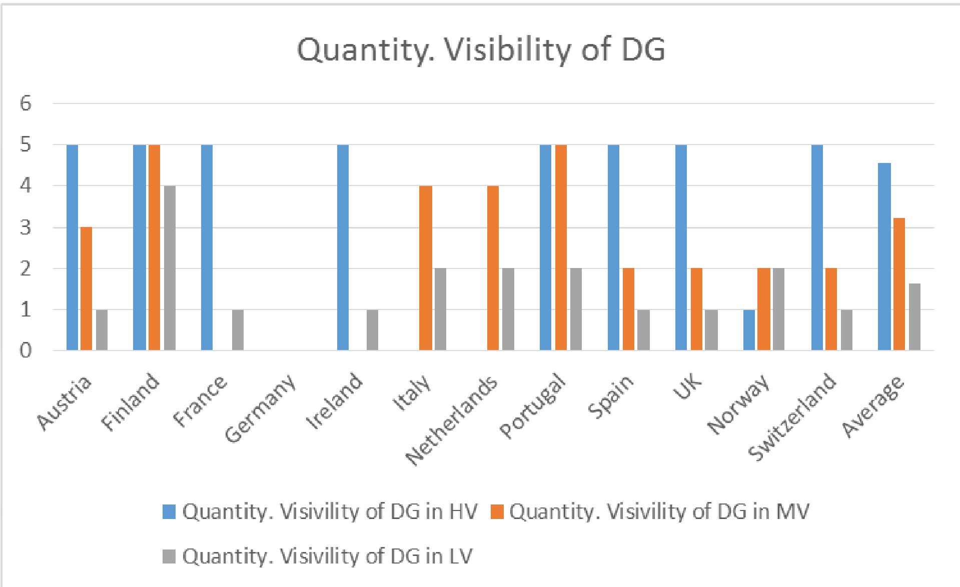


Figure 3: Quantity of visibility of DG depending on the country and the voltage level.

Figure 4 represents the quality that has the previous amount of information considered in Figure 3. Data showed in following charts consider ‘value 1’ as ‘very low quality’ and 5 as ‘very high quality’. It has been considered three voltage levels for each country.

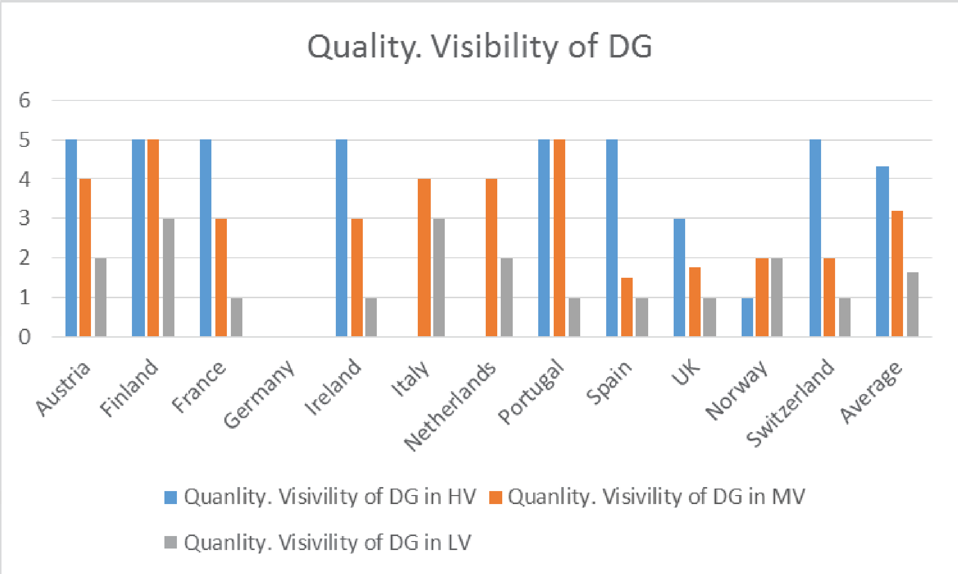


Figure 4: Quality of visibility of DG depending on the country and the voltage level.

Both figures show that there is a better quality and quantity of information as soon as voltage increases. There is an exception in Norway where the quality and quantity of visibility at high voltage level is the lowest of the grid for this country.

The best country with better visibility in any of the voltage grids is Finland followed by Austria and Portugal. The country with the worst DG visibility is Spain either in terms of quantity and quality. The Spanish case has a very good HV; however, there is a very low rate of visibility of this DG in the MV and LV.

How DG information is now sent to the system operators

Companies and National associations were asked if their DSOs were receiving information directly from the users or through TSOs. Just in Spain and in UK TSOs receive the information directly from DSO users, which may be justified by correspondent TSOs with the fact they are (almost) electrical islands. In the rest of countries, the DSO receives directly the information from users located at distribution voltage level.

2.2.3 Operation over DER

In this module it is going to be assessed the operations that DSOs are able to consider over DER. Three scenarios are considered for this module: actions considered under normal conditions, actions under network constraints scenario and actions under emergency scenario.

This module will be divided in three parts. First one considers the actions that can be requested under a normal scenario without any constraint. In the second part, actions that DSO can do when there are issues to solve in the grid either for constraints or an emergency are considered. Finally, it is assessed who should act over DER in a future scenario.

<u>Actual DSO actions that can be considered under normal scenario</u>

In this part are shown the actions that distribution companies can consider when there are no constraints in the network. Usually, these actions are useful in order to improve the losses of the system.

	Set cos(fi) in units for voltage control	Set Q inj/ consum in DG for voltage control	Set Fixed Voltage in DG for voltage control	To ask the generator for ramp up/down in terms of active power	Switch off generator	None
Austria	L	L				I
Finland	I	I	I	I	I	
France	L	L				I
Germany	L	L	L	L		
Ireland	L	L	L		L	I
Italy	L	L				I
Netherlands	L					I
Portugal						L
Spain						L
UK	L	L	L	L	L	I
Norway	I	I	I	I	I	
Switzerland	L	L	L			

Table 6: Operations that DSO are legally allowed 'L' or economic inventive 'I' under normal operation.

Table 6 represents the actions that DSOs are allowed or economic incentivized to do under normal operation conditions. Note that *L* stands for 'Legally allowed' and *I* stands for 'Incentivised' to save investment cost through the use of DER. Looking at the Table 6, four countries stand out from the rest:

- Norway and Finland. Both are incentivised to use DER for the five different cases.
- On the other hand, Spain and Portugal are not legally allowed for any operation.

<u>Actual DSO actions that can be considered under emergency and constraints</u>

In this part it has been considered scenarios where is needed to act over an infeasibility. Two tables are going to be presented: Table 7 considers the actions that can be applied over distributed generation while Figure 6 considers actions when it is used demand side response. Furthermore, in both tables, there is a last row that shows how many countries out of 12 are able to act in each case. In both tables is possible to see the actions that DSO can do over DG either directly or via TSO depending on the scenario considered (constraints or emergency scenario)

	Give DG directly some new set points (v & Q)				Ask DG directly to reduce/increase their active power				To switch DG off.				None of others	
	Directly		Via TSO		Directly		Via TSO		Directly		Via TSO			
	Con	Em	Con	Em	Con	Em	Con	Em	Con	Em	Con	Em	Con	Em
Austria	L	L				L				L			I	I
Finland	I	I	I	I	I	I	I	I	I	I	I	L		
France		L				L				L			L	I
Germany	L	L			L	L			L	L			I	
Ireland												L	L	I
Italy	L	L											I	I
Netherlands						L				L			L	I
Portugal										L			L	
Spain			L	L			L	L			L	L	I	I
UK	L			L	L			L	L	L			I	I
Norway	I	I		L	I	I	L	L	L	L				
Switzerland	L	L	L		L	L		L		L				
Total	7	7	3	4	5	7	3	5	4	8	2	3		

Table 7: Actions that DSO can take over DG, directly, via TSO, in case of constraints (Con) or in case of emergency (Em). '*L*' means legally allowed. '*I*' stands for economically incentivised.

Looking at the last row of Table 6, which represents the total values, it is possible to highlight that:

- Considering actions that DSO can take over DG: there are more countries where DSO can act directly rather than through the TSO.
- In case of emergency: actions that the DSO can take over DG increase, which makes sense due to the fact that security is a direct responsibility of the DSOs.

Looking at the last two columns, it is clear that there is a lack of economic incentives to use these resources. Although the DSO is entitled to use these services, they are not incentivised to save costs of new reinforcements taking advantage of DER.

Similar questions were asked for the Demand Side Response. Results are published in Table 8. In this question related to DSR, for any reason, Switzerland has no answers.

Analysing Table 8 it is possible to see that there is also a clear lack of economic incentives in most of the countries considered. One case that needs to be highlighted is the case of Spain, which is the only country who have to act always throw TSO and do not have any economic incentives for operating over RES (either DG or DSR). The cases of Ireland and Spain are very similar; both countries have the DSOs with fewer rights to operate the network in terms of DSR.

	Reduce/Increase consumption of DSR				Switch DSR off				None of others	
	Directly		Via TSO		Directly		Via TSO			
	Con	Em	Con	Em	Con	Em	Con	Em	Con	Em
Austria		L				L			L	I
Finland	I	I	I	I	I	L	I	L		
France						L			L	I
Germany	I	L	I			L				
Ireland	L	L	L	L					I	I
Italy									L	L
Netherlands		L				L			L	
Portugal					L	L				I
Spain								L	L	I
UK	L				L	L			I	I
Norway	I	I			I	I				
Switzerland	-	-	-	-	-	-	-	-	-	-
TOTAL	5	6	3	2	4	8	1	2		

Table 8: Actions that DSO can take over DSR, directly, via TSO, in case of constraints (Con) or in case of emergency (Em). '*L*' means legally allowed. '*I*' stands for economically incentivised.

On the other hand, Finland Germany and Norway are countries where DSOs have the right to act directly over DER (either in cases of constraints or emergency). There are other cases (such as Netherlands, Austria, UK…) where the DSO can act or not depending on the issue that is going to change and the scenario.

Looking at each country, Finland continues at the top of management rights for DSR. In this country, DSO is allowed and also incentivised for consumption changes or switch off DSR. On the other hand, it appears Italy which is not allowed to interact with DSR followed by Spanish DSOs that only are able to operate DSR via the TSO in case of emergency in order to switch off.

Comparing Table 7 and Table 8, DSOs are allowed to do changes in DG in the 40.2% of the cases considered in this survey. DSR can be managed by the DSO in a 30% of cases that has been considered here. These values give the idea that DSR is behind DG in terms of controllability by DSO (either directly or via TSO).

Distribution and national associations had the possibility to make any comment regarding these issues previously considered. A repetitive comment is that DSOs are asking for improvements in regulation and looking for special bilateral contracts directly with the costumers. These contracts will allow them to operate the system with more tools than now.

Future stage: Who should act over DER?

Companies and National associations were asked about the new actions that should be considered by TSO and DSO in the future. A general comment in the survey is that TSO has interest to act over DG or DSR since these actions can also impact on transmission network and energy markets.

However, companies pointed out that the main role over this issue should be developed by DSO, which is affected by all this new connections (EV, DG, storage, demand response, etc.). A common proposal is to consider that if TSO is interested, it will be indirectly involved in smart grids using the DSO interface.

DSOs have also complained about the lack of flexibility that they have now. According with some companies, regulation should allow DSOs to implement more flexibility in their networks and support the development of a new Regulation where services of DER are used to achieve the objectives of their roles.

Smart grids development can hinder DER penetration if DSOs does not have the information needed with them or if DSO are not fully allowed to use all services provided by DER connected at the distribution networks. Comments show that there is fear in case TSO use Smart Grids for their purposes, not being exploited the full value that also has for DSOs.

2.2.4 Operation coordination TSO-DSO

This module considers the issues that appear in the survey that are related with the coordination among both system operators when they are acting over DER. It will be discussed who have to act when a system operator request any change from DER. Within this aspect it should be consider hierarchy issues: if it is necessary to inform to the other SO and if it is necessary to wait for the approval.

Future stage: How coordination among TSO-DSO should be

Regarding the hierarchy of the network and if TSO should act directly into the distribution network or not, a general comment of the distribution companies is that TSO should act always via the DSO to check if this change leads to new problems in DSO's network. The orders should be given from TSO to DSO. Finally, it is DSO who should decide which units involve. However, DSO and TSO can create agreements so that TSO can act over distribution network with a previous agreement. This model, in which TSO never acts alone on DSO area of responsibility, is supported by most of the companies.

Other idea proposed by a distribution company is that if the DSO increases control over its grid due to smart grids, it will be possible for the DSO to provide system balance by adjusting its behaviour according to the conditions of the system. In this sense, DSO may act as a virtual power plant. When a distribution company is considered as a virtual power plant, it behaves as a ‘black box’. Using this approach and considering a TSO perspective, TSO sees the distribution companies as generation plants that are able to provide services to the TSO. Using this model, it will be integrated DER services for the requirements of the distribution companies as well as for whole system necessities.

Figure 5 and Figure 6 represent what the distribution companies and national associations prefer in terms of hierarchy over DG. Figure 5 shows the procedure preferences when DSO acts. Figure 6 shows the procedure preferences when TSO acts.

From Figure 5 it is clearly seen that there is a preference for the idea where DSO can act directly (it sums 71% either informing the TSO of the changes once the change is done or not).

In case the TSO needs to act, there is a clear preference for the situation in which TSO informs and waits for the DSO approval. Some distributors and national associations consider as second preference the situation where the TSO informs but does not wait for the DSO approval a possible solution. It should be taken into account that when it is said that informing and/or waiting for approval would be done through automatic means with very low response times (seconds).

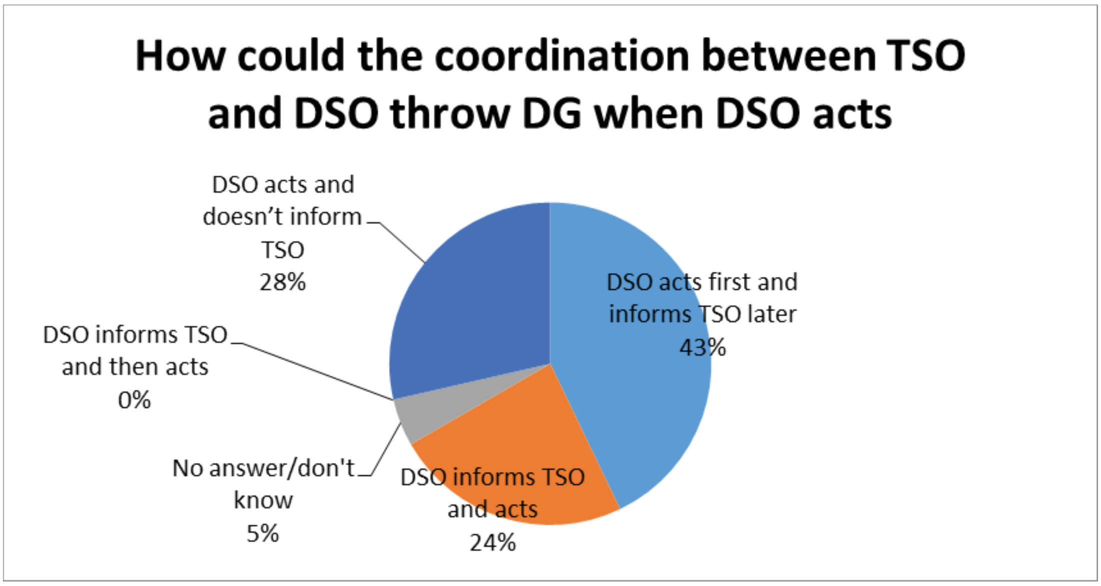


Figure 5: How could the coordination between TSO and DSO throw DG when DSO acts.

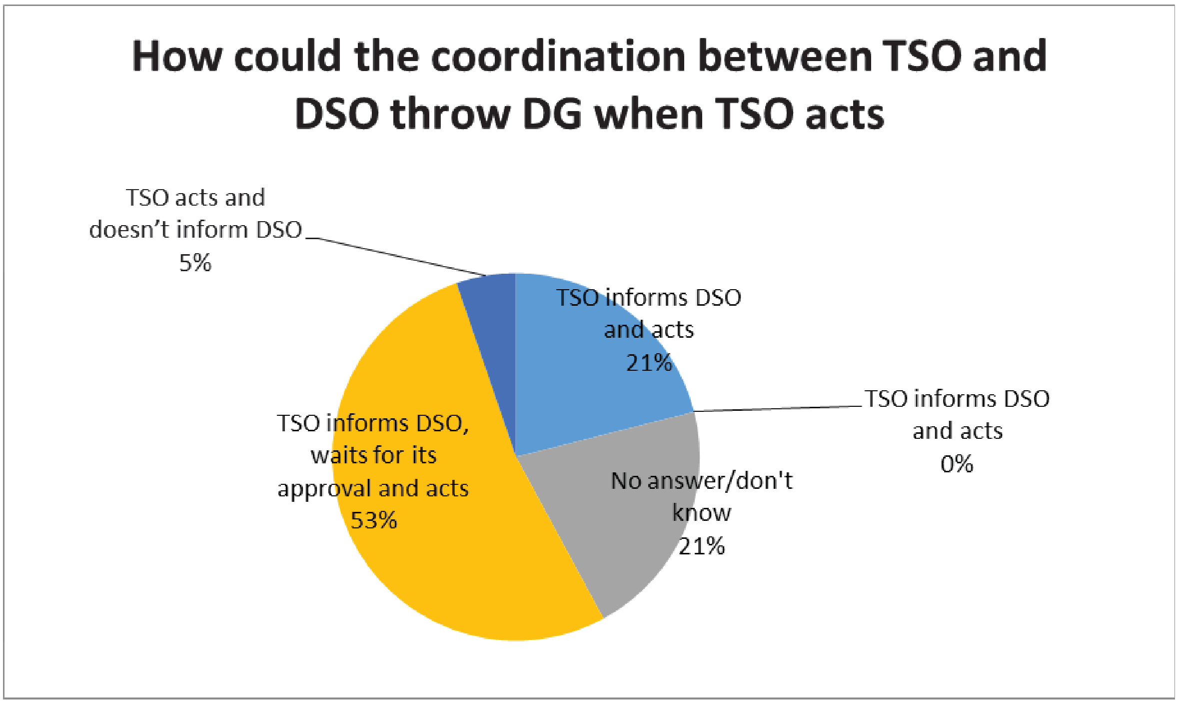


Figure 6: How could the coordination between TSO and DSO throw DG when TSO acts.

Future stage: What else is needed for a better integration of DG?

Answers comment that TSO needs more information about the operation of the DSO's network since it is the agent in charge for the stability of the electric system. In particular, it should be improved information about reactive power and active power coming from DG. These needs may facilitate the development of smart grids (more measures and always on communication).

2.2.5 Primary substation connection

Looking at the actual regulation in terms of the primary substations (connection point where both distribution and transmission grid are connected), countries were asked if the set points of their primary substations were set by law or agreed by both system operators. In Table 9 are shown the results where it is possible to see that each country acts with different procedures.

Within the comments of the question, in Austria there are no commitments about withdraw active power at the connections points. The tariff for active power withdraws is stipulated in a regulation while the remaining aspects (reactive power withdrawal, voltage value, quality of signal) are fixed by means of bilateral contracts and standards.

	Active power withdrawal (from TSO to DSO) or injection (from DSO to TSO) at the connection point.	Reactive power withdrawal (from TSO to DSO) or injection (from DSO to TSO) at the connection point.	Voltage value guaranteed at connection point during normal operation and emergency situation.	Quality of signal (flicker, harmonics, short circuit values...)
Austria	Regulatory	Contractual/ Regulatory	Contractual/ Regulatory	Contractual/ Regulatory
Finland	Contractual	Contractual	Contractual	Contractual
France	Contractual/ Regulatory	Contractual/ Regulatory	Contractual/ Regulatory	Contractual/ Regulatory
Germany	Regulatory	Contractual	Contractual	
Ireland	Regulatory			
Italy			Regulatory	Regulatory
Netherlands	Contractual	Contractual	Contractual	
Portugal	Contractual	Contractual/ Regulatory	Contractual	Contractual
Spain		Regulatory	Regulatory	
UK	Contractual	Contractual	Regulatory	Regulatory
Norway	Contractual/ Regulatory	Contractual/ Regulatory	Contractual/ Regulatory	Contractual/ Regulatory
Switzerland	Contractual	Contractual		

Table 9: Obligations/commitments has the TSO – DSOs at primary substations.

Something similar appears in Finland where everything works through contracts among system operators. However, some of those interconnection points between TSO/DSO should be are approved by the regulator anyway (for example, in case of reactive issues).

A European distribution company explains that each primary substation is considered as a connection point with a connection capacity for active power that is set in the connection agreement. For Voltage and Reactive Power the commitments are reciprocal: TSO must deliver Voltage in a given value band and DSOs must keep within a given band using capacitors banks. These bands have different values during winter time (November-

March) and the rest of the year (April-October). In this country, principles are regulatory while the values set are agreed through a contract.

2.2.6 Data exchanged TSO-DSO

This module is going to deal with the information exchanged among the system operators: quality, quantity and type of information. It will be consider the current situation but also the necessities from the distribution companies' side for future.

The module has been divided in two parts. First one considers the information exchanged as a whole, just making differentiations of voltage level. The second part considers the different types of information that can be exchanged among both system operators.

Information exchanged in terms of quantity and quality as a whole

In order to know what is the information exchanged among DSO and TSO Figure 7 and Figure 8 represents the quantity and the quality of the exchanged information among both system operators. Values obtained are the average of each country taking value 1 if there is *very low* quality/amount and 5 if the value corresponds to a *very good* quality/amount of information.

These two new figures are different to the Figure 3 and Figure 4. Previous tables were considering the quality and amount of information that DG was providing in general terms (independently if these information was being received by the TSO or DSO). In Figure 7 and Figure 8 it is considered just the information (quality and amount) that DSO is receiving from DG.

Looking at the tables it is possible to see that quality and amount varies a lot depending on the country. A clear trend is that the amount of information and the quality decrease with the voltage.

It is not clearly defined the country with better information exchange is because it is needed to be considered three different levels at the same time. What is possible to say is that the Spanish case is the worst of the cases considered either in terms of amount and quality.

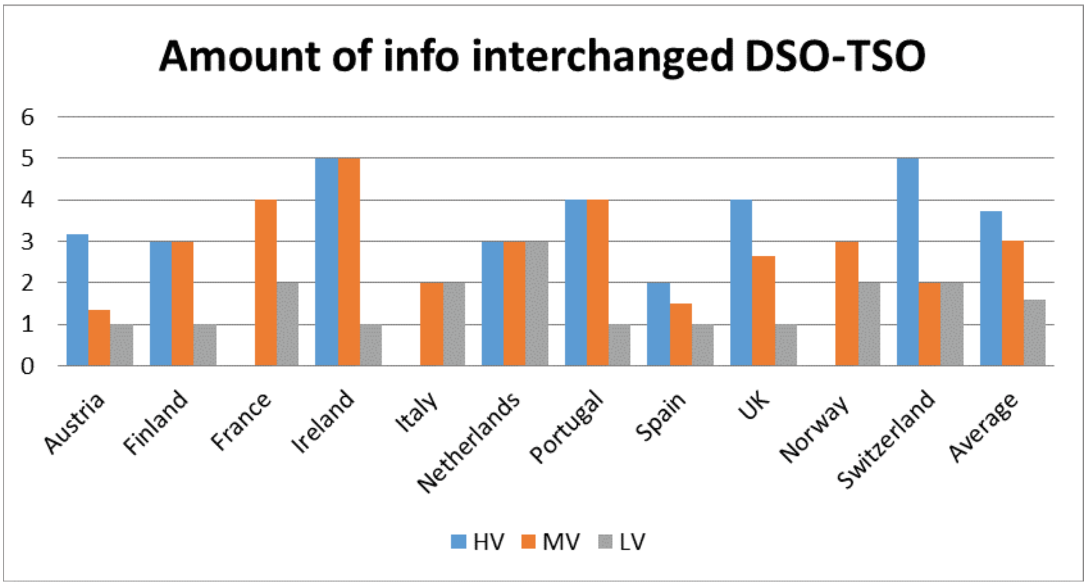


Figure 7: Amount of information exchanged DSO-TSO for DG connected to DSO grid

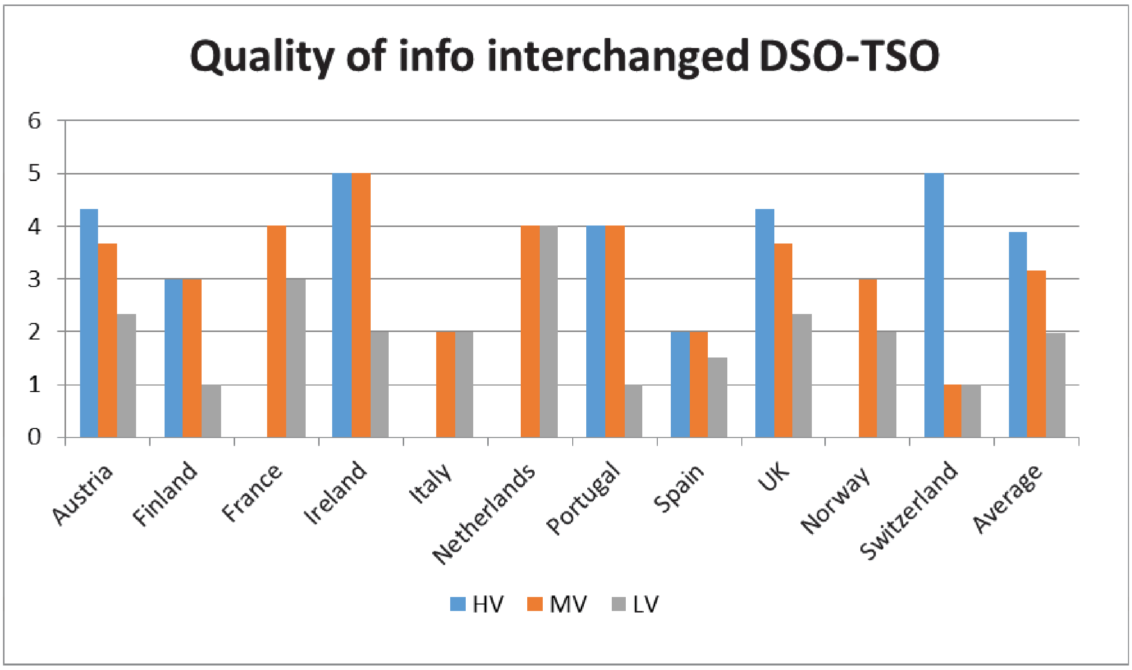


Figure 8: Quality of information exchanged DSO-TSO for DG connected to DSO grid

<u>Information exchanged depending on the information type.</u>

Four different information types are going to be considered in this part:

- Real Time data: Used for a coordinated operation and control of the networks, close to real time.
- Structural data: Used for medium term or long term purposes: management of connection requests, planning etc.

- Market Data: energy market, ancillary services markets, load shedding market, capacity market etc. Technical data of those markets.
- Operational data: planned outages and demand/generation forecasts.

In Table 10 is possible to see the data that is being exchanged from TSO to DSO. Roughly speaking, what it is usually sent from TSO to DSO is real time, structural and scheduled data related to operation. It seems that Scheduled Data related to market it is not usually considered, at least for the majority of the countries.

	Real Time Data	Structural	Market data	Operational data
Austria	x	x	x	x
Finland		x	x	x
France	x	x	x	
Germany		x		
Ireland		x		
Italy		x		
Netherlands		x		x
Portugal	x			
Spain	x	x		x
UK	x	x		x
Norway		x		x
Switzerland	x	x		x

Table 10: Data transferred from DSO to TSO

	Real Time Data	Structural	Market data	Operational data
Austria	x	x		x
Finland		x		
France	o	o		o
Germany	o	o		x
Ireland	o	x	o	x+
Italy	x			x
Netherlands		x		
Portugal	x+	x		x
Spain	x+	x+	o	x+
UK	x	x		x
Norway	o	x	o	x
Switzerland	x	x		x

Table 11: Data transferred from TSO to DSO(x), would like to receive the DSO (o) and which data is being received but is not enough (x+)

In the Table 11 is possible to see the data that DSOs receive from TSO (marked with x), which one do not receive but they want to (marked with 'o'), and which data DSO receive but is not enough for them (marked with 'x+'), depending on the country. Most of the distribution operators are asking or already have the same type of data: Real time, structural and scheduled time related to operation.

Table 12 shows the data that is being transferred from distributed generators to the DSOs depending on the country. In this direction (from generator to DSO) it appears the same trend than in previous tables. There is a clear trend to exchange real time, structural and operational data.

	Real Time Data	Structural	Market data	Operational data
Austria	x+	x+		x
Finland	x			
France	x+	x+	x+	o
Germany	o			x+
Ireland	x	x	o	
Italy	o	x		o
Netherlands		x		x
Portugal	x+			o
Spain	o	x+	o	o
UK	x	x	x+	x+
Norway	o	o	o	o
Switzerland	x	x		x

Table 12: Data transferred from generators to DSO(x). DSO would like to receive the DSO (o) and which data is being received but is not enough (x+).

If it is both Table 11 and Table 12 are overlapped, it is possible to see that all distributors needs, independently of the country, same data information: real data, scheduled data related to energy market and scheduled data related to the operation. There are just two exceptions which are:

- One exception is the case of Netherlands. In this country it does not appear as necessary real time data. This may happened because it is the second country where distributors owns less voltage levels.
- The case of Finland that does not see scheduled data related to operation. One of the reasons may be that since Finland does not have a big penetration of wind or solar energy (see Table 3), for this reason this country may not see as necessary data the schedule operation.

How to improve the data exchanged

Some comments of the survey provide ideas of how the information exchanged among both system operators can be improved. Comments are summarised below.

A Spanish company sees that there is a large potential for information improvements and coordination between TSO and DSOs. In this line, a distributor company sees a possible solution the integration of SCADA systems of both system operators. The same distributor company sees that it will be necessary to have an interconnected forecasting module with a real time power flows. According to them, this idea will provide the capability to have a more dynamic electrical network configuration and therefore more stable and adapted to the new integration of DER.

2.2.7 Countries Types

Once seen this survey, it is possible to see the differences among the countries nowadays: regarding the visibility/quality of information, differences in the way they operate the system, differences in rights and duties of the DSOs... Countries considered within this survey have been grouped considering that differences. There groups has been created in order to check different regulatory scenarios for the rest of this master thesis.

First group considers countries where it is allowed to manage most of the parameters of DER under normal, constraints or in an emergency operation. These are countries where it is possible to act over DG (giving directly new set points of voltage and reactive power, asking them to change the active power or switching them off). Most of them are also allowed to change the consumption of DSR or even switch them off. Usually, these types of countries have a good visibility of DG either in terms of quality or quantity. The country that has been considered as a representative of this group is Finland.

In the second group are considered countries where it is allowed to manage some of the parameters of DER under normal operation. These are countries where it is possible to act over DG (giving directly new set pints of voltage and reactive power, asking them to change the active power or switching them off). These countries are usually allowed to change the consumption of DSR or even switch off them. These types of countries usually have a good visibility of DG either in terms of quality or quantity. Actions that DSOs can consider over DER depend on the system status (normal, constraints or emergency scenario). The representative country of this group is Austria.

Third group are the countries where it is allowed to manage almost none of the parameters of DG or RES under normal operation. These are countries where is possible to act over DER just in a few situations. If DSOs can act, they have to operate throw the TSO. Usually these requests from DSO are because of an emergency operation scenario. Actions that DSO can request under constraints or emergency scenario are also very limited. The country that represents this group is Spain.

Table 13 shows the countries grouped depending on the criteria explained above. The first country in each column is the country representative of the group. Due to the fact that there are not real limits between the different groups, some countries can be located in different groups depending on the issue that is being considered. This is the case of the countries with asterisk.

GROUP 1	GROUP 2	GROUP 3
Finland	Austria	Spain
Germany	France	Portugal
UK	Italy*	Italy*
Ireland*	Netherlands	Ireland*
Norway		
Switzerland		

Table 13: Country groups depending on the Network Codes regarding the distribution grid

The voltage level that the distribution companies own in each country will be considered in the subsequent analysis of this master thesis. However this data have not been considered when the countries were group in three blocks.

2.2.8 Eurelectric Survey Conclusions

Following key aspects represent the highlights that are important to consider for future coordination DSO-TSO:

- There is still possibility for higher increments of wind and PV panels in the European grid. With this new scenario voltage band will be used broadly.
- Reactive power, voltage quality and voltage issues will become an issue more difficult to manage in future.
- DSOs request to be able to manage their DG resources
- Just one country, Austria, receives the forecast in advance in order to check possible congestions. This situation should be improved.
- Information received from DG, either in terms of quality or quantity, differs depending on the country. The way it is received this information also depends on the country: usually it is received by the DSO directly. However, in Spain and UK it is done through the TSO,
- There are also differences among the different countries in the way it is operated DG and DER. The actions that can be taken depending on the scenario (normal, constraints or emergency scenario).Depending on the scenario considered and the action that wants to be taken the request can be done directly by DSO or through TSO. There are also differences in terms of payments: some countries are incentivised while others not.
- DSO request for the possibility to have bilateral contracts with the consumers in order to operate the system with more tools.
- Future actions to be taken over DER:
    - In case the DSO needs to act: Most of the answers look for the actions where DSO acts first (either informing or not to the TSO) over DER and there is not necessity to wait for the approval of the TSO.
    - In case the TSO needs to act: Most of the answers look for the actions where TSO informs to the DSO, waits for DSO approval and acts.
- In terms of data (DSO to TSO, TSO to DSO and DG to DSO), it is possible to see that adding up the actual situation of the countries and their necessities for the future, there is a clear preference to exchange real time, structural and operational data. Market data it is not seen as a relevant as the other information.

3 CURRENT AND FUTURE ROLES IDENTIFICATION

Once considered the above information of section 2.1 LITERATURE REVISION, it is possible to see that it is a key aspect to define the roles of each DSO and TSO. Documents as (Florence School of Regulation, 2013) (Acer - A Bridge to 2025, 2014) (EDSO, Flexibility: The role of DSOs in tomorrow's electricity market, 2014) have present their expectations for a role clarification among both system operators.

For this reason, this section is going to defined the roles that both DSO and TSO had in the past and which will be the situation in the future for these roles. First of all it is important to define roles. Looking at RAE (Spanish official dictionary), role is defined as the function or position that someone have...

When the roles are being assessed, it is important to differentiate the actions that are done by an agent, the objective that should be achieved and the role itself that is meet if the related objectives are meet using the different tools. On one side, there are objectives in order to evaluate if the role is being accomplished or not. On the other side, there are tools that the agent uses in order to achieve the objectives of the role.

3.1 Current roles

DSO CURRENT ROLES

The current tasks that DSO is developing up to now such as grid planning, maintenance, consumption verification, not discriminatory access have been divided in different groups in order to clarify the roles that DSOs have had up to now.

When grouping those tasks it is possible to differentiate 3 different groups of functions: ensure quality of service levels for the consumers, ensure security of supply for the system and to be a market facilitator:

- Quality of service
    - How is controlled: Checking the continuity of supply (either zonal quality or individual quality looking at the number and the duration of interruptions) and verifying the wave quality.

    - Tools: Grid planning and maintenance of the distribution grid
- Security of supply
    - How is controlled: Checking overloading and voltages.
    - Tools: Grid planning and maintenance of the distribution grid.
- Market facilitator
    - How is controlled: It is assessed by regulator
    - Tools: Verification the consumption and generation of the clients and allowing transparent and not discriminatory access.

It is possible to see that in order to ensure quality of service and the security of supply DSO only can use grid planning and maintenance tools.

TSO current roles

It was done the same procedure with the TSO: there were grouped all the actions that TSO have been developing. The same roles that have been considered for the DSO are also roles of the TSO, which is an innovative approach explained later regarding the role of quality of service for TSO. However, the TSO have different objectives within the same roles and different tools in order to achieve those objectives.

- Quality of service
    - How is controlled: Controlling the voltage
    - Tools: Grid planning, maintenance of the transmission grid and use of the flexibility operational market services.
- Security of supply
    - How is controlled: Checking frequency, voltages and overloading of the transmission grid
    - Tools: Grid planning and maintenance of the distribution grid, use of exchange borders, use of the flexibility operational market services and technical supervision of the electrical market
- Market facilitator
    - How is controlled: It is assessed by regulator.
    - Tools: Ensure a use of the grid, exchange borders and flexibility operational market in transparent and not discriminatory access.
    - The user connections have to be done in a transparent and not discriminatory way.

Differences among both TSO and DSO roles

It is possible to see that looking at the tools that are considered in order to accomplish with the different objectives of each role, TSOs have grid planning and maintenance tools (as the DSO also has) but also other tools such as exchange borders, flexibility operational markets…This difference appears because up to now there was almost not generation at the distribution grid and the consumption was not possible to control since ICT was not developed for low voltage levels as it is now.

Distribution and transmission grid have different realities. Transmission grid is planned with a mesh approach and in transmission it is always meet the N-1 criteria. On the other hand Distribution grid is usually planned at low voltages with a radial layout approach where the number of elements of the grid increases as well as the voltage level decreases. These differences among both networks lead to different weights for the security of supply and the quality of service roles depending on the voltage that it is being considered.

Figure 9 represents in a simplified way the important differences of security of supply and quality of service roles depending on the voltage level. It is possible to see that both roles appear along the different voltage levels.

Due to the radial layout of the grid and the high amount of elements at low voltage levels quality of service acquire more importance for the DSO than for the TSO. On the other hand security of supply has more importance for the TSO because some issues as frequency control should be considered for the whole system at the same time. In this thesis we have considered this innovative approach where roles differ on voltage levels but not on the SO. A DSO who owns lower voltage levels will have smaller security of supply role while TSO who have higher voltage levels will have smaller quality of supply role.

From next figure it is important to extract that those operators managing HV (150-45 kV) have both a role in the Quality of Service and in the Security of Supply. Taking into account that depending on the countries, voltage levels are owned by a different operator (either DSO or TSO). It may be concluded that role of the DSO on the security of supply is higher when HV networks are owned by him.

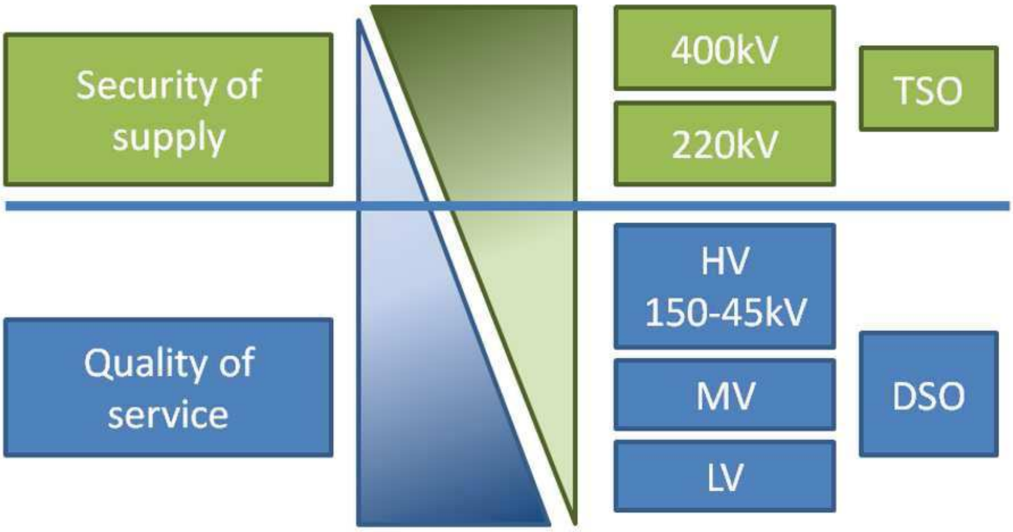


Figure 9: Security of supply and quality of service importance depending on voltage level (Eurelectric, 2012)

3.2 Transition from current to future roles

In order to see which will be the future roles, it is necessary to identify which are the transitional elements that are appearing and changing the current roles. This section is going to deal with these changes that already have appeared in the current scenario.

ICT improvements and the appearance of DER are two issues that are appearing nowadays and may cause a difference of functions among the tasks that system operators are considering nowadays and which functions will have in a future. These changes bring new situations for both system operators. As previously mentioned, the electrical flows were very predictable in the past because generation was usually located at transmission level and the consumption was normally located at low voltages.

Due to the appearance of distributed generation, electric vehicles, electric storage… flows are not any more as predictable as before. For this reason, distributed system operators will have to address new flows, manage bidirectional flows or allow new connections considering third party access.

However, not all the issues that DER brings are drawbacks, there are also advantages. DER will offer services for both DSO and TSO that may be useful for the system management in order to accomplish with the objectives of the roles. These new services may bring new alternatives to the tools that are available nowadays.

Furthermore, this change of functions goes through the Information and communication technologies improvements. Since technologies allow controlling lower voltages at a reasonable cost, there is a new possibility for the system operators in order to manage better the electric system.

3.3 Future roles

Considering the roles of both system operators that have had up today and adding them the changes that characterise the transition from the past roles to the future (increments and improvements of DER and ICT), it may be possible to know which might be the future roles of TSO and DSO.

When the actual roles of both system operators are put in with the transition elements that DER and ICT brings, it is possible to see that the three roles of each system operator does not change. Quality, security and market facilitator are kept as the three roles that both DSO and TSO have. The objectives that are assessed in order to know if the system operator is accomplishing the different roles are also maintained.

However, what it changes are the tools that may be available for each system operator depending on the role. Although there will be more difficulties to meet the objectives of the three roles independently of the system operator (as previously seen due to the new connections, bidirectional and complex flows), DER will bring new tools to the existing ones, which will help to achieve the objectives of the roles.

Future roles of the DSO

Considering the present roles and the new DER incorporation, some changes may appear for the DSO roles. Please, note that all the changes are new tools that may appear in order to add new possibilities available to achieve objectives of the roles added while keeping the actual ones. The future objectives, assessment issues and tools to achieve them are here presented for the DSO:

- Quality of service role
    - How is controlled: Checking the continuity of supply (either zonal quality or individual quality looking at the number and the duration of interruptions). Verifying the wave quality.
    - Tools: Grid planning and maintenance of the distribution grid. DER and ICT may bring the possibility of using operational tools to achieve quality of service targets by the distribution companies.
- Security of supply role
    - How is controlled: Checking overloading and voltages.
    - Tools: Grid planning and maintenance of the distribution grid. Furthermore, DER and ICT may bring the possibility of using operational tools to achieve quality of service targets.
- Market facilitator role
    - How is controlled: It is assessed by regulator.
    - Tools: Verification of the energy consumed and generated by the clients done in a transparent and not discriminatory way.

      The user connections have to be done in a transparent and not discriminatory way. The accommodation of new agents such as DER should be also considered for the regulatory assessment.

      If DSO runs a flexibility operational market, that market should be run in a transparent and not discriminatory way.

It is possible to see that, as previously said, the roles and objectives have not changed and the number of available tools may increase. The final consideration of the new tools depends on the final model implemented.

TSO future roles

It was done the same procedure with the TSO: there were grouped all the actions that TSO is now developing adding up the possibilities that the new agents can bring to the

TSO. Those future roles with the actions and tools that might be available are explained bellow:

- Quality of service
  - How is controlled: Controlling the voltage.
  - Tools: Grid planning, maintenance of the transmission grid and use of the flexibility operational market services. With the consideration of DER, the flexibility operational market services that are already being run by TSO might consider services provided by DER.
- Security of supply
  - How is controlled: Checking frequency, voltages and overloading of the transmission grid
  - Tools: Use of grid planning and maintenance of the distribution grid, use of exchange borders, use of the flexibility operational market services and technical supervision of the electrical market.

    In order to achieve a good quality with the new problematic that DER can bring, it should be considered a new control logic when running the flexibility operational markets.
- Market facilitator
  - How is controlled: It is assessed by regulator
  - Tools: Exchange borders use, transparent and not discriminatory access to the transmission grid, run the flexibility operational market in a transparent and not discriminatory way.

    The flexibility operational market that nowadays TSOs are running should use possible DER services in a transparent and not discriminatory way.

As previously said, it is possible to see that new services are added to the existing ones. It will be possible to use this new services depending on the model implemented.

During the rest of this report it will be possible to see that new tools of DSO and TSO may be available for them depending on which type of coordination among SOs is proposed.

4 ASPECTS WHERE COORDINATION IS NEEDED

Coordination nowadays depends a lot on the different countries along Europe. It is usually set by the regulatory authority of the country or agreed by the both system operators. The set values of those primary substations depend on the season, hours, state of the grid.

Once analysed the actual and the future roles of the system operators, this section is going to analyse if there is needed any further coordination. Coordination will be needed for the areas overlapped by the actions of both system operators.

A new coordination is needed when the new tools that might appear due to the increment of DER and the improvement of ICT are analyzed. In order to see better what are the overlapped areas Table 14 represents the actual and future roles of both system operators. Tools written in black letter are the actual tools that are available while letters in red are new possible tools that might appear depending on the coordination model implemented.

Doing a comparison of the areas that the roles of both system operators cover, it is possible to see that the new coordination will concerns the new services and operations offered by DER. This DER will offer operational tools in form of flexibility services to both system operators that might be used in order to achieve the targets of quality of supply. Furthermore, these new services might be used to ensure quality of supply for the grid. In terms of market facilitation, both system operators have to ensure that when running flexibility operational markets all the services –including DER services- will be used in a transparent and not discriminatory way. Furthermore, new connections of new users must be done also in a transparent and not discriminatory way.

-

	DSO		TSO	
	Control variables	Tools/Operations	Tools/Operations	Control Variables
QUALITY OF SERVICE	Continuity of supply: • Zonal QoS • Individual QoS(duration & frequency) Wave quality	•Grid planning •Maintenance of the distribution grid **•Use of operational market services (considering DER)**	•Grid planning •Maintenance of the transmission grid •Use of operational market services **(considering DER)**	Control: •Voltage
SECURITY OF SUPPLY	Control: •Voltage •overloading	•Grid planning: •Maintenance of the distribution grid **•Use of operational market services**	•Grid planning •Maintenance of the transmission grid •Use of operational market services •Use of exchange borders •Technical supervision of the electrical market **•New control logic with DER**	Control: •Frequency •Voltage •Overloading
MARKET FACILITATION	Regulation assesment	•Transparent and not discriminatory access •Clients consumption/ generation verification **•It may run operational market in a transparent and not discriminatory way.** **•Accommodate DER**	•Transparent and not discriminatory access •Exchange borders •Running operational market in a transparent and not discriminatory way**(considering possible DER services).**	Regulation assessment

Table 14: Current (black) and future (black and red) role of TSO and DSO

Then, it is possible to see that the new coordination needed concerns the operation and information that has to deal with DER. For this reason, it is necessary to define how system operators receive the information of DER (directly or through any other agent) and how requests to DER are sent (directly or through any other agent).

To sum up, the new coordination needs to establish which is the agent or agent that is going to have direct connection with DER (either receiving the information or sending requests) and how is going to be the new relationship among both system operators (exchanging DER information and requesting services to DER).

In Figure 10 are represented the issues that should be defined in order to stablish a new TSO-DSO coordination. First it should be stablished which of both SOs will be receiving the information of DER and acting over DER directly. Once that step is done, it should be defined how the other SO (who cannot act directly over DER) will be receiving information of DER and acting over DER (throw any agent) so that both can take advantage of DER services.

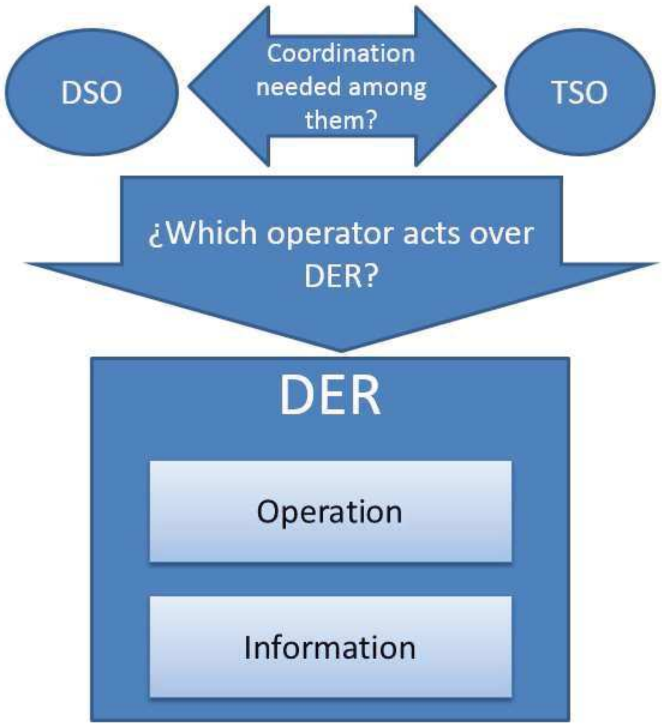


Figure 10: Coordination issues that should be defined

5 MODELS PROPOSAL

Three different models are going to be proposed within this section. In order to define these three models, it has been considered which are the necessities of the grid, what the DSOs are asking for in the Eurelectric survey (Eurelectric, 2014) and which are the proposals of different agents such as European Commission, TSOs, DSOs, Academia, associations or aggregators reviewed in 2.1 LITERATURE REVISION and 2.2 EURELECTRIC SURVIEW .

The definitions of the three different models are based on the ones proposed by Italian paper that has been covered in the State of arts chapter (Delfanti, 2014). This paper introduces a general idea of the three different models.

In the first model it is the TSO who runs a unique flexibility operational market for the whole system. All the actions have to pass through the TSO, even the requests of DSOs over RES located in their own grid; it is an extension of the current model. DSO is not running an operational flexibility market (OFM)

The second model proposed has two flexibility operational markets (one run by TSO and the other is run by each DSO). In this model DSO is able to provide services to the TSO in an aggregated way. DSOs can trade services for the TSO, this brings the possibility of using the cheapest service by TSO and DSO.

Third model proposed has also two flexibility operational markets (one run by TSO and the other is run by each DSO). DSO can act directly over DER. The difference with the previous proposed model is that here the DSO is no incentivized to trade services for the TSO. The coordination here appears at the connection point between distribution and transmission grid, what is called primary substation. System operators have to agree among them which must be the set points for each primary substation with the users that they have in the grids.

A common issue for all the models is the way that all DER users are controlled with respect to which product they are offering and at what time. This data must be sent to different SO depending on who runs a flexibility operational market in each model that is being implemented.

In this chapter the models have been defined with more detail considering the ideas and proposals of the different agents. Models have been analysed technically regulatory and economically.

5.1 Explanation of the models Proposed

5.1.1 Model 1: Centralized and extended dispatching.

In this model all DER located either on distribution or transmission network producers connected to HV, MV and LV networks will have to submit a forecast of their injection into the grid to the TSO the day before the day of delivery.

All production units are able to provide ancillary services which will be provisioned and coordinated by TSO. TSO is the agent in charge of managing the flexibility operational market for the whole system. DER agents are responsible of maintaining their planned production avoiding unbalances. TSO is in charge of modifying production plans of power plants in order to ensure the system security.

The complexity of new bidirectional flows can lead to some constraints in the distribution grid. When DSO is solving constraints it might create new problems at the transmission grid. In order to avoid this situation, the actions requested by the DSO will be done through the TSO which will try to avoiding any further problem in the transmission grid. This problematic situation is illustrated above with an example and explanations of how relationships among both SO are.

Furthermore, previously to the real time operation, DSO should check the operational schedule and send constraints that will appear in its own grid previously to the real time so they can be considered by the TSO. Although it is the TSO who runs the flexibility operational markets, DER monitoring information should be given also to DSO as soon as possible so that the DSO can react in emergency situations and act over the most appropriate user of the grid.

In case DSO has to act over DER, it can appear two different situations:

- DSO has a request to DER but there are more agents offering services than needed. For this reason, DSO will send the request to the flexibility operational market (which is being run by TSO) and TSO will select the units that will be involved depending on the market result.
- DSO needs to send a request to a precise number of clients due to a local constraint. In this case DSO has to send the request to the TSO of which units must be involved in the solution of the constraint. TSO will implement the necessity of the DSO through the users specified in the request. Fixed payments for the users that provide those services are established by the regulator.

Idem situations will appear when regarding the payments services are requested by the TSO. However, since TSO concerns are more related with system services than with local issues, usually it will be needed to act through a market in order to know which units should be involved.

Figure 11 represents schematically over which users of the grid can DSO and TSO take decisions. In this model, TSO can act over two groups of users: the ones located at distribution level and transmission level.

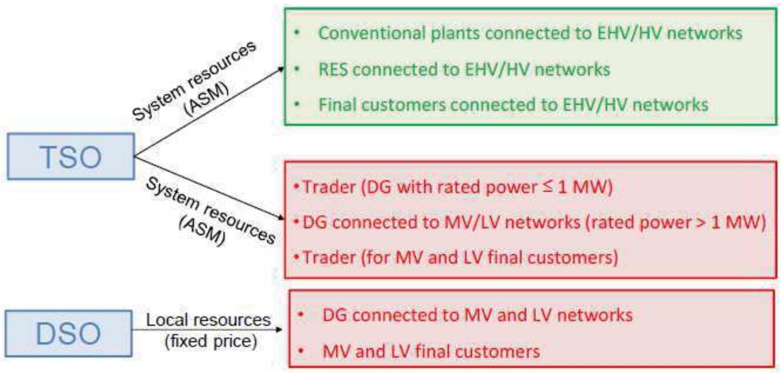


Figure 11: Model 1 – Centralized and extended dispatching: DSO and TSO agents in which they can act. (Delfanti, 2014)

The services are considered through system resources: In the other side, DSO can act just over distribution grid users paying them at fix price

5.1.2 Model 2: DSO cumulative services

In this model, DSO could both procure services to satisfy its own needs (to operate the distribution networks within technical parameter) and also provide services to the TSO in a cumulative way as a virtual power plant.

DSOs are able to consider flexibility offered from DER or aggregators located at its own distribution area for its necessities. TSOs can consider flexibility offered from its users and the aggregated services provided by DSOs for its own necessities. Since TSOs can use services from different DSOs, TSO can find the cheapest sources within the whole geographical area which is responsible.

TSO cannot act on any individual user of the distribution grid directly; orders over distribution grid must be implemented juts by the DSO. Regarding gird balancing and constraints services, the TSO accepts bids/offers from conventional plants located at transmission level and from the DSOs in an aggregated way. DSO acts for the TSO as a virtual power plant

TSO can solve residual congestions and create secondary and tertiary reserve at minimum costs with the same distributed energy resources. DSOs purchase distributed energy resources for itself and also sell them to the TSO. When DSO procures system services, it interacts with the market in a more direct way than with the actual models.

Furthermore, in this model DSO is also able to make direct calls to specific agents in order to solve local problems, settling an administrative fixed fee for the used services as it was being done in the previous model. The use of direct calls should be done in cases where is not possible to choose which units should be involved through a market. This usually happens when it is a very local problem where just a few agents are offering services to the SO.

All DER have to be monitored with respect to what product they are offering and when. Forecast data regarding dispatch should be given to DSOs as soon as possible so that

DSOs can react accordingly depending on the situations and act over the most appropriate DER.

To sum up, Figure 12 represents schematically how DSO and TSO can act over the users of the grid. It is possible to see that TSO can use services of the whole grid but considering the DSO as counterparty for the users located at distribution grid. The two arrows that goes from DSO to the users located at distribution level represent the two ways to act over DER: solve local constraints with specific units at a fix price or use system resources in a flexibility operational market.

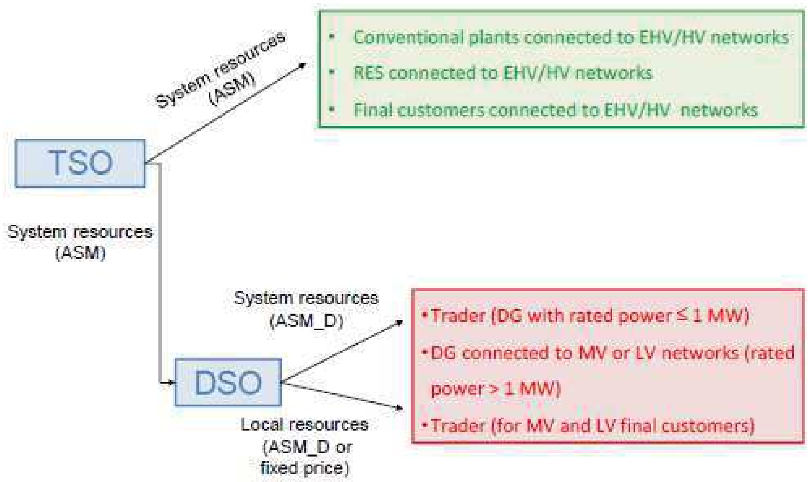


Figure 12: Model 2 – DSO cumulative services: DSO and TSO agents in which they can act. (Delfanti, 2014)

5.1.3 Model 3: Coordination at primary substation

This model is very similar to the previous one: each system operator can act directly just over its own grid. However, in this model DSO is not incentivized to offer services to the TSO. For this third model, DSO and TSO have to agree the set points of their primary substations (substations that are among distribution and transmission grid) considering the resources that they have in their grids.

In order to reduce the unbalances at each primary substation, the DSO will be able to use all balancing resources on the distribution network, while TSO will manage the users connected to the transmission grid. One of the advantages of this model is the decrement of information that has to go through TSO systems. This will bring a correspondent economical saves it produce in the operation. The drawback of the coordination model is the decrement of services traded; the fewer services traded, the more competition is lost. However, there are new necessities such as the continuous agreements for primary substations. There should be the possibility to agree in an emergency way a new set point due to an emergency scenario.

The services that are used by both DSO and TSO are services that do not create any constraint from a planning perspective. There should be designed a procedure to define operational set points of the interface TSO/DSO. Different solutions must be considered and studied depending on different substations and scenarios (normal, constraints or emergency scenario) in order to choose the best alternative.

Furthermore, it should be decided if these set points must be defined by the regulator or by both distribution and transmission system operator using common agreements. If the set points are decided by both operators through an agreement, it appears another issue that must be solved: the frequency they meet to decide these points: How often they should meet to decide new set points.

Within this model it should be considered the issue introduced by (ISGAN, 2014): the management and the ownership of the transformer that is located in the connection point of both grids. Depending on the country, different owners of the primary substation may appear. These differences will lead to different operational procedures that should be considered when operating the grid. There may appear two situations:

- The transformer is owned and operated by the distribution company. This is a great advantage for the DSOs since they can operate the grid and the transformer as a whole. If there are voltage problem downwards of a transformer, it is possible for the DSO to change the set points of the primary substation in order to fit the values of the grid within the operational limits.
- When transformer is owned by the TSO, it is necessary stronger coordination among TSO-DSO in order to have set values at the primary substation that help with the operation of the rest of the grid. For example, if there are voltages problems downwards of a primary substation due to high injections of distributed

renewable resources, Distribution Company should request to change the set values of the primary substation to the owner of the substation (TSO in this case) who finally will change those values.

Figure 13 represents schematically how DSO and TSO can act over the users of the grid. It is possible to see that TSO can act over the users located at transmission grid through flexibility operational markets. The DSO is able do requests over the distribution grid through a market in order to achieve the set values agreed with the TSO for the primary substations. Furthermore, DSO can act over local resources in order to solve constraints through a market or at a fixed price depending on the units that can provide the services.

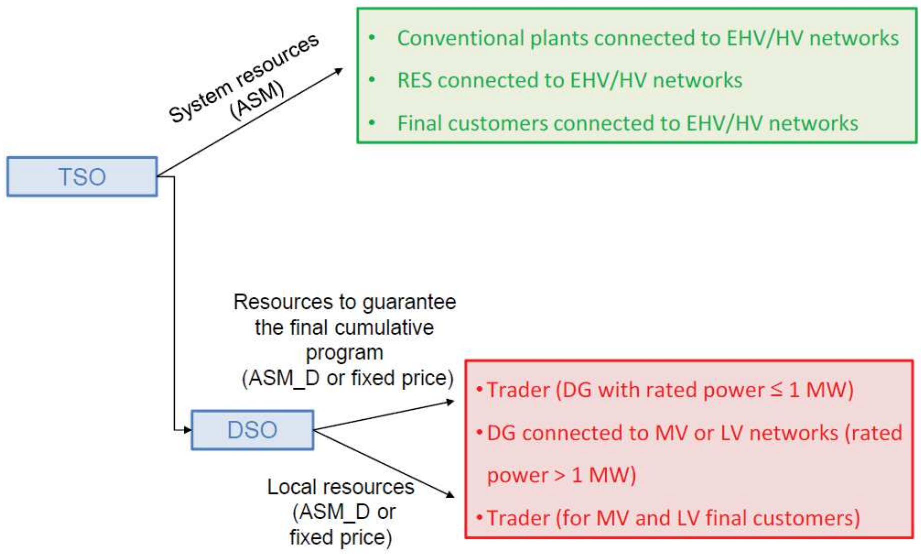


Figure 13: Model 3 – Coordination at primary substation: DSO and TSO agents in which they can act. (Delfanti, 2014)

5.1.3.1 Examples of the operational procedures using the different models

The following case study is going to be applied to each scenario considering each of the models introduced in the previous section in order to see how the DSO and TSO behaves when necessities appear.

Figure 14 represents a simplified grid based on the one proposed by Rivier and Batlle (Rivier, 2012). The figure represents a node on the transmission grid that consists on a transmission substation TS1 to which a 132-kV radial distribution grid is connected. This distribution grid is split into two distribution substations:

- D1: Substation that contains two bars among other elements:
  - DBHV1: Bar of high voltage
  - DBMV1: Bar of medium voltage
- D2: Substation that contains two bars among other elements:
  - DBHV2: Bar of high voltage
  - DBMV2: Bar of medium voltage

The distribution substations have connections of domestic distribution, two generators (one connected to HV and the other connected to MV) as well as distributed generators connected to LV. DG and RES users are represented by their aggregator/retailer (C#). There is also a big load that is able to offer grid services that is connected to DBMV2. This factory may provide services changing its own consumption.

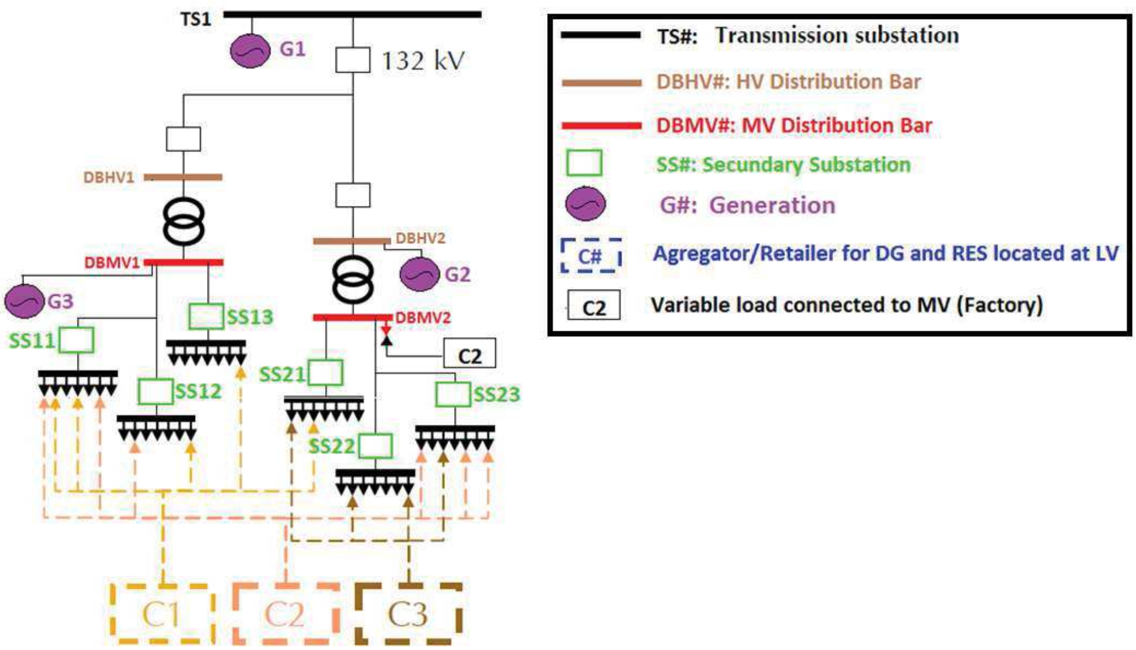


Figure 14: Simplified grid considered in the case study

The base case considers that there are connected 30.000 customers who have a load of 150MVA (assumed demand factor is 0,33), are connected to the bar DBMV1 with a capacity of 50MVA. Consumers have a choice of three different retailers. Retailers offer the possibility of installing DSR devices needed to control consumption in their homes. The same happened with the factory located at MV.

Furthermore, there are three generators that are connected to different nodes (see diagram of Figure 14). These generators are not the only ones that provide energy to the system. TS1 bar is also connected to other bars with generators.

5.1.3.1.1 DSO need DER services

Considering the same issues as in (Rivier, 2012), Distributor can take advantage of the flexibility in three different situations:

- In order to avoid or postpone reinforcements of the grid. In these cases the distributor will be keen on limiting demand when, for example, the substation is in danger of saturation.
- Avoiding losses. Since the lower losses the higher earnings, the distribution considers the possibility of remunerating consumers (throw the retails) in distribution area to flatten their aggregated demand curves.
- Furthermore, DSOs can use DER services to ensure quality of service required.

These three points are going to be considered studding within the three different models that has been defined before.

Centralised and extended dispatching

Applying this model, DSOs send constraints of its own network to the flexibility market Operator in order to be considered when real time services are requested by TSO. Distribution Company needs the unit commitment forecast and the production/consumption of each generator/load in order to foresee the constraints that can appear.

In the example that is considered, it is going to be considered the first necessity of the DSO: avoid constraints and reinforcements. Once the DSO knows the unit commitment of its part of the grid, DSO sees that there will be restrictions in the DBMV1 due to the high DG generation connected to SS11 SS12 and SS13.

Once the TSO receives the constraints, services that do not cause any problem in the distribution network are the ones available to be used. The TSO has to decide which offers (services offers that TSO receives from different agents located in both distribution and transmission grid) should be invalidated in order to cope with the restrictions of the DSO.

In real time, in case DSO might have necessity to change the consumption/generation of local services. In those cases, DSO is allowed to act over DER of its network for local services purchasing services at a fixed price. Applying this to the case study, it will be considered that there are overvoltage problems at DBHV2. This problem can be solved in three different ways depending on the real scenario:

- There is a unique possibility to decrease power of G2 and increase DER connected at SS21, SS22 and SS23. In this case, this request will be sent from the DSO to TSO, this last agent will implement the request if it is approved.
- There are different possible solutions among agents: G2, factory located at DBMV2 and DER connected at SS21, SS22 and SS23. In this case, it will request to decrease the power that is going through the substation that is located among DBHV2 and DBMV2 bars. Finally, it is the TSO who decides running a market which units should be involved accordingly to the services that have been offered.
- Third option is for the long term. This solution consider the reinforcement of the substation

In case of problems of quality of supply, it will be considered that voltages along the grid are within the limits. However, due to an increment of loads at SS21, SS22 and SS23 voltages levels of the clients are under the limits. This problem can be solved in three different ways depending on the real scenario:

- There is not possibility to run a market due to the few services that are offered. In this case, services on direct call are requested to users (either generators or consumers located at those substations). This request is done directly through the TSO.
- There is possibility to run a market with the services that have been offered to the flexibility market operator. DSO will send the necessity to the TSO. TSO will decide which units should be involved and will implement the request.

- Third option is for the long term. This solution considers new reinforcements such as capacitors banks.

With this example it is possible to see that the network can be operated properly: congestions and voltage issues can be solved. Furthermore, with this procedure, the DSO can avoid/postpone reinforcements of the grid. However, this model it is not taking advantage of the possibility to have a lower level of losses.

DSO cumulative services:

In this model, it is the DSO who acts as a flexibility market operator purchasing services from the distribution grid and using them for grid operation purposes. These services can be also offered aggregately to the TSO as a virtual generation plant.

As in previous model, if the distribution company needs a local service where it is not possible to run a flexibility operational market due to the few services that are available, it can be done requests on direct call. However, in this model, these services on direct call can be implemented directly by the DSO while in the previous model all services were implemented by TSO.

First it is going to be analysed if congestions may be avoided or solved. In case DSO wants to avoid congestion in the HV/MV transformer located between DBGV2 and DBMV2 the DSO can take three different actions depending on the real situation:

- There is a unique possibility to decrease power of G2 and increase DER connected at SS21, SS22 and SS23. In this case, this request will implement directly by the DSO considering the constraints of the TSO that were sent previously to real time.
- There are different possible solutions among agents: G2, variable load (C2) located at DBMV2 and DER connected at SS21, SS22 and SS23. In this case, it will be requested to decrease the power that is going through the substation that is located among DBHV2 and DBMV2 bars. Finally, it is the DSO who runs a market to decide which units should be involved accordingly to the services that they offer.
- Third option is for the long term. This solution considers the reinforcement of the substation

In case of problems of quality of supply, it will be considered that voltages along the grid are within the limits. However, due to an increment of loads at SS21, SS22 and SS23 voltages levels of the clients are under the limits. This problem can be solved in three different ways depending on the real scenario:

- There is not possibility to run a market due to the few services that are offered. In this case, services on direct call are requested to users (either generators or consumers located at those substations). It is the DSO who sends directly the requests to the grid users.
- There is possibility to run a market with the services that have been offered to the flexibility market operator. DSO will run the market and will implement the request considering the previous constraints that were received from the transmission grid.
- Third option is for the long term. This solution considers new reinforcements such as capacitors banks.

Within this situation, DSO can choose which is the most efficient product can be applied in order to postpone a reinforcement of the grid and solve the congestion. Depending on the services prices that are provided by DG, consumers or generation located in the area where the problem is located, a different approach can used in order to solve the problem.

In this model, the DSO can also buy services in order to have a flatter voltage profile diminishing the losses of the whole system and increasing the efficiency. For example, peaks of production in the factory that are located at DBMV2 may provoke some spiky voltage profiles. These peaks lead to an inefficient system because of the losses that are being produced. Solution for this case may have two approaches:

- Purchase a service from the load C2 changing the consumption profile throw its aggregator/retailer
- Purchase a service from the generator where the generator changes the commitment to follow the load of the factory avoiding peaks along the rest of the grid.

Services chosen depend on the prices that are available. Cheapest offer that solves the problem must be considered and acquired as the most efficient. Decisions should consider the effects that may have subsequently: the possibility where the G2 follows the load of the factory may still lead some voltage issues at LV that have still to be solved. This subsequent problems may be considered in the price.

For this reason, with this model, if it is purchased the service where the generator follows the load of the factory it may also be considered the necessity of purchasing also services of DG or RES at LV in the total price of this service. It is part of the service that it is necessary to implement. With this approach, it is considered the cheapest solution including subsequent changes that might be needed.

The good point of this model is that each flexibility market operator (either DSO or TSO) buys just for itself and DSO also offers to the other flexibility market operator the products that could be interesting for the real time having internalised subsequent problems that might appear. Finally, both operators can use services provided by DER using all the advantages that DER flexibility resources can bring to the system.

Coordination at primary substation:

In this model DSO can purchase products that allow postponing the investment or shift/reduce loads in order to decrease the losses in its own network. This can be done directly since it is the DSO who purchases DER services in its market. Both TSO and DSO have different flexibility operational markets that are being run by their self.

First it is going to be analysed if congestions may be avoided or solved. In case DSO wants to avoid congestion in the HV/MV transformer located between DBGV2 and DBHV2 the DSO can take three different actions depending on the real situation:

- There is a unique possibility to decrease power of G2 and increase DER connected at SS21, SS22 and SS23. In this case, this request will implement directly by the DSO while considering the set point values that should be meet at primary substation
- There are different possible solutions among agents: G2, load C2 located at DBMV2 and DER connected at SS21, SS22 and SS23. In this case, it will be requested to decrease the power that is going through the substation that is located among DBHV2 and DBMV2 bars. Finally, it is the DSO who runs a market to decide which units should be involved accordingly to the services that have been offered.
- Third option is for the long term. This solution consider the reinforcement of the substation

In Primary Substation model, the DSO can buy services from all the consumers of the distribution grid and all the DG that is connected in low level from its aggregator or retailer (C1, C2, and C3).

In case of problems of quality of supply, it will be considered that voltages along the grid are within the limits. However, due to an increment of loads at SS21, SS22 and SS23 voltages levels of the clients are under the limits. This problem can be solved in three different ways depending on the real scenario:

- There is not possibility to run a market due to the few services that are offered. In this case, services on direct call are requested to users (either generators or consumers located at those substations). In this case, it is the DSO who sends directly the requests to the grid users.
- There is possibility to run a market with the services that have been offered to the flexibility market operator. DSO will run the market and will implement the request considering the set points of the primary substations.
- Third option is for the long term. This solution considers new reinforcements such as capacitors banks.

Within this model, the DSO can also buy services in order to have a flatter voltage profile diminishing the losses of the whole system and increasing the efficiency. For example, peaks of production in the factory that are located at DBMV2 may provoke some spiky voltage profiles. These peaks lead to an inefficient system because of the losses that are being produced. Solution for this case may have two approaches:

- Purchase a service from the factory changing the consumption profile throw its aggregator/retailer
- Purchase a service from the generator where the generator changes the commitment and follows the load of the factory avoiding peaks along the rest of the grid.

Distribution Company might have problems when it has to meet demand of their loads as well as the set points of the frontier point with the transmission system operator. This situation might be difficult to manage for the distribution company, while it could be easier to be solved if the TSO helps throw changes in the transmission grid.

The synergies of running both models at the same time are lost. For example: In case of big generation in the low voltage levels because of DG, there could be changed the flows of the distribution grids. These new flows may go upstream generating big congestions in the nodes located at medium and high voltage bars. Considering this situation, it may be more efficient/cheaper for the systems if the conditions set in the frontier TSO/DSO are relaxed. One way of relaxing these constraints may be if the TSO can reduce power in this node using a cheap service, helping to the Distribution to control the constraints of the HV/MV bars.

Furthermore, it could appear a situation where TSO may prefer to relax the condition of the frontier voltage set points in one sense (upwards or downwards) while the DSO also prefers in that moment to change the conditions agreed in the same way (upwards or downwards).

Since the distribution and transmission grids are split in two and both grids are not operated as a whole, this may lead to inefficiency actions by both TSO and DSO in order to meet the operational points that were agreed previously. With this model, the DSO always has to meet the set point agreed by both operators, not knowing the reality that the TSO have in this moment.

The most important problem of this model appear due to grid is split in two: one part belonging to the distribution and other to the transmission companies. This could lead to some inefficient procedures since the market is not run by a single entity as a whole. Synergies that appear when both models are run as a whole are lost if this model is used.

To sum up, the appearance of congestions, voltage issues or technical constraints are solved locating the agents that can bring a solution and using a market or direct call approach depending on the agents that can bring services that solves the issues.

5.1.3.1.2 TSO need for DSR and DG

Transmission System Operator can take advantage of the flexibility in three stages:

- Avoiding congestions in nodes of the Transmission Network
- Avoiding technical losses

- Ensure security of supply for global necessities such as frequency control.

These three issues are going to be considered within the three different models that have been defined before.

Centralised and extended dispatch:

In this model, TSO runs the system resources provided by the generators of transmission grid and DER. Considering that TS1 is congested, TSO is allowed to use the system services from generators and demand that are connected to both distribution and transmission grid. It is considered that the DSO has sent to the Flexibility Market Operator the restriction at DBMV2 since there is located a load (Factory) that should have an ensured quality and security of supply. Considering this restriction, TSO will not be able to change the operational points of G2 in order to have correct set points at node DBHV2 (there is no other solution).

Considering the situation introduced above, if TSO needs to decrease the power at bar TS1, it can be used the services provided by users directly connected to the flexibility market operator (using G1 for example) or the services that are connected to the DSO grid. Trying to cope with the restriction of power of the lines connected to the bars DBGV2 and DBMV2 there will be run a market by the TSO in order to acquire a cheap/efficient solution including distribution and transmission offers and constraints.

Finally, TSO decides to decrease the power generated by G1 and G3 (which were not constrained by DSO). Both actions are directly requested by the TSO. However the request over G3 should be accepted by the DSO. With these changes TSO achieve normal values at bar TS1. Changes are applied and this will be the situation of generation/consumption since there are no subsequent changes from TSO or DSO and there are no more restrictions in the grid.

However with the new situation, it might also appear some problems in real time. Lines connected to SS11, SS12 and SS13 are under the allowed voltage value. In order to solve this there could be two situations:

- Increase the power of generators G1/G3. This cannot be done since there have been changes over these generators.

- Change the values of the consumers/DG connected at SS11, SS12 and SS13 throw their aggregators. This may require to the DSO to purchase local services at a fixed price from the DG or the consumers located at those nodes.

The changes at SS11, SS12, SS13 and downstream have been considered through direct call by the DSO. However, this request should be finally implemented by TSO.

TSO might also have changed the set points of the nodes that are located at transmission grid close to TS1. This situation may be more expensive and inefficient than changing G1/G3 and for this reason TSO finally have decided to change G1 and G3. However, considering the final situation with the changes produced by both TSO and DSO, it could be better if nodes located close to TS1 were had changed. This is the problem that appears in this model since TSO can act directly in to the DSO grid, and DSO can just act over its own grid.

With this model, TSO knows the constraints of the distribution network, but it does not know the future changes that the system will need when system services are acquired. When operations over the grid are done as a whole, subsequent problems that might appear are considered.

There could be other procedure for solving the problem of the congestion at the node of TSO that is cheaper/more efficient than the sum of actions that were taken by TSO and DSO separately.

Regarding the security of supply, it could be needed an increment of power in order to increase the frequency of the system for all the users connected. In this situation, TSO acts using the services that have been provided to the Flexibility Market Operator (who is also the TSO) while fulfilling the constraints previously sent by DSO (set points of bar DBMV2). TSO will purchase services from a lot of generators since frequency is a global problem. In this case it is considered that the TSO will purchase services from the DG located at LV since those are the ones who solve the problem in the cheapest way. This purchase will be requested directly by TSO. Finally this action may provoke subsequent congestions at MV/HV bars in real time operation that cannot be considered by TSO. This new congestions will be solved by DSO purchasing local resources to the generators G1 or G2.

As in the previous case, this solution may be solved in another way that is cheaper/more efficient for the system if the TSO consider the subsequent changes in grid. However, since this model splits solution in two parts (purchase system services run by TSO and purchase local products by DOS); it may lead to inefficient situations.

TSO can also consider services in order to have a flatter voltage profile in order to have lower loses along the system. TSO can run a market in order to buy services along the whole grid that compensate the energy losses. The problem with these requests in this model is that, as in previous issues, subsequent problems might appear in the distribution grids that are not consider by the TSO. Finally, services bought by TSO to have a flatter profile added to the services purchased by DSO in order to solve subsequent problems may not compensate the total losses amount.

DSO cumulative services model:

First of all in this model, the DSO (as flexibility operational market) have to publish aggregated services from the users that are connected to its own grid. Those services can be used by TSO.

In this model there are not different procedures to operate the system by the TSO when there is congestion in node (i.e. Bar TS1). TSO can use directly the system resources provided by the generators/consumers that are connected to its own grid changing power (in this case generators/consumers located at TS1 bar) and also the services that has been provided by the DSO in a cumulative way.

The TSO have to take the decision if it prefers to use the services provided by users at transmission level or the services provided by the DSO.TSO will run a market in order to solve this issue and it will opt for the cheapest product. Three situations may appear:

- The cheapest solution is provided by the TSO users (change the set point of G1). It will be implemented and it may change the reality at the distribution grid with a necessity of subsequent new purchase of services by DSO in order to solve the new distribution problems that have appeared.
- The cheapest solution is provided by the DSO. When purchasing this services throw the DSO, it has been already internalised all the changes that are needed

even at the distribution needed. Distribution will decide which units/users involve in this process according with the necessity, availability, constraints, price... There will not be a necessity of a second procurement to solve the problems. In this case are is considered a reduction of power of both G3 and G2 and the subsequent necessity to increase DER power located at LV.

- There can be another solution which is a combination of the previous ones. The use of the services from one of the options is the cheapest solution but it is not enough to solve the issue. For this reason a combination of both is needed.

It can be also considered for the long run a reinforcement of the grid that allows solving this issue.

It is important to note that in this model it is internalised subsequent necessities of a change. It is not necessary to readapt the grid when the DSO changes the operation in the distribution network. DSO have internalised in the price of purchasing the services the necessities that will be needed in order to offer the service to the TSO. This is an advantage in comparison with the previous model since this leads to less inefficiencies.

In case TSO needs to ensure security of supply (frequency of the system). This issue will be solved in the flexibility operational market of the TSO. Then, solution and new set points will be request to the users by the SO that manages the grid where they are located. Subsequent problems that might appear in the distribution grid have been internalised in the price.

TSO can also consider services in order to have a flatter voltage profile in order to have lower losses along the system. TSO is allowed to run a market in order to buy services along the whole grid that compensate the energy losses. Solution and new set points will be request to the users by the SO that manages the grid where the users affected are located. Subsequent problems that might appear in the distribution grid have been internalised in the price. For that reason, requests do not create subsequent problems.

Coordination at primary substation:

When the TSO needs to change generation/consumption power of its users at transmission level due to a constraint at bar TS1, it can be used the user services of the transmission level that are able to provide services and the summary of services that the

DSO have provided to the TSO. TSO must always consider the agreement that has with the DSO in order to cope with the set points at the primary substations between TSO and DSO. In order to solve this issue, TSO will run a market just considering the services of the transmission grid and will be implemented by itself directly.

In case of problems of security of supply (frequency problems), it will be solved in the same way: running a flexibility operational market just considering the services of the transmission grid and will be implemented by itself directly.

The last case where TSO can use services offered by grid users is the losses reduction issue. TSO can also consider services in order to have a flatter voltage profile in order to have lower loses along the system. TSO is allowed to run a market in order to buy services of the transmission grid that compensate the energy losses.

The problem of this procedure is that sometimes it could be cheaper to change the generation/consumption that there is downstream the bar TS1 instead of changing the generation at bar TS1 or the bars that are in the transmission level. When the TSO is operating the grid, it does not know what the reality of the distributor is and cannot take advantage of a whole coordination. SO just knows what should be the operational point among them.

Advantages of RES/DG connected at distribution level are not being used for the problems of the TSO losing the efficiency and the power that Smart grid could bring to the system. This model is easier to develop since each system operator manages its own grid trying to cope with the set points of the interface TSO/DSO. However this leads to a grid where both grids need consumers/generators that can provide the same services in both parts. With this model it might appear unnecessary duplicities in order to offer services.

5.1.4 Analysis of the model proposed

The analysis of the different models is going to be done with three different approaches: technical, regulatory and economical necessities. First, it is assessed the technical necessities that the model needs in order to be implemented. Then, it is checked which are the regulatory issues that are needed for the implementation of each of the different models. Last section of this chapter assesses the economical necessities for the technical and regulatory necessities that have been previously evaluated.

5.1.4.1Technical Requirements

In this section it will be assessed the common technical requirements of the different models proposed in this master thesis as well as the particular necessities that will be needed in each single model.

5.1.4.1.1 Common requirements

There is a necessity for the users (generation and consumers) for installing a device in order to measure the changes provided by them in their consumption/generation. Smart meters currently being installed may fulfil this requirement. This is common for all the models since it is consider that future scenarios DER will be able to provide services and it will be necessary to control if they are committing those services.

The cost of these installations depends on the amount of how many users will be covered. However, it is not necessary to install these devices in all the connections of the grid. Maybe it is not necessary to install these devices in all the consumers, just installing them on the loads that can provide demand side response. The same situation appears for the generation: maybe it is not necessary to install the devices in very small generators which do not represent a big amount for the system or if the generator cannot provide services for the system. This issue should be studied with more detail.

The device inversion for DER users that wants to offer services is variable. DRIP project (DRIP Project, 2014) suggest that it is needed to install two devices:

- A power meter in order to be able to read the measures (kW, kVar, kVA, Voltage, Current, Power Factor, Demand, Min/Max values, Harmonics...)
- Modbus Ethernet Gateway: device that is able to send the information to the aggregator/system operator.

Installations of these devices are needed in order to control the new connections at the distribution side that nowadays are not being controlled. This device installation will be done independently of the new model that is applied. Depending on the model where these devices are applied it changes the receiver of the information from these users.

Regarding the bids from the generators, they should be able to send their availability for different offers either directly or through their aggregator. Similar procedure will have to fulfil RES, which have to send offers to change their consumption through their retailer or aggregator. Adaptation of system and devices will be required independently of the scenario

Four different issues are going to be assessed for each technical analysis of each model: which technical necessities are needed among flexibility market operator (FMO) and DER, which technical necessities are needed for the exchange of TSO-DSO information, TSO technical necessities and DSO technical necessities.

5.1.4.1.2 Centralised and extended dispatching model

DER is monitored with the technical devices considered in the common part. This information will be sent to the TSO. Regarding this consideration TSO will need bigger data bases in order to be able to cope with all this monitored information. Furthermore it is needed that its systems are able to process and send this information to the different distribution companies connected to its grid.

Figure 15 represents the flows of information that have a centralised and extended model. It is possible to see that TSO is the central counterparty and all the information should go through TSO system.

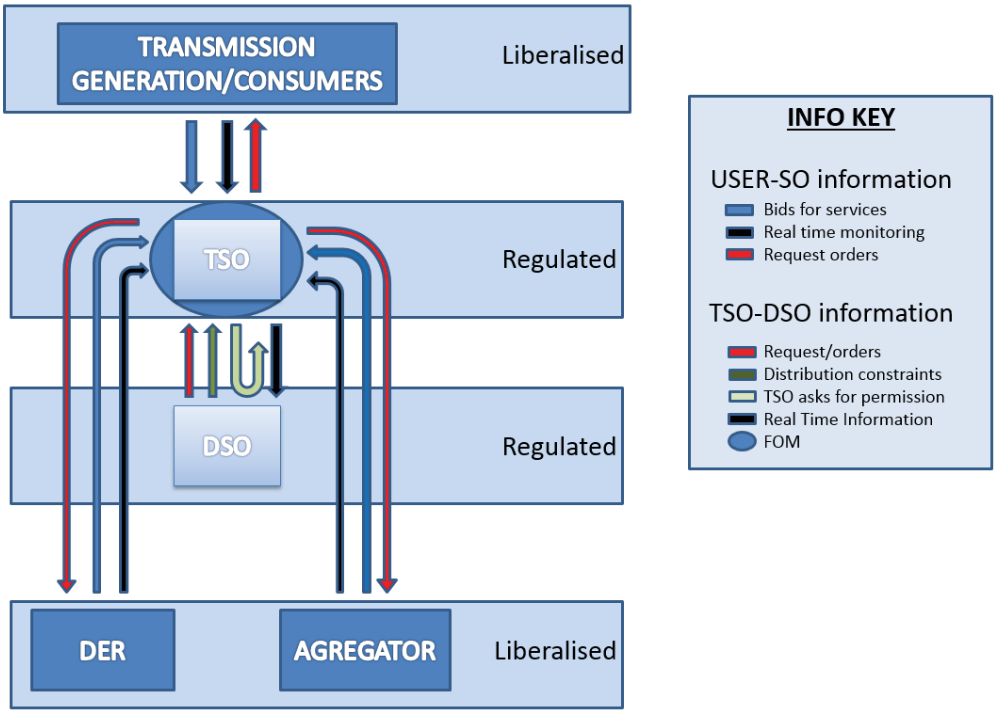


Figure 15: Centralised and extended dispatch information exchange

MO-DER information

Three different types of information will be exchanged between DER users and FMO (which is the TSO in this case):

- Real time monitoring information from DER to the flexibility market operator
- Bids for the services that they can offer to the system.
- Services requests from FMO to DER.

TSO-DSO information

DSOs companies will receive schedules information from the TSO the information of the DER that has connected. Monitored information of the generation and consumption of the generation is duplicated in both systems (TSO and DSO system).

Four different type of information will be exchanged among DSO and TSO to manage the grid and be coordinated among them.

- Information from DSO requesting changes in the distribution grid.
- Forecasted schedule and sending back to the TSO the constraints that will appear with that schedule.

- Permissions of the DSO when the TSO needs to act over the distribution grid.
- DSO will receive the real time monitoring information of the different DER uses that are sending the information to the TSO.

TSO necessities

TSO will need systems that are able to cope with the information of all the grid users (both transmission and distribution levels). It is important to consider that the amount of information that goes though TSO systems is not negligible for this model.

Furthermore, TSO will have to consider systems that make possible to run a flexibility operational market.

DSO necessities

DSO needs systems that are able to consider the information of its distribution grid. Furthermore, it should consider the information (requests, constraints...) that have to exchange with the TSO.

DSO does not need systems to run flexibility operational market. However, its systems must allow operating, managing and sending the requests to the TSO.

5.1.4.1.3 DSO cumulative services model

DER and conventional generation is monitored with the technical devices considered in the common part. This information will be sent to different system operator regarding where it is located the user of the grid: users located at distribution level must send the information to the DSO and users of the transmission level must send the monitoring information to the TSO.

Figure 16 represents the flows of information that have a DSO cumulative services model. It is possible to see that both SOs run flexibility operational markets and both system operators have the possibility to purchase services from each other.

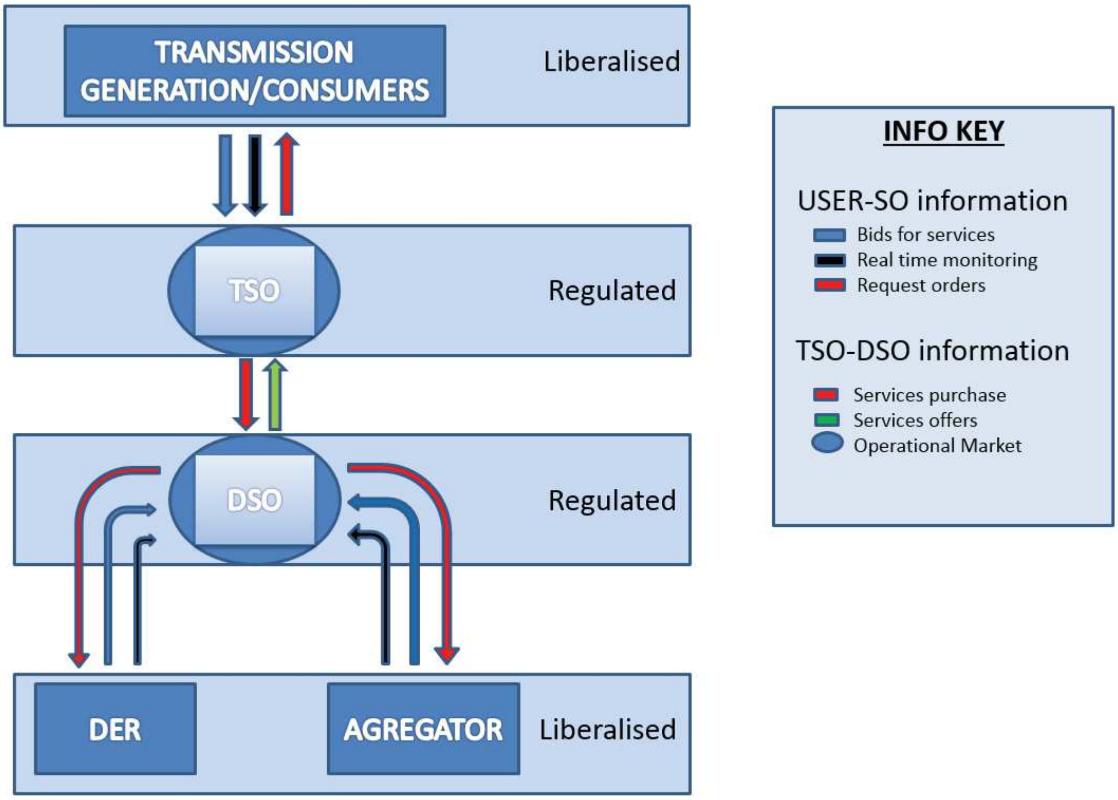


Figure 16: DSO cumulative services model – Information exchange

MO-DER information

Three different types of information will be exchanged between DER users and FMO (which is the DSO in this case):

- Real time monitoring information from DER to the flexibility market operator
- Bids for the services that they can offer to the system.
- Requests send from DSO to DER.

TSO-DSO information

Four different information types will be exchanged between DSO and TSO to manage the grid and be coordinated among them.

- DSO requests services from TSO or other distribution companies.
- TSO requests services from the distribution company in a cumulative way.
- TSO receives possible services offered by the distribution company in a cumulative way.
- DSO receives possible services offered by TSO.

TSO necessities

TSO will need systems that are able to cope with the information of the transmission grid users but not the distribution users. TSO systems will be able to consider the information that is being exchanged with DSO.

TSO must have technical systems to run a flexibility operational market for the whole system. However this market will not have all the bids for the services of all the users. It will be necessary to have just the bids offers from the transmission users and the bids of the distribution companies (one per primary substation).

DSO necessities

DSO will need systems that are able to cope just with the information of the distribution grid. DSO systems will be able to consider the information that is being exchanged with TSO.

DSO must have technical systems to run a flexibility operational market for the distribution system. It will be necessary to have just the bids offers from the distribution users.

5.1.4.1.4 Coordination at a primary substation model

Third model leads to separate grids, managed and operated independently by its system operator, having as a common point the primary substations.

The connection needed between TSO and DSO for their coordination it is the simplest of the three models. This model has to support bidirectional information in that allows both system operators to set the values spectrum where their primary substations can work depending on the necessities of the grid.

This model has the cheapest connections and coordination among system operators. Furthermore the channels that connect the users of the grid with its own system operator are the same as in previous models. This model and the previous one has the lowest redundancies since the system operators receive/send directly the data/requests.

In terms of systems and data bases, this model needs to run two flexibility operational markets, one for each system operator. Each system operator has just the data base needed for the operation of its grid with no redundancies of information among TSO and DSO.

Figure 17 represents the flows of information that have the coordination at primary substation model. It is possible to see that the unique information that is being exchange among both SOs is the information related to the agreements for the primary substation set values.

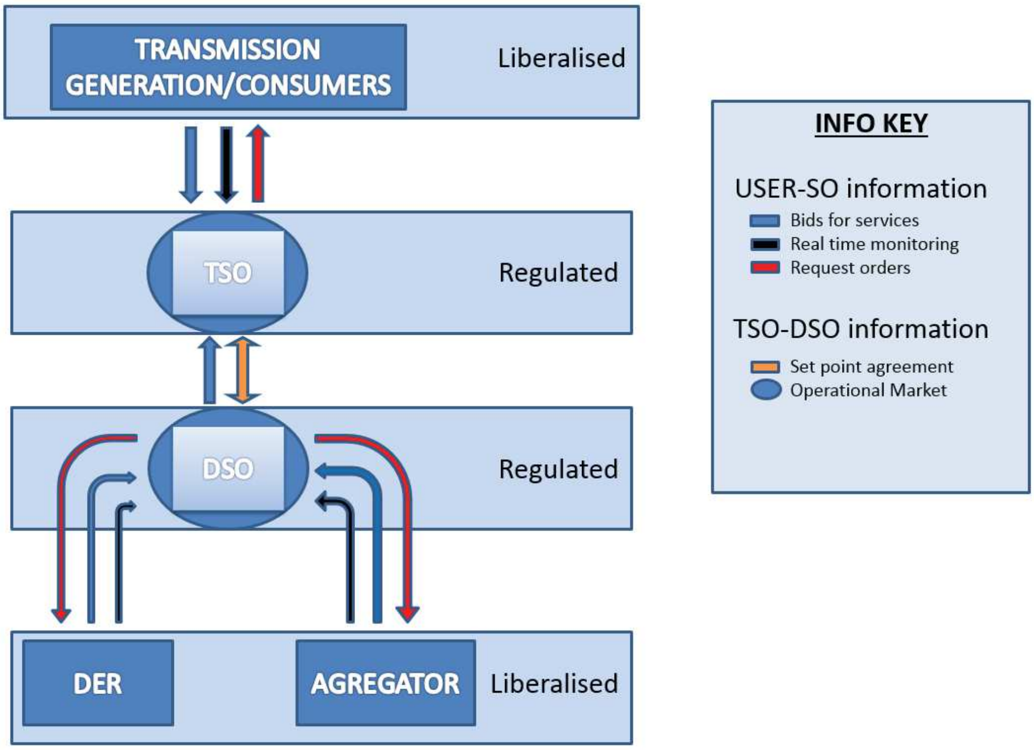


Figure 17: Coordination at primary substation – Information exchange

MO-DER information

Three different types of information are going to be exchanged between DER users and FMO (which is the DSO in this case):

- Real time monitoring information from DER to the flexibility market operator
- Bids for the services that they can offer to the system.
- Requests of services from the TSO.

DSO-TSO information

DSO will have to send a summary of information with the services that can be requested. With this summary and the services available at transmission grid, it will be possible to establish a new coordination and to send set values of primary substation to the DSO.

TSO necessities

TSO will need systems that are able to cope with the information of the transmission grid users but not the distribution users. TSO systems will be able agree with the DSO the set points of the different primary substations

TSO must have technical systems to run a flexibility operational market for the whole system. However, this market will not have all the bids for the services of all the users. It has just the bids offers from the transmission users and the bids of the distribution companies (one per primary substation).

DSO necessities

DSO will need systems that are able to cope just with the information of the distribution grid. DSO systems will be able to consider the information that is being exchanged with TSO.

DSO must have technical systems to run a flexibility operational market for the distribution system. It will be necessary to have just the bids offers from the distribution users.

5.1.4.2 Regulatory Requirements

5.1.4.2.1 General requirements

It is important to note that there should be a standardisation of the process, protocols, and necessities for installations across all Europe. Otherwise, it will appear signals for leakage: new installations will decide where to operate operating depending on the country and depending on the model implemented. For example, nowadays in Spain generators above 1MW have to send real time data, generators located in Finland have to send the real time data if they are connected at MV and HV levels while in Austria just the generators that are above 50MW have to send real time information to the system operator.

The situation explained in previous paragraph leads to a European system where the investor prefers to go different countries depending on the power that wants to install. The situation explained above may suggest to the investors not to install small generators in Spain since there have more requirements just for an installation of 1MW while in other countries -as in Austria- it is possible to install up to 50MW with just technical requirements but not real time information monitoring. If Europe does not want to give different signals to the investors depending on the countries, national regulatory authorities should require same information and requisites along the European continent.

The models that are being analysed in this Master Thesis may be combined with Traffic Light (BDEW, 2014) approach in order to know when the market should be used and where unilateral decisions can be implemented. For all the cases there may appear three different scenarios:

- Normal conditions: no changes are needed to be implemented. Flexibility operational market must be running freely.
- Constraints scenario: When constraints appear, request through the market must be considered. Efficiency is achieved when using a market since it will provide the least costly operation as a solution.
- Emergency scenario: An operation that solves the problem can be considered directly through a fixed price (if any) instead of acquiring it in the market. This is due if emergency scenario appears it is because direct actions should be taken in a short time of period.

5.1.4.2.2 Common regulation necessities for the actions among flexibility market operator and users

This section considers the regulation necessities when it is just considered the relationships between the agents of the grid and the flexibility operational markets. As a general approach, the information (bids and real time monitoring information) must be sent to the flexibility operational market and the requests must be sent from the flexibility operational market to the users of the grid. However, case by case should be considered.

If any of these models is implemented, regulation must consider that not all the users of the grid may provide services to system. Loads may provide services or not depending of their necessities and capacity (if they are able to change set points).

However, it should be considered that any load can be disconnected from the system in case of an emergency scenario due to security reasons. This disconnection should be done automatically with the responsibility of the system operator that is managing the flexibility operational market in the area.

Model 1: Centralised and extended dispatching

In this model TSO have to be allowed to act over all the users of the grid. TSO is the agent allowed to have right to be in direct contact (receiving information and bids for services and sending requests) with the users of the grid since it is the unique running flexibility operational market. DSO is allowed to receive the real time monitoring information through the TSO.

Model 2: DSO cumulative services model

The users able to provide services to the grid must send the information and receive the requests to the system operator (either TSO or DSO) that corresponds with the voltage level where they are located. For example, loads and generators located at distribution level should be in contact with the DSO. The same happens with TSO and users located at transmission level.

Model 3: Coordination at primary substations

The users that have the possibility to offer services must send and receive information and requests through the system operator (either TSO or DSO) that corresponds with the voltage level where they are located. For example, loads and generators located at distribution level should be in contact with the DSO. The same happens with TSO and users located at transmission level.

5.1.4.2.3 *Regulation necessities for the coordination DSO-TSO*

In this chapter are considered the regulation requirements for a proper role definition and coordination of the DSO and TSO. Rights and obligations that regulation should consider depending on the models that is preferable to be implemented.

Model 1: Centralised and extended dispatching

For this model it is necessary to provide both to TSO and to DSO different rights and obligations. This model needs that the DSO have rights to:

- Accept or reject the requests that the TSO wants to implement in the distribution grid.
- Send requests for its different necessities to the TSO and receive an answer in order to know if the request will be considered or not due to technical constraints.
- Know the operational planning forecast in the distribution grid, in order to be able to send the constraints of the grid.

However the DSO has also one obligation added: The DSO should send the distribution grids constraints before the real time operation.

Looking at the TSO, there are also rights that should be implemented with the regulation:

- Receive the bids for the flexibility operational market from all the agents either from distribution or from transmission grid.
- Right to request any change to the agents located at transmission level for technical reasons
- Right to request any change to the agents located at distribution level for technical reasons when the request is previously accepted by the distribution company responsible for the area.
- TSO have right to receive from the distribution company forecasted technical constraints that will appear in real time within its distribution area.

Also there are obligations to the TSO:

- TSO have to send the real time information received from the users of the grid to the DSOs.
- TSO must not consider/implement the services that contradict the technical constraints that the DSO has previously sent.

- TSO must have to send the programmed schedule of its distribution area to the respective distribution company with enough time so that the DSO can analyse and forecast possible technical restrictions that may appear in the grid.
- Ask for permission and wait for acceptance from the distribution company when it is required to change the set points of any agent located in the distribution grid.
- Have the obligation to consider the requested by the distribution companies.

Model 2: DSO cumulative services

Rights for DSO:

- TSO have rights to know directly the monitoring information of the users that are connected to the transmission grid.
- The flexibility operational market is run by TSO have right to have access to the services offered by the flexibility operational market run by the DSO in an aggregated mode.
- Right to request to the TSO services for local grid that is not able to implement on one side.

Obligations for DSO

- Offer services to the TSO in an aggregated way considering the technical constraints of the grid.
- Send the actions necessary to the users of the grid in order to implement the requests from the TSO in the distribution grid accordingly to the services offered previously.

Rights for the TSO:

- Receive the information in real time of the users located at the transmission grid.
- Receive the bids for the services of the users located at the transmission grid.
- Request offer to the DSO accordingly to the previous services offered.
- Request changes of set points of the users located in the transmission grid.

Obligations for the TSO:

- Consider and act accordingly to the request of the DSOs for services that they need and they cannot provide their selves.

Model 3: Coordination at primary substation

Rights of the DSO

- Receive real time information and bids for services from the DSR and DG located at distribution level.
- Request new set points for the DSR and DG located at distribution level.

Obligations of the DSO

- Agree with the TSO the values scale for the primary substations.
- Send a summary to the TSO with the services of the distribution grid that can be requested

Rights of TSO

- Receive real time information and bids for services from the users located at distribution level.
- Request new set points for the users located at distribution level.
- Receive services of the distribution grid that can be applied.

Obligations of the TSO

- Agree with the DSOs the values scale for the primary substations.

5.1.4.2.4 Unbundling Necessities

In some of the models considered in this Master Thesis, DSO becomes an important and visible actor in the energy industry where DSOs are playing a role in the efficient functioning of Europe's energy markets acting as 'entry gates' to retail markets. For this reason it is very important to ensure a proper unbundling when it may appear influences and competition must be ensure.

Third package calls for careful unbundling in DSO case. Within the Third package, the Directive 2009/72/EC ('Electricity Directive'), European energy networks are subject to unbundling requirements which oblige to the members states (MS) to ensure unbundling of the DSOs (article 26). These unbundling requirements are focussed on the legal, functional and operational separation of the DSO from other actors in the supply chain. The body does not mention ownership unbundling. However with the new tools of DSO this situation may change.

In one recent report from Eurelectric in response to a CEER public consultation (EURELECTRIC, 2015) Eurelectric prefers not to implement ownership unbundling because it is not considered the better solution. The document explains that the actual unbundling requirements –if properly implemented by the MS and the companies- are enough to ensure perfect competition of the markets.

The statement of Eurelectric can be considered for the first model where the DSO is not running any market. That document considers that DSO just ask for the necessities and it is the TSO (who is ownership unbundled from any other activity of the grid) the agent that decides which units must be involve.

However, for the second and the third model there is an open question about the necessity of a further ownership unbundling as it is going to run a flexibility operational market and is able to decide which units are involved in the request/necessity. If the DSO is going to be in direct contact with the liberalised part in a much more intensively way than it is doing now, DSOs may be more unbundled than it is now.

In case that a model where distribution companies have to run a flexibility operational market and the ownership unbundling is not wanted to be implemented, the flexibility operational market of the DSO may be run by a separated new entity. This ensures market efficiency. However, if the flexibility operational market of the distribution company is run by an external entity, the new situation created it is very similar to the first model proposed.

With this parallel entity are lost all the advantages and synergies of running the flexibility operational market by the same system operator. For example, it has been considered that may be cases where the TSO request services from the distribution grid. For this case in the second model, Distribution Company internalise future changes that may be necessaries if that service is implemented. This does not happened with the separate entity because that market entity does not know the reality of the distribution grid.

In the third model there are not synergies if the DSO runs the flexibility operational market or not. For this reason, within this the ‘Final cumulative program at HV/MV interface” it is possible to separate the flexibility operational market with other agent.

It is possible to see nowadays situations where distribution companies make unavailable some grids in order to have the right from the TSO to be committed with some of the plants of the same holding. If this is happening now, it might also happened situations like this one with ownership unbundling. For this reason, what is really needed is to implement auditable processes that ensure that procedures and decisions are being taken with responsibility.

For this reason, transposing the European regulation that exists for the TSO, it should be enough if it is available a regulatory certification like the one that have to pass the TSOs in Europe where different unbundling can be considered:

- Ownership unbundling (OU): clear-cut separation
- Independent system operator (ISO) a fully unbundled system operator without the grid assets (still belonging to the holding)
- Independent Distribution Operator (ITO): a distribution system operator owning the assets and belonging to a vertically integrated company with special rules to guarantee its independence.

This gives to the DSOs the same possibilities that are having DSOs in Europe. Each company will decide which approach wants to take in order to pass the certification process and ensure that will be a fair market facilitator.

It should be considered that some decisions will bring extra cost. For example, if ownership unbundling is mandatory distribution companies will lose a lot of synergies with the holding company: systems, resources, shared departments... Those synergies lost will bring an increment of the recognised cost for the distribution companies which it will increase the costs for the system. An intermediate solution such as ITO approach could be considered.

5.1.4.2.5 Remuneration regulation scheme

Most of European countries have a remuneration scheme based on assets and/or energy distributed. However, considering the new models introduced along this thesis, it is

important to see that both distribution and transmission companies will needed a new economic regulatory scheme that allows them to receive enough incomes to operate the system.
The new regulatory scheme should consider the use of new tools that are available in the system: flexibility operational markets, services, management of the system... The new regulatory scheme should give incentives and signals so that network companies have the correct incentives and signals to use services provided by DER instead of investing in new network.

Since both transmission and distribution sector are regulated sectors, if this remuneration scheme is not change, companies will behave doing the same actions as they are doing now in order to receive the necessary incomes.

5.1.4.3 Economical Requirements

This economical assessment of the model will be done for the long term of each of the different models.

Common economical requirements

Having more clients providing services does not make any change in the model since the same clients will be considered in any of the models. For this reason amount and way to be communicated with the users will be treated as an independent issue.

Information sent by generators (bids, monitoring information...). Depending on the model, this information will be sent to a different operator (TSO or DSO) depending who is running the flexibility operational market in each case. For this reason, the devices necessities and the channels needed in order to send information and receive the requests are the same for all the models with the difference of the receiver.

Since the relation, necessities, and information exchanged between generators-consumers and the flexibility market operator is the same in all the models, this part is not going to be assessed economically. The parts that make the difference economically are the relations and the actions that have to be done by TSO and DSO and the necessities of each SO.

Centralized and extended dispatch model

This first model has a main advantage: the unique operation market run by TSO. This is an advantage in terms of systems needed since it is not necessary that each distributor have its own systems and resources to run the market, with their corresponding back-ups. However, in order to achieve this advantage, this model has other drawbacks such as the relationship and the information exchanged need among DSO-TSO.

Four types of information, with its associated costs, are needed to be exchanged between TDO and DSO. This increment of information lays on the necessity of systems that are able to process more information. Furthermore, part of this information is real time data that should be sent instantaneity to both SO. This may increment the cost of the systems.

Operational speaking, this model may be also more expensive since it is needed that DSO accepts any changes that TSO wants to do over the distribution grid. This situation is not practical if any change should be sent to the DSO, reviewed from it, accepts or rejects the proposal and sends it back to the TSO. This is inefficient process may lead to higher costs than other models.

Other important economic issue is that both TSO and DSO need systems that are able to cope with the information of the distribution grid. This situation may seem redundant; however it is necessary that both operators have real time information of the grid since both can make decisions over the distribution grid.

DSO cumulative services model

Comparing this model with the previous one, model two have the drawback of the two markets that must be run by TSO and DSO. However, the good point of running both models is that TSO just run the flexibility operational market in which information managed is lower since the information and services of the distributor grid is provided in a cumulative way.

Each system operator just has the real time information of the grid that really needs which decreases the capacity of the systems and the information exchanged among agents.

Just three types of information are needed for a proper relationship among TSO and DSO, which lower the channels width needed between SOs in comparison with the previous model:

- Offers of services in a aggregated way from the DSO to the TSO
- Offers of services in a aggregated way from the TSO to the DSO
- Services purchased by the TSO from the DSO.
- Services purchased by the DSO from the TSO.

The first and the second type may be bigger amount of information that the others two. It is important to see that this first type is substituting the type of model 1 where all the real time information is exchanged. It is obvious that the channel of this model have to cope with less information in terms of quantity. This leads to cheaper economical necessities for the operation.

As previously said, the last two types of information between DSO and TSO have to cope with even less information than the previous channel. For this reason, once analysed the channels and the information that should be managed, it is possible to see that connections in this model are lower than in the previous one. The key aspect when comparing both models is to know if the savings within the connections DSO-TSO balance out the economical increment that is necessary when the flexibility operational market is not run as a whole by the TSO.

<u>Coordination at a primary substation model</u>

Third model have the same costs in terms of flexibility operational market since both DSO and TSO runs its own market. For this reason, the cost of running flexibility operational markets is the same as in the previous model. As previously mentioned, this cost is higher than in model one where just one single market it is run.

Information that has to be computed by either TSO or DSO systems is not big in comparison with the previous models since each SO manage just its own grid.

In terms of channels needed for the TSO-DSO information, this model has the fewest quantity of channels needed among both agents. Furthermore, the channel needed does not have to cope with a lot of information either in terms of quantity and frequency. This is because the information that must be exchanged through this channel is the agreement of the set points of the primary substations (connection points of both grids).

6 METHODOLOGY

6.1 AIM OF THE METHODOLOGY

Coordination has been shown to be a critical factor along the history of the electrical system. During the last years in Europe, there was a traditional hierarchical structure where TSO take decisions unilaterally and DSO adapts its own programs, schedules, operations, planned outages… However, as previously seen, situation is changing with the appearance of DER and the development of information technologies.

On one hand, the whole Europe is looking for a single European market model. European Network Codes propose regulation that is directly applicable and not transposable into the regulation of each country in order to achieve the same unified rules along Europe.

On the other hand, nowadays, each country is considering the management RES issue in a different way (as previously described in the Eurelectric Survey). Furthermore, the management that today is being considered may not be the most efficient for the system or users.

This section proposes a methodology to check the feasibility and problems of the different models for the management of DER when are implemented in the countries of the European Union. The methodology consists of three different steps.

6.2 PHASES OF THE METHODOLOGY

The methodology proposed in this thesis is built with three phases. First phase analyses the boundary conditions of the country where a model is going to be implemented. The second phase analyses the changes needed in the country in order to start running a model. Third phase analyses the efficiency of the model as a whole within the country for the long term.

6.2.1 Phase 1: Boundary conditions definition

First step consists on defining the boundary conditions of the country. It should be defined how is the actual scenario of the country. These boundary conditions must give answer to the following questions in order to define the scenario for the next steps of the methodology:

- Distribution voltage levels: It will be necessary to identify the voltage levels that the distribution company owns.
- DG penetration: it should be analysed the amount of current DG penetration. In the following case studies analysed in this Master Thesis it will be considered just the penetration of wind and PV panels as both are the most popular generation in distribution grid along Europe.
- Operations over DER: It should be considered who can request actions from DER and in which situations (normal operation, constraints, emergency scenario). Furthermore, it should be evaluated how the system operators can do the requests (directly, through the other system operator…) DER.

  It should be considered how many flexibility operational markets are run, who is engaged to run them and which units can provide services to this market. It should be also considered if just the agent who is running the market can use the services or also the other system operator can use DER services.
- Data of DER: Which information receives each of the system operators directly from DER? Which information receives any of the system operators through the other?
- Exchange DSO-TSO. How the SOs know what is going to be the operational schedule? How many flexibility operational markets are run? Who runs those markets?

  How is the coordination of the system operator that is able to control DER and with the other system operator? Which information exchanges? Which operations can be requested? Which services are provided among them?
- Furthermore, it can be analysed how many distribution countries there are in the country and how is the share of DER among them. In cases where a few distribution companies have a lot of power in the system, it may have no sense to implement a model where the DSOs have a lot of power in the management of the flexibility market procedures.

6.2.2 Phase 2: Transition evaluation

This second phase is going to assess the transition that a country has to afford depending on the situation analyzed in the previous phase and the one that has to be achieved if a model is implemented.

This assessment is going to be done with three approaches. First of all, a technological assessment of the new technical aspects that are needed to change. Second approach is a regulatory assessment considering law changes that are necessary when the model is implemented in the country. Finally, an economical assessment of the technical necessities and the regulatory changes of this transition are considered. These three approaches are extended below.

Technologically assessment

In this part are considered technical aspects that should be changed depending on the current situation of the country. These technological necessities are the ones that allow DSOs, TSOs and users of the grid to develop the new functions they acquire with the new model proposed.

However, not all the technological changes that a model needs to be implemented are going to be considered in this section. This methodology is going to recognize just the technological assessment that makes differences within the three different models. For example, to install a smart meter to all DER users will not be considered since this is necessary for all the models and does not make any difference.

Following point are the issues that should be evaluated since are the ones that make the differences:

- Relationship FMO-DER. It should be evaluated the changes needed for the connections among flexibility market operator and DER. It should be done a comparison of each of the information among DER and FMO needed in the new model with the information that nowadays is exchanged.

  It is necessary to see how many channels should be created, extended, if the receiver or the sender of information should be changed…

- TSO-DSO information. It should be taken into account the technical necessities among DSO and TSO. These technical necessities must allow both system operators to exchange the information and the requests as the new model demands.
  In this category, it should be done a comparison of each of the types of information needed among DSO and TSO in the new model with the types that are needed nowadays.
- TSO necessities. It should be considered the Technical improvements needed by the TSO in order to be developing the functions that the model assigns. These technical considerations must allow TSO to send, receive and process the information and the requests associated with its role.
  Two different tasks should be considered in this assessment: if a new market is going to be carried out by the TSO and if the systems of the TSO should be improved in order to be able to cope with more information.
- DSO necessities. It should be considered the Technical improvements needed by DSO in order to be developed the functions that the model assigns. These technical considerations must allow DSO to send, receive and process the information and the requests associated with its role.
  Two different tasks should be considered in this assessment: if a new market is going to be carried out by the DSO and if the systems of the DSO should be improved in order to be able to cope with more information or more actions.

Regulatory assessment:

The regulatory assessment should be done with two approaches:

- One approach looking at the local legislation: it may be necessary to implement changes related to the rights and obligations of the users and system operators.
- In case of appearance a new market run by the DSO, it will be necessary to change European regulation in order not to restrict the use of operational flexibility market just for the TSO.

Economically assessment

Once the technological and regulatory issues are assessed, both should be considered and transposed into an economic analysis. On one side it must be considered how expensive are the technical requirements that the system needs when the model is implemented. As previously mentioned, just the issues that make differences among the models should be considered.

On the other hand, it should be assessed economically the regulatory changes needed when is implemented the model.

This economical assessment considers the changes needed from the actual model to the model proposed but not future economical savings that the model could bring for the long run. Long run time scale will be considered in the third phase.

Four issues should be evaluated considering previous two assessments:

- Channels evaluation. Economical assessment of the channels among DSO-TSO and also RES-MO. Creation of new channels, improvements of the existing ones...
- Improvement for the systems: economical necessities related to the capacity necessary in order to be able to cope with all the information and data related to RES.
- Changes in markets: Necessity of creation of new flexibility operational markets or changes in the current market related with the new logic control.
- Regulatory changes: Changes in regulation needed in terms of local and European level.

6.2.3 Phase 3: Assessment of the decision variables.

In this third and last phase it should considered the key points evaluated in the previous phase and adding them the long term issue of the model that is being evaluated.

If previously it was assessed the transition necessities, now it should be considered if all those transition changes and costs are worth to the long run considering the benefits and drawbacks that the model will bring.

It should be assessed if the voltage levels and the penetration of DER will provide enough services for the necessities of the model. Within this issue it should be considered DER, the voltage levels that the DSO owns (in order to see if there will be possibilities for the DSO to use services enough while running the model).

Furthermore, it should be analysed the power of the DSO in that model and the number and the share of the DSOs in that country, in order to ensure enough competition if necessary. It should be assessed if there is competition enough among the DSOs for a market: enough number of DSOs and size of them.

There is a key aspect to consider for the long run when it is assessed balance of the investments and the long run. This key aspect is the possibility to let the market to internalize the operations. When an issue is solved through a market instead of using a direct approach, the buyer of the service have the opportunity of taking the most efficient service or way to solve that problem. The more opportunities that have the SOs, the cheapest product will be bought and the biggest the efficiency will be achieved.

The services that DSO and TSO will use from DER were explained before, in the section 5.1.3.1 where it was explained the Examples of the operational procedures using the different models. In order to highlight them now, these services are:

- For the DSO: services for the reduction of congestions, services for the reduction of losses, services that concerns voltage issues.
- For the TSO: services for the reduction of congestions, services for the reduction of losses, services that concerns global necessities for the security of supply.

The possibility for both DSO and TSO of using the same services will be an advantage for the whole system since it will lead to the possibility of using the most efficient services by both system operators.

Finally, it should be also considered if all the investments previously assessed that are necessary and the costs for the long run will be worth for the country considering the penetration of distributed generation and the voltage levels that are owned by the distribution company. In cases like the French one, it may have no sense to spend a lot of money during the implementation and the long run of a new operational electric model giving a lot of rights to the DSOs since the French distribution companies owns just up to MV (20kV) and the penetration of distributed generation is low.

7 CASE STUDIES

This section provides a real application of the methodology defined in previous section in order to demonstrate its robustness and suitability. In this chapter, it is going to be applied the methodology to 3 representative countries that have been considered representatives in the European Union. The chapter has 9 sections. First three sections are related to Finland. Those are followed by another 3 sections of Austria. Finally, there are other 3 sections for the application of the methodology in Spain.

For each country there are 3 sections because it is applied the methodology 3 times: one per model proposed. Information obtained from the Eurelectric Survey has been used in order to define the boundary conditions definition. (Eurelectric, 2014). Furthermore, in order to have a reliable analysis, Austrian TSO was contacted again in order to have complementary information. Some assumptions were considered in the Finn case due to the lack of precise information.

In this chapter when are consider DER services, those services are considered that are being provided directly or through an aggregator to the flexibility market operator.

7.1 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF A CENTRALISED AN EXTENDED DISPATCHING IN FINLAND

7.1.1 Phase 1: Boundary conditions definition

Due to the lack of information for the Finn electric system, it has been supposed some issues in order to complete the whole definition of boundary conditions that are necessary. Suppositions that have been considered are explicitly specified.

Distribution voltage levels

In Finland, distribution companies own LV, MV (20kV) and HV (110kV).

DG penetration

The penetration of distributed generation is low (both for Wind and PV).

Who acts over RES

Finish DOSs can give instructions to all the agents that are connected to its own grids (DER). DSO can request any of the actions considered in this master thesis (Considering the DG actions: give new set points, increase or reduce active power and switch off DG. Considering DSR it is possible to reduce/increase consumption and switch DSR off). In most of the operations where they are legally allowed to act they are also incentivised economically. DSOs can act in any of the scenarios considered (either in a normal, constraints or emergency scenario).

Regarding DER actions, TSO may not be able to act over DER or act through DSO or directly over DER. The case where TSO is not able to act seems to be not a real possibility since the actions of DER affects the roles of TSO. Spanish TSO is able to act directly over DER and Austrian TSO acts through DSO. Since Finn regulation is much closer to the Austrian regulation (see country groups 2.2.7 Countries Type), it has been supposed that TSO cannot act over DER directly. In case of necessity, requests must be done through DSO.

Who receives DER information

RES information either in terms of quantity or in terms of quality is very high in Finland. Regarding the data that the finish DSOs receives from the distribution users, all the information they receive is received directly. There is no information that has the TSO, concerning the distribution grid, without being previously considered by the DSO.

Regarding DER information, TSO may not receive DER information or received it through DSO or directly by DER. The case where TSO do not receive that information seems to be not a real possibility since this information affects the roles of TSO. Spanish TSO receive it directly from DER and Austrian TSO receives it through DSO. Since Finn regulation is much closer to the Austrian regulation (see country groups 2.2.7 Countries

Type), it is supposed that TSO receives the information of DER that is within the transmission influence network. This information is received through DSO.

How is relationship DSO TSO

DSOs do not receive generation schedules of the distribution grid in advance. This is because Finland nowadays does not have any congestion in the distribution network. If some planed outages are planned and congestions appear the problem by negotiation or agreements with the customer in advance.

The other exchange of information of the other two countries analysed in this case study consider the influence network as an information exchange among TSO and DSO. For this reason, it is going to be considered that in Finland there is also exchange of the influence network information.

Constraints information may be exchanged or not. Comparing this country with the Austria and Spain, it is possible to see that the most similar country with Finland is Austria. Since Austria exchange constraints information among both system operators, it is going to be supposed that Finland also do it.

As previously considered in this section, TSO-DSO relationship considers that in case that the TSO needs to act over DER located at distribution level, these requests should be done through the DSO.

Set points of primary substations are agreed by both system operators.

7.1.2 Phase 2: Transition assessment

7.1.2.1 Technical assessment

MO-RES information

It will be necessary to change the actual requests channel that has the DSO with RES. With this new model it is the TSO who do the requests over DER. Then, the FMO-RES information must be redirected to the TSO instead to the DSO as it is now.

It is also necessary to change the existent channel that Finland has nowadays connecting DSO and DER to send real time information. With this model 1 it is TSO who receives real time information.

It will be needed to improve the channel used by DER to send bids for the different services. Nowadays DER cannot offer bids and this should be changed if this model is implemented.

TSO-DSO information

Nowadays DER services and information are being exchanged directly among DSO and DER. For this reason 4 new types of information will be needed among DSO and TSO to run model one:

- Requests/orders information from DSO to TSO does not exist now and will be needed.
- It will be needed to exchange information among both system operators regarding the forecasts of the grid.
- It will be needed to exchange information of the requests where TSO ask for permission to act over distribution grid and DSO accepts or reject the proposal.
- Since the information of DER now is being sent to the TSO, it is needed to redirect this information so is being sent from the TSO to DER.

Then, big changes in information exchanged among system operators should be done.

TSO necessities

TSO will need new systems that are able to cope with all the information of DER that will be managed by the TSO if this model is implemented. Now this information is being managed by DSOs.

The already existing flexibility operational market, which is being run by TSO nowadays, will be improved considering the new services that DER can provide.

DSO necessities

In terms of system improvements, DSOs will new to change their systems in order to be able to check the implementations that the TSO needs to do over the distribution grid.

DSO will not need to implement any new market. Nowadays, DSOs systems are prepared to act directly over DER in any scenario. This logic will change because, with this new model, DSOs can request in any scenario but the requests should be done through TSO.

7.1.2.2 Regulatory assessment

It will be changed the rights among both DSO and TSO. It is also necessary to change the rights that consider who receives the information of DER, in which direction (directly or through other agent)... Furthermore, with this model it should be consider the obligation for DER to provide bids for the different services that can be offered.

Regarding the markets there will not be needed to implement new markets; regulation will not change in this aspect.

7.1.2.3 Economical assessment

In economic terms, it is needed to increment quantity of information. For this reason, channels should be improved. Three new types of information should be considered and two types of info already exist but will need to be redirected.

The good point is that it is not necessary to implement new markets. However it is needed to update the existing one that will consider the new services provided by DER. Therefore, it is necessary to improve the transmission system operator systems in order to be able to accommodate all the information that have to go through the TSO.

In regulatory terms, changes are not economically big since it is not necessary to change regulation in order to create new market. It will be enough to change the rights and obligations of DSO and TSO in national regulation.

7.1.3 Phase 3: Decision variables assessment

It is necessary to change some issues (channels information, rights, obligations and market logic). However these changes are not that big as it will be to implement a new market run by the DSO. Furthermore, it is not necessary to do a lot of regulatory changes, which is other advantage of the implementation of this model in Austria.

One of the drawbacks with this model is that doing all these changes it is not internalised the whole cost of the request that TSO do over the network. However, current DG penetration is not high.

Roughly speaking, there are small costs that can be recovered considering the new services that system will use (postpone of reinforcements, quality and security of supply...)

With a situation in which the penetration DG is not high, it could be worth to implement centralised and extended dispatch coordination in Finland. However, it should be considered that levels of DG may increase in this country for distribution companies since the voltage levels that DSOs companies own are not despicable (up to 110kV).

7.2 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF DSO CUMULATIVE SERVICES COORDINATION MODEL IN FINLAND

7.2.1 Phase 1: Boundary conditions definition

Idem as in previous section 7.1 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF A CENTRALISED AN EXTENDED DISPATCHING IN FINLAND

7.2.2 Phase 2: Transition assessment

7.2.2.1Technical assessment

MO-DER information

The monitoring information of DER and the requests that DSO exchanges with DER in this model already exists nowadays in Finland. However, it will be needed to improve this channel in order to make possible to receive bids for the different services from DER to DSO.

TSO-DSO information

It is needed to improve the channel among system operators in order to make possible to exchange requests of services (one for each direction). Furthermore, the transmission form DSO to TSO in order to send the services that DSO can provide using the services of the agents located at distribution level should be implemented.

TSO necessities

TSO should be provided with a new operational system which allows not only to manage requests sent by DSOs but also to request services provided by DSOs.

DSO necessities

DSO needs improvements in its systems in order to be ready to run a new flexibility operational market while provide services to TSO (now DER services are being used just by direct call). This necessity considers new systems that are able to provide services to the TSO and consider request by the TSO.

7.2.2.2Regulatory assessment

The implementation of this model requires regulatory changes both in a European perspective and in a local (Finn) perspective.

From a European perspective it is necessary to change regulation in order not limit the running of a flexibility operational market just for the TSO. DSO needs to be allowed to carry with a flexibility operational market with the services provided by the distribution of its own area.

In local terms it is necessary to set the rights and obligations of each agent typical of this model as previously shown in chapter 2.

Regulatory changes necessary to implement for the Finn electrical model are fewer than in other countries. This is because Finn DSOs have already rights to manage DER directly in any scenario.

7.2.2.3Economical assessment

Four new types of information and the improvement of systems are necessary to consider for the implementation of this model. Also, it is important to consider the creation of a new flexibility operational market that is necessary for the DSO.

In regulatory terms, not small changes have to be produced in a European and local stages. This will have an incremental cost for the whole Europe in an ex-ante position.

Roughly speaking, if this model is implemented, it is necessary a lot of changes (both technical and regulatory) with the economical associated cost.

7.2.3 Phase 3: Decision variables assessment

So many implements have to be done if this model is implemented in this country: 4 new types and 2 changes of information, new flexibility operational market, necessity of changes in regulation...

However, looking for the long term and the system as a whole, this model brings a lot of improvements and increments of the efficiency in the whole system and particularly in the market such as the consideration of the whole cost when there are changes at the distribution level.

The possibility of market access for the DSO makes possible for distribution companies to choose whether reinforce the network or use a service provided by grid users is a tool that can be used by all the DSO necessities. This possibility was not accessible in previous model.

Distribution system logic in order to use DER services is much more advanced in this country than in others (use of DER services by DSO in any scenario). This makes easier the implementation of this model in countries like this one since rights and obligations and the systems are more prepared to achieve this new model.

The possibility of using all the services provided by all the agents of the grid independently where they are located (transmission or distribution grid) is other advantage of this model that compensate the initial investment in the long run.

It is possible to see that although Finn electrical system needs some initial changes, advantages for the long run are big enough in order to be able to make up for all the initial investments.

Furthermore, the changes needed in countries like this one are not that big as them are in countries like in Spain. This is because Finn DSOs receives monitoring information and request services directly as this model proposes.

With a situation in which the penetration DG is not high, it could not be worth to implement DSO cumulative services coordination in Finland since not many services will be provided by DG. However, it should be considered that levels of DG may increase in this country for distribution companies since the voltage levels that DSOs companies own are not despicable (up to 110kV).

Investments and cost for the model run may not compensate the efficiency achieved with the current situation. However, in a future situation with higher DG penetration, this model fits much better than the previous one.

7.3 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF COORDINATION AT A PRIMARY SUBSTATION IN FINLAND

7.3.1 Phase 1: Boundary conditions definition

Idem as in previous section 7.1 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF A CENTRALISED AN EXTENDED DISPATCHING IN FINLAND

7.3.2 Phase 2: Transition assessment

7.3.2.1 Technical assessment

MO-DER information

Idem as in previous section 7.1 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF A CENTRALISED AN EXTENDED DISPATCHING IN FINLAND

TSO-DSO information

Nowadays the Finn primary substations set up values are agreed through a bilateral contract among both TSO and DSO. Then, the unique information exchanged among both system operators already exists nowadays.

TSO necessities

Fiscally, TSO does not need to implement new systems with the implementation of this model in Spain. TSO will continue running a flexibility operational market. However, TSO operation logic will change because with this model TSO can only use the services located at its own voltage level.

Nowadays it is the DSO who manages all the information of DER. Nowadays, TSO consider DER information that is located in the influence network. This model sees that each SO has to consider just the information of its own voltage levels. For this reason, TSO will consider less information than what is considering now.

DSO necessities

The DSO will consider the same DER information that is considering now. However, it will be increased the services that DSO can use from DER. Furthermore, DSO systems have to consider the bids of the different services that each DER can provide. For this reason, improvements on the DSO systems are needed in order to be able to cope with all this new information.

DSO does not need to consider the influence transmission network anymore, which leads to a reduction of information managed in its systems.

DSO now uses DER services in any scenario directly. It should be considered the use of these services through a market instead through direct call (as it is being doing now).

7.3.2.2 Regulatory assessment

This model needs changes in a European framework in order to allow DSOs the rights of running a flexibility operational market with the distribution grid users.

It is necessary to change the local regulation giving the new rights and obligations to TSO, DSO and grid users. However, these changes are lower because the DSO is already allowed to act over DER directly in any scenario.

The regulatory changes needed in this model are the same as in the previous model but the rights and obligations among DSO and TSO are reduced to the agreement of the primary substations.

7.3.2.3 Economical assessment

Considering the improvement of channels, just one type of information among DSO and DER has to be implemented. The rest of the channels needed for this model already exist. It exists also the methods and the channels needed for the operation among both system operators.

Information systems are reduced since each system operator has to consider just the information of its own grid. Then, there is not a duplication of information as in other models may appear. However, in comparison with the actual situation of the Finn DSOs, DSO systems have to be improved to consider the parameters that correspond to the DER bids services.

It should be considered DSO systems that are necessaries to run a flexibility operational market. Economical necessities are not that big in countries like Finland where are considered all the services by DSO on direct call and the unique thing that must be improve is the management of these services through a market instead by direct call.

Regulation needs to be changed both in local and in European stages: it should be changed the new obligation/rights for the different agent. It should be given the right to the DSO to run a flexibility operational market. This leads also to an economical investment for the legal implementation of the model.

7.3.3 Phase 3: Decision variables assessment

It is true that in terms of initial necessities for the implementation of this model in Finland it is necessary much fewer investments than in the previous models proposed in this thesis: just one type of information will be exchanged and the implementation of the new flexibility operational market for the DSOs should be considered. To these technical necessities it is necessary to consider the regulatory changes in the European and local stages.

However, looking at the long term and at the system as a whole, a good point is the simplicity just having one type of information being exchanged among both system operators. This leads to small transition cost and maintenance for the long run. The worst point is the impossibility of using the services provided by the users that are not in its grid. Then, not all the advantages of the users for all the operators can be used.

Then, it is possible to see that while there are necessities in both technical and regulatory terms. Regulatory changes that are needed are big (European and local level) while the improvements achieved for the market and for the system are not that big for the long term (a key aspect is that it is lost the possibility of using all the services of the grid by both DSO and TSO).

Distribution system logic in order to use DER services are much more advanced in this country than in others (use of DER services by DSO in any scenario). This makes easier the implementation of this model in countries like this one since rights and obligations and the systems are more prepared to achieve this new model.

With a situation in which the penetration DG is not high, it could not be worth to implement coordination at a primary substation in Finland since not many services will be provided by DG and DSOs may have problems to achieve the agreed set values of the primary substations with almost none tools. However, it should be considered that levels of DG may increase in this country for distribution companies since the voltage levels that DSOs companies own are not despicable (up to 110kV).

7.4 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF A CENTRALISED AN EXTENDED DISPATCHING IN AUSTRIA

7.4.1 Phase 1: Boundary conditions definition

Distribution voltage level

In Austria, distribution companies own LV, MV (10, 20 and 30kV) and HV (110kV).

DG penetration

The penetration of distributed generation is low (both for Wind and PV).

Operations over RES

Austrian DSOs are allowed to act directly over DER in two different situations: either constraints or emergency scenario. DSO when acts over DER, services are purchased through direct call at a fix price. Under constraints scenario, DSOs can provide new set points to DG.

The other situation where DSO can act is when the system is under an emergency scenario. In this case DSO can provide new set points, reduce/increase active power, or switch off the DG. Looking at DSR, DSO is allowed to reduce/increase consumption or switch them off. This change is done directly without permission of the TSO. Furthermore, TSO cannot act over DER. Although DSO are legally allowed to do this operations explained above, they are not incentivised economically.

TSO is not allowed to act over DER resources. It is just the DSO the agent allowed to act over DER located at distribution level.

Data of RES

Information of the DER is sent to the distribution companies directly. Data of RES is sent to DSO real time monitoring, structural and operational information. Both DER services offers and real time information is received by DSO and not considered by the TSO. TSO receives DER information neither directly nor through the DSO.

Data exchanged DSO-TSO

Austria is the unique country in the European Union that receives the Operational Schedules in advance. DSOs receive the schedule for large generators (>50MW). This information is used in order to check congestions and provide restrictions to generators in case of constraints or emergency scenario.

TSO informs the DSO about the schedule planned and measured values at the interconnecting substation. DSO considers these constraints exchanged before DER services are requested.

Regarding the information that the TSO send to the DSO, Austrian DSOs send real time, structural and schedule operation information to the TSO. Austria receives from DG and from TSO real time, structural and scheduled data related to operation.

The DSO informs the TSO about the schedule planned and measured values at the interconnecting substation. TSO consider this schedule in order to run the system flexibility operational market. DSOs send to TSO is structural, market and operational data but not real time information.

7.4.2 Phase 2: Transition assessment

7.4.2.1Technical Assessment

MO-DER information

It will be necessary to change the actual information that goes from DSO to RES and vice versa. With this new model it is the TSO who do the requests over DER. Then, the FMO-RES information must be redirected to the TSO instead to the DSO as it is now.

It is also necessary to change the existent channel that Austria has nowadays connecting DSO and DER to send real time information. With this model 1 it is TSO who receives real time information.

It will be needed to consider the offers of DER (bids) regarding the services that they are offering. Nowadays, DER cannot offer bids and this should be changed if this model is implemented.

TSO-DSO information

Since nowadays DER services and information are being exchanged directly among DSO and DER, the 3 new types of information will be needed among DSO and TSO to run model one:

- Requests/orders information from DSO to TSO does not exist now and it will be needed to be considered the information that makes possible for the DSO to act through TSO over DER.
- It will be needed to consider new information that TSO checks with the DSO for the new TSO implementations in the distribution grid in order not produce any subsequent constraint in distribution network that cannot be solved.
- Information of DER that is being sent to the DSO should be redirected. With the new model it will be considered that DER information should be sent to the TSO.

The channel among both system operators where are exchanged constraints of their networks now exists and it will be used with the implementation of this new model.

TSO necessities

TSO will need new systems that are able to cope with all the information of DER that will be managed by the TSO if this model is implemented.

The already existing flexibility operational market, which is being run by TSO nowadays, will be improved considering the new services that DER can provide.

DSO necessities

In terms of system improvements, DSOs will new to change their systems in order to be able to check the implementations that the TSO needs to do over the distribution grid.

DSO will not need to implement any new market.

7.4.2.2 Regulatory assessment

It will be changed the rights among both DSO and TSO. It is also necessary to change the rights that consider who receives the information of DER, in which direction (directly or through other agent)... Furthermore, with this model it should be consider the obligation for DER to provide bids for the different services that can be offered.

Regarding the markets there will not be needed to implement new markets; regulation will not change in this aspect.

7.4.2.3 Economical assessment

In economic terms, it is needed to implement three new information types that should be considered and two that already exists and they will need to be redirected.

The good point is that it is not necessary to implement new markets. However it is needed to update the existing one that will consider the new services provided by DER. Therefore, it is necessary to improve the transmission system operator systems in order to be able to accommodate all the information that have to go through the TSO.

In regulatory terms, changes are not economically big since it is not necessary to change regulation in order to create new market. It will be enough to change the rights and obligations of DSO and TSO in national regulation

7.4.3 Phase 3: Decision variables assessment

It is necessary to change some issues (channels, rights, obligations and market logic). However these changes are not that big as it will be to implement a new market run by the DSO. Furthermore, it is not necessary to do a lot of regulatory changes, which is other advantage of the implementation of this model in Austria. One of the drawbacks with this model is that doing all these changes it is not internalised the whole cost of the request that TSO do over the network.

Roughly speaking, there are small costs that can be recovered considering the new services that system will use (postpone of reinforcements, quality and security of supply...) With a situation in which the penetration DG is not high, it could be worth to implement centralised and extended dispatching coordination in Finland since penetration of DG is not very high and the duplication of information (the main drawback) will be not very high. Furthermore, there is already one flexibility operational market being run by the TSO and channels connecting DSO-TSO and TSO-DER are already implemented.
However, it should be considered that levels of DG may increase in this country for distribution companies since the voltage levels that DSOs companies own are not despicable (up to 110kV).

Investments and cost for the model run may not compensate the efficiency achieved with the current situation. However, in a future situation with higher DG penetration, this model fits much better than the previous one.

7.5 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF DSO CUMULATIVE SERVICES COORDINATION MODEL IN AUSTRIA

7.5.1 Phase 1: Boundary conditions definition

Idem as in previous section 7.4 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF A CENTRALISED AN EXTENDED DISPATCHING IN AUSTRIA

7.5.2 Phase 2: Transition assessment

7.5.2.1 Technical assessment

MO-DER information

The monitoring information of DER and the requests that DSO exchanges with DER in this model already exists nowadays in Austria. However, it will be needed to improve the already existing channel to make possible that DER bids for the different services are received DSO.

TSO-DSO information

It is needed to include two more types of information among both system operators that makes possible to exchange requests of services (one for each direction). Furthermore, it is needed to include information regarding the services that DSO can offer to the TSO using the services of the agents located at distribution level.

TSO necessities

TSO should be provided with a new operational system which allows not only to manage requests sent by DSOs but also to request services provided by DSOs.

DSO necessities

DSO needs improvements in its systems in order to be ready to run a new flexibility operational market while provide services to TSO (now DER services are being used just by direct call). This necessity considers new systems that are able to provide services to the TSO and consider request by the TSO.

7.5.2.2 Regulatory assessment

The implementation of this model requires regulatory changes both in a European perspective and in a local (Austrian) perspective.

From a European perspective it is necessary to change regulation in order not limit the running of a flexibility operational market just for the TSO. DSO needs to be allowed to carry with a flexibility operational market with the services provided by the distribution of its own area.

In local terms it is necessary to set the rights and obligations of each agent typical of this model as previously shown in chapter 2.

7.5.2.3 Economical assessment

Four new types of information and the improvement of systems are necessary for the implementation of this model. Also, it is important to consider the creation of a new flexibility operational market that is necessary for the DSO.

In regulatory terms, not small changes have to be produced in a European and local stages. This will have an incremental cost for the whole Europe in an ex-ante position.

Roughly speaking, if this model is implemented, it is necessary a lot of changes (both technical and regulatory) with the economical associated cost.

7.5.3 Phase 3: Decision variables assessment

So many implements have to be done if this model is implemented in this country: 4 new types of information and 2 more types with changes, new flexibility operational market and necessity of changes in regulation should be considered as transitional changes.

Looking for the long term and the system as a whole, this model brings a lot of improvements and increments of the efficiency in the whole system and particularly in the market such as the consideration of the whole cost when there are changes at the distribution level.

The possibility of market access for the DSO makes possible for distribution companies to choose whether reinforce the network or use a service provided by grid users is a tool that can be used by all the DSO necessities. This possibility was not accessible in previous model.

The possibility of using all the services provided by all the agents of the grid independently where they are located (transmission or distribution grid) is other advantage of this model that compensate the initial investment in the long run.

With a situation in which the penetration DG is not high, it could be worth to implement centralised and extended dispatching coordination in Finland since penetration of DG is not very high and the duplication of information (the main drawback) will be not very high. All the advantages of the model will be really used with medium-high penetration of DG.

However, it should be considered that levels of DG may increase in this country for distribution companies since the voltage levels that DSOs companies own are not despicable (up to 110kV).

Investments and cost for the model run may not compensate the efficiency achieved with the DG current situation for the long term with a new model. However, in a future situation with higher DG penetration, this model fits much better than the previous one.

7.6 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF COORDINATION AT A PRIMARY SUBSTATION IN AUSTRIA

7.6.1 Phase 1: Boundary conditions definition

Idem as in previous section 7.4 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF A CENTRALISED AN EXTENDED DISPATCHING IN AUSTRIA

7.6.2 Phase 2: Transition assessment

7.6.2.1 Technical Assessment

MO-RES information

Idem as the issues related in 7.5 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF DSO CUMULATIVE SERVICES COORDINATION MODEL IN AUSTRIA

TSO-DSO information

Nowadays the Austrian primary substations set up values are regulated by both regulatory and bilateral agreements among TSO DSO. Although active power is set by regulation, the rest of terms are agreed among both system operators (reactive power withdrawal, voltage value and quality of signal).

For this reason, it will not be necessary to improve new systems or channels among both system operators.

TSO necessities

Fiscally, TSO does not need to implement new systems with the implementation of this model in Spain. TSO will continue running a flexibility operational market. However, TSO operation logic will change because with this model TSO can only use the services located at its own voltage level.

Nowadays it is the DSO who manages all the information of DER. Nowadays, TSO consider DER information that is located in the influence network. This model sees that each SO has to consider just the information of its own voltage levels. For this reason, TSO will consider less information than what is considering now.

DSO necessities

The DSO will consider the same DER information that is considering now. However, it will be increased the services that DSO can consider from DER. Furthermore, DSO systems have to consider the bids of the different services that each DER can provide. For this reason, improvements on the DSO systems are needed in order to be able to cope with all this new information.

DSO does not need to consider the influence transmission network anymore, which leads to a reduction of information managed in its systems.

7.6.2.2 Regulatory assessment

This model needs changes in a European framework in order to allow DSOs the rights of running a flexibility operational market with the distribution grid users.

In similar lines of the previous models it is necessary to change the local regulation giving the new rights and obligations to TSO, DSO and grid users.

The regulatory changes needed in this model are the same as in the previous model but the rights and obligations between DSO and TSO are reduced to the agreement of the primary substations.

7.6.2.3 Economical assessment

Considering the information exchange, just one more type of information among DSO and DER has to be adapted. The rest of the information needed for this model already exist.

Information systems are reduced since each system operator has to consider just the information of its own grid. Then, there is not a duplication of information as in other models may appear. However, in comparison with the actual situation of the Austrian DSOs, DSO systems have to be improved to consider the parameters that correspond to the DER bids services.

It should be considered that the Austrian DSOs have to run a flexibility operational market. For this reason, DSOs will need the systems and the logical procedures that make possible to run these markets. Nowadays, Austrian DSOs consider some requests over DER on direct call at a fixed price. Considering the actual situation, it is necessary to increase the actions that DSO can request to DER and manage all them through a new operational system.

Regulation needs to be changed both in local and in European stages: it should be changed the new obligation/rights for the different agent. It should be given the right to the DSO to run a flexibility operational market. This leads also to an economical investment for the legal implementation of the model.

7.6.3 Phase 3: Decision variables assessment

It is true that in terms of initial necessities for the implementation of this model in Austria it is necessary much fewer investments than in the previous models proposed in this thesis: just one single type of information and the implementation of the new flexibility operational market for the DSOs. To these technical necessities it is necessary to consider the regulatory changes in the European and local stages.

However, looking at the long term and at the system as a whole, a good point is the simplicity just having one type of information being exchanged among both system operators. The worst point is the impossibility of using the services provided by the users that are not in its grid. Then, not all the advantages of the users for all the operators can be used.

Then it is possible to see that while there are necessities in both technical and regulatory terms. Regulatory changes that are needed are big (European and local level) while the improvements achieved for the market and for the system are not that big for the long term (a key aspect is that it is lost the possibility of using all the services of the grid by both DSO and TSO).

With a situation in which the penetration DG is not high, it could be worth to implement centralised and extended dispatching coordination in Austria since penetration of DG is low and distribution companies will have not a lot of tools to manage the grid and meet the set points of the primary substations using services of DG.

However, it should be considered that levels of DG may increase in this country for distribution companies since the voltage levels that DSOs companies own are not despicable (up to 110kV).

7.7 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF A CENTRALISED AN EXTENDED DISPATCHING IN SPAIN

7.7.1 Phase 1: Boundary conditions definition

Number of distribution companies.

There are around 300 distribution companies in Spain. However, just 5 have around 95% of the consumers.

Distribution voltages

Spanish electrical grid owns one of the highest voltage levels in Europe: LV, MV (11, 15, 20 and 30kV) and HV (45, 66,110,132kV).

DG penetration

The penetration of DG in Spain is higher that most of the European countries analysed (in terms of wind and PV panels): penetration of wind generation is high while PV penetration is still low.

Operations over RES

Spanish DSO are not allowed to act neither DG nor RES directly. DSOs have to operate through the TSO. TSO can act over them directly because of its own necessities and also considering requests of the distribution companies

Actions over RES can be considered in short term when there are constraints or under an emergency scenario. In long term, reinforcement of the grid should be considered in case of constraints scenario.

TSO is the agent engaged to run the flexibility operational market. However, RES cannot offer operational services to this market as conventional generation do.

Data of RES

The DSO receives from DG just structural information of the installation. This is because DSO is the agent that has to accept the connection.

Real time Information that DSO receives is always received through TSO (who receives directly from RES users). Real time information is never done directly RES-DSO. Nowadays, just the active power is sending just the active power of the generators above 1MW.

Exchange DSO-TSO

Spanish DSOs are not entitled to receive the operational schedules in advance in order to calculate the necessities/constraints that may appear. Nowadays, these countries that do not receive schedules it is because in normal situation there does not exists congestion in

DSO network. TSO have the operational schedules because it carries out what is called PDVD (definitive viable daily schedule) considering the market program provided by the flexibility market operator, constraints and complementary services.

Spanish TSOs send real time information (the value of active power for generators above 1MW), structural and operational data to the DSO.

There is a unique flexibility operational market that is being run by the TSO. DSO can neither use nor provide services to this market. DSO can just request actions to the TSO in case of an emergency.

7.7.2 Phase 2: Transition assessment

7.7.2.1Technical assessment

MO-RES information

The information TSO-RES (for this model) needed is already implemented. This channel is managing the same information that it will be considered in the future with this new model. Nowadays it is the TSO who receives the information of RES. Real time information, and requests orders information is already being exchanged with the TSO.

However, there is a necessity of a new type of information among TSO and RES. This new information type is necessary in order to send the bids of the services that they are able to provide.

TSO-DSO information

DSO has nowadays a channel prepared to be used when is necessary to act over RES. However, this channel is possible to be used just in case of emergency. An improvement of this channel is necessary in order to be used when it is preferable to use a service from RES instead of reinforce the grid.

There is the necessity to consider information provided by the DSO regarding the constraints of the distribution grid. This information is not being considered nowadays.

Furthermore, it is necessary that the DSO receives in advance the generation schedule (this is not being done nowadays)

Furthermore, it is necessary to consider information that TSO will send to the DSO in order to ask for permission when changes are needed in the distribution grid.

In terms of information exchanged, TSO nowadays just send the active power of RES but not the rest of variables. Just active power may be not enough to manage the grid when more agents appear in the distribution grid. DSO may need to have more information from the RES through the TSO.

TSO necessities

TSO will need a system that is able to cope with all the information of RES. Since TSO will be a key agent and all the information have to pass through it, an improvement of the systems either in capacity and speed will be needed.

TSO will continue running the flexibility operational market as it is doing now. However, it will be considered the new services that DER can provide.

DSO necessities

Systems of DSO will be improved since it will need to consider more options and tools. However the system improvements of the DSO will be negligible in comparison with the improvement necessaries for the TSO.

DSO will not be running any flexibility operational market as it is doing now.

7.7.2.2 Regulatory assessment

Regulatory changes are needed in order to consider rights and obligations regarding information exchanges. It is necessary to implement changes giving to the TSO, DSO and RES the rights and obligations presented in the Chapter 2.

Same flexibility operational markets are now and with the proposed model. An increment of unbundling because of the appearance of new markets is not necessary.

7.7.2.3 Economical assessment

It is necessary to consider new types of information and also improve two types that already exist. Furthermore, the system of the TSO needs an improvement as previously said.

Although it is necessary the channels improvement, the good point for this model is the small regulatory changes that are needed. Furthermore, there is not necessity of implementation of new flexibility operational market.

7.7.3 Phase 3: Decision variables assessment

This model has not a big changes regarding neither to infrastructure nor to the regulation. For this reason economically is cheap to implement.

Looking at the long term and assessing the whole system, this model has the disadvantage of the duplicity of distribution RES information which has to be in both TSO and DSOs systems. This duplicity will be higher in terms of quantity due to the high penetration of DG in Spain.

Furthermore, this model does not fit in countries like in Spain where there are a lot of possibilities to use DER services and the use of those services by the TSO may lead to subsequent necessities for the DSO. This will lead to an inefficient use of DER resources. This drawback will be for any country. However, it will be more important in countries like in Spain due to the high amount of DG penetration.

7.8 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF DSO CUMULATIVE SERVICES COORDINATION MODEL IN SPAIN

7.8.1 Phase 1: Boundary conditions definition

Idem as in previous section 7.7 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF A CENTRALISED AN EXTENDED DISPATCHING IN SPAIN

7.8.2 Phase 2: Transition assessment

7.8.2.1Technical assessment

MO-RES information

Since DSO is the agent who runs the flexibility operational market within this model, the channel that carries real time information of DER and the operational requests from TSO to RES should be changed. If this model is implemented, both types of information will be received from DSO instead from TSO.

Furthermore it is necessary to consider new information being sent by RES regarding the services that they are willing to provide.

TSO-DSO information

Nowadays there is not a possibility from DSO to offer services to the TSO neither of requesting services among TSO and DSO. All the information among TSO and DSO is new information if this model is implemented.
Furthermore this system has to be able to read and choose the cheapest service

TSO necessities

TSO should be provided with a new operational system which allows not only to manage requests sent by DSOs but also to give request to the DSOs.

DSO necessities

DSO needs improvements in its system in order to be ready to run a new flexibility operational market while provide services to TSO. This necessity considers new systems that are able to cope with the information of DER, provide services to the TSO and consider request provided by the TSO.

7.8.2.2Regulatory assessment

The implementation of this model requires regulatory changes both in a European perspective and in a local (Spanish) perspective.

From a European perspective it is necessary to change regulation in order not limit the running of a flexibility operational market just for the TSO. DSO needs to be allowed to carry with a flexibility operational market with the services provided by the distribution of its own area.

In local terms it is necessary to set the rights and obligations of each agent typical of this model as previously shown in chapter 2.

7.8.2.3Economical assessment

Improvement of channels and systems are necessary for the implementation of this model. Also, it is important to consider the creation of a new flexibility operational market that is necessary for the DSO.

In regulatory terms, not small changes have to be produced in a European and local stages. This will have an incremental cost for the whole Europe in an ex-ante position.

Roughly speaking, if this model is implemented, it is necessary a lot of changes (technical and regulatory) with the economical associated cost.

7.8.3 Phase 3: Decision variables assessment

So many implements have to be done if this model is implemented in this country: 4 new information types and 2 more with changes, new flexibility operational market, changes in regulation...

However, looking for the long term and the system as a whole, this model brings a lot of improvements and increments of the efficiency in the whole system and particularly in the market such as the consideration of the whole cost when there are changes at the distribution level.

Furthermore, the high voltage levels that Spanish DSOs owns and the high penetration that wind have in this country, makes this model more optimal for this country than centralised and extended dispatching or primary substation coordination models.

The possibility of market access for the DSO makes feasible for distribution companies to choose whether to reinforce the network or use a service provided by grid users is a tool that can be used by all the DSO necessities. This possibility was not accessible in previous model.

The possibility of using all the services provided by all the agents of the grid independently where they are located (transmission or distribution grid) is other advantage of this model that compensate the initial investment in the long run.

It is possible to see that although Spanish electrical system needs some initial changes, but advantages for the long run could be big enough in order to be able to make up for all the initial investments.

Since there are 5 companies out of 300 that own 95% of the distribution grid, there could be market power if this model is implemented. Distribution companies could take advantage of this situation increasing prices for the services provided by the DSO to the TSO as a virtual power plant.

7.9 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF COORDINATION AT A PRIMARY SUBSTATION IN SPAIN

7.9.1 Phase 1: Boundary conditions definition

Idem as in previous section 7.7 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF A CENTRALISED AN EXTENDED DISPATCHING IN SPAIN

7.9.2 Phase 2: Transition assessment

7.9.2.1Technical assessment

MO-RES information

Idem as the issues related in 7.8 APPLICATION OF METHODOLOGY CONSIDERING THE IMPLEMENTATION OF DSO CUMULATIVE SERVICES COORDINATION MODEL IN SPAIN

TSO-DSO information

Nowadays the Spanish primary substations set up values are regulated by law. This model proposes an agreement among TSO and DSO for these primary substations. For this reason, it is necessary to improve the channel among both TSO and DSO in order to make possible the consideration to agree the set values of the primary substations taking into account the possibilities that each one of the agents have in its own grid.

TSO necessities

Fiscally, TSO does not need to implement new systems with the implementation of this model in Spain. TSO will continue running a flexibility operational market. However, TSO operation logic will change because with this model TSO can only use the services located at its own voltage level.

DSO necessities

The DSO will have available much more information than what is having now in terms of RES. For this reason improvements on the DSO systems are needed in order to be able to cope with all this new information.

7.9.2.2Regulatory assessment

This model needs changes in a European framework in order to allow DSOs the rights of running a flexibility operational market with the distribution grid users.

In similar lines of the previous models it is necessary to change the local regulation giving the new rights and obligations to TSO, DSO and grid users.

The regulatory changes needed in this model are the same as in the previous model but the rights and obligations between DSO and TSO are reduced to the agreement of the primary substations.

7.9.2.3Economical assessment

The technical changes needed are not that expensive to implement in comparison with the previous models. Channel among both TSO and DSO is reduced down to the minimum with unique agreement of the primary substation.

Systems information is reduced since each system operator has to consider just the information of its own grid. Then, there is not a duplication of information as in other models may appear. However, in comparison with the actual situation of the Spanish DSO, it will be necessary to improve DSO systems in order to be able to cope with the parameters that correspond to the RES users of its distribution grid.

In terms of market running there is a necessity of implementation and run a flexibility operational market by the side of DSO.

Regulation needs to be changed both in local and in European stages. This leads also to an economical investment for the legal implementation of the model

7.9.3 Phase 3: Decision variables assessment

It is true that in terms of initial necessities for the implementation of this model in Spain it is necessary much fewer investments than the second model proposed in this thesis: just one new type of information, the redirection of two information types and the implementation of the new flexibility operational market for the DSO. To these technical necessities it is necessary to consider the regulatory changes in the European and local stages.

However, looking at the long term and at the system as a whole, a good point is the simplicity just having one type of information among both system operators. The worst point is the impossibility of using the services provided by the users that are not in its grid. Then, not all the advantages of the users for all the operators can be used. This drawback it is a real inefficiency for the Spanish system due to the high amounts of wind and the low PV penetration will be not used for system services.

Then it is possible to see that while there are necessities in both technical and regulatory terms. Regulatory changes that are needed are big (European and local level) while the improvements achieved for the market and for the system are not that big for the long term (a key aspect is that is lost the possibility of using all the services of the grid by both DSO and TSO as previously mentioned).

In the Spanish case where 95% of the distribution grid is owned by 5 out of 300 distribution companies, this model can have more sense than the one where the distribution companies act as a virtual power plant. This is because with this coordination at a primary substation DSO provide pass the services that are possible to request to the TSO but not acting as a virtual power plant.

8 CASE STUDIES COMPARISON

Considering the 9 case studies (3 countries per 3 models), it is possible to see that different costs are necessary depending on the country and the model that is analysed to be implemented. There is not a single model that fits perfectly in all the European countries with all the different current situations.

Regarding the transition costs, the economical necessities depend on the differences among the model that is analysed and the country where it will be implemented. This difference varies along the different cases considered. There is one clear example when the first model is analysed in Finland in comparison with the adaptation of First model to Spain: it is much more expensive the adaptation information and local regulation if first model is implemented in Finland than in Spain due to the current situation in each country.

On the other hand, if the same countries are considered but the model implemented is a cumulative services model, it is possible to see that there will be lower changes in Finland than in Spain due to the current situation in that countries. There is not a model that has lower its changes more than the rest. On the other hand, there is not a country that adapts better to the different models. Particular situations should be studied case by case considering the couple country-model.

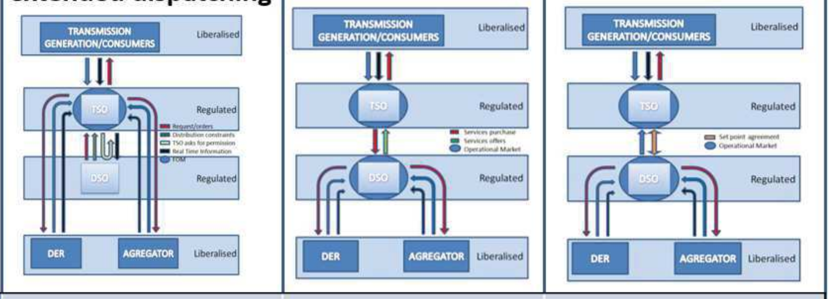
In countries where there are not a lot of resources available in the distribution grid, it will have more sense to go for a model like the first one where everything is centralised by the TSO and the operational costs for the long run are reduced (just one operational model is being run). This model fits better in countries where the distribution company will not request a lot of services from DER: maybe because DSO manages just very low voltage levels or because there are not a lot of DER resources in that country.

Considering the long run, it is possible to see that in countries with more distributed energy resources, it has more sense to implement models like second or the third one where both system operators are able to consider system services provided by any user of the grid.

The possibility to implement cumulative services or primary substation model depends on the number of distribution companies and the share of the DSOs in the selected country. A cumulative model can be considered in countries where there is enough number of DSO companies and they have similar size so there is enough competition among them to provide services to the TSO. If not, it should be considered the primary substation model as a possible solution. This last model restricts the possibility to take market power by the DSOs.

To sum up, in order to achieve the best model for each country, it should be achieved a solution where the transition costs and the long run costs are worth looking at the levels of DER penetration in the system (both current and future) and the market power that DSO can have with the new model. There is not '*one size fit all'* solution.

It has been represented in Figure 18 a comparison of the different models and the main differences for the long run when these models are applied in a country.



		Centralised and extended dispatching	DSO cumulative services	Coordination at primary substation
Model Definition	Who acts directly over DER?	TSO	DSO	DSO
	Who run markets?	TSO runs OFM	TSO & DSO runs OFM	TSO & DSO OFM
	DSO incentivised to offer services to TSO?	NO	YES, DSO is incentivised to offer services to TSO	Depending on the economical regulation
In which countries does it fits better?	DER penetration	Low DER services	High DER services	High DER services
	DSO profiles	Not an issue	Competition among DSO	Not an issue
	Unbundling	Same as now	May be higher	May be higher

Figure 18: Models comparison.

In order to get a full analysis it has to be considered the table data (which consider the advantages for the long run) with the transmission costs that depends on the current situation of each country and are cheaper as soon as the country have more similarities with the model.

9 CONCLUSIONS

9.1 Conclusions

In a first stage, It has been analysed the current roles, objectives and tools that SOs have nowadays in order to manage the European electrical system. It have been analysed that the actual tools that SOs have nowadays may change due to DER penetration and the improvement of ICT.

Adding up the current roles, objectives and tools that have both DSO and TSO with the increment of DER and improvement of ICT it is possible to draw the future of the European network management. In future scenarios they will have same roles and objectives as they have today. However, both system operators may have more tools than what they have today if they can use DER services.

Both system operators will be willing to use those services in order to have more tools for the management of the system. In order to make possible that DER services are being used by both system operators maximising the tools for them, it has defined a coordination model among DER, DSO and TSO. It has been identified the coordination issues that have to be defined:

- Who can act over DER? If either DSO or TSO is going to be in the hierarchical level just above DER, information that is going to be received, information that is going to be sent... Just one SO must be allowed to act directly in order to avoid requests that are mutually selective.
- How the other SO, that cannot act directly over DER can consider DER, services in daily operations. Information that both system operators are going to be exchanged, actions that can consider...

Once identified the coordination issues that should be considered in future scenario, it has been proposed three different models that are feasible with the appearance of DER and ICT. Those models solve, using different approaches, the coordination issue with different advantages and drawbacks First model is an extended version of a traditional model where TSO manage the whole system as a central counterparty. TSO is the unique agent that can act over DER directly. In a second model, each SO can act over the users of its grid. In this second model DSO can provide services to the TSO as a virtual power plant do. There is a last model in which each SO can act over the users of its grid. In this third case, it is the same as the previous one but DSO is not incentivised to use DER services and there is a coordination on which services are necessary to activate. This coordination may be done in real time by automatic means.

A systematic methodology is proposed to be followed by Regulatory Authorities when new future models are analysed. The methodology is composed by three different steps:

1. Analysis of boundary conditions: It should be analysed the current conditions of the country indifferent aspects: market power of DSOs. Voltage levels of distribution companies, current level of DER penetration, which are the operations that can be done over DER, who is being considered the data of DER, the information and the requests exchanged among DSO and TSO.
   This step will give the conditions of an initial stage that will be compared with the necessities of the different models that are analysed for the country.
2. Transition assessment: Should be analysed the different issues necessary to implement the new model in the country considered. The evaluation has three different approaches: technical, regulatory and economical assessment.
3. Decisions variables assessment: It is considered the previous transition assessment and the advantages that each model will bring. It is balanced the necessities that the model requires in the transition with the long term possibilities that the model will bring. Furthermore, it is analysed if the model analysed is worth to be implemented considering the voltage levels of the distribution companies and current DER penetration.

To test the designed methodology robustness, it has been considered different real case studies. It has been applied this methodology with three different coordination models to be implemented in three different European countries.

In order to apply the case study into three real country situations, it has been analysed the current situation in 12 countries of the European Union in order to draw an idea of how Europe system is nowadays. With this analysis, the countries were grouped in 3 different blocks depending on how the actions over DER are being considered nowadays. One country of each block was considered as representative. The representative country was necessary for further analysis and application of the methodology.

The comparison of the results of the different models considered in different representative countries shows that there is not ‘one size fits all’ model. There is not one country that is the cheapest for any country. Transition costs of each model depend on the country where the model is implemented.

Depending on the amount of DER in each country, it may be necessary to implement a different operational model that gives the opportunity to both system operators to use the services of DER in a different way. Centralised and extended dispatching model fits better for countries where there are not DER users able to provide services to the system. DSO cumulative services model and Coordination at primary substation model fits better in countries where it is expected high amount of distributed energy resources. In countries where some DSOs have high market power it is better to implement a Primary substation coordination model since this approach limits the decisions that DSO can take unilaterally.

Since the core of the change is being produce for the relationship of TSO and DSO and both system operators are regulated sectors, it is very important to provide precise signals to the system from a regulatory perspective. Regulation issues have been considered along the thesis. There is a chapter which deals with different aspects such as: general regulatory requirements, why it is preferable to have a common regulation across Europe, which are the regulatory necessities among FMO-grid users and DSO-TSO, remuneration and unbundling. It is recommended to read that chapter in order to get more information regarding that issue.

In order to give the correct signals, it is very important to define a proper the remuneration scheme regulation. In terms of remuneration, regulation should make a shift from an asset base scheme to a scheme that also consider the operations and management of the system activities related with flexibility market uses.

In terms of DSO unbundling it might be required to improve regulation depending on the model implemented. A scheme where the DSO has to complete a process like the European for the TSO might be a possible option. DSOs will have the possibility to follow a full separation, separate system operation and assets (such as ISO) or to be a distribution system operator owning the assets and belonging to a vertically integrated company with special rules to guarantee its independence (ITO).

9.2 Limitations

The analysis that have been done in this Master Thesis is a qualitative analysis. The methodology proposed also considers just qualitative analysis. Depending on the weights allocated to the transition necessities and the advantages and drawback consider for the long term results may be different.

In the case study developed with the methodology proposed by this thesis, it was considered the information provided by national network codes, European network codes, Eurelectric survey and a survey done to an Austrian electric company. However, due to the lack of information some assumptions were considered for the Finn case.

9.3 Future research

As previously said in the previous section, this document analyses different models for the different countries with a qualitative approach. The methodology proposed in project may be transposed into a quantitative methodology using a CBA for the analysis of the transition costs in each country.

This transition cost will be different depending which users that will have devices to control the different services that they are offering to the FMO. As previously mentioned in this master thesis, it should be evaluated which users (both generators and consumers) are going to have devices to control their power generated/consumed.

If different models are implemented to different countries along Europe, it should be studied how it affects to the coordination and to the security of supply of the European electric network.

Models proposed in this master thesis has been analysed from an operational point of view. However, it should be also considered in future research how the different models behave for different issues such as a blackout scenario.

The master thesis considers three different models for a future coordination among both system operators. However, the methodology considered in this thesis can also be applied to new models that may appear or even to a combination of the models considered in this thesis. The use of the three different models in this master thesis does not mean that European electric system have to change to one of the proposed models.

Due to the narrow relationship that DSO may have with liberalised agents, this master thesis sees that it is enough, if it is correctly implemented, a regulatory certification process similar to the one that exists for ITOs at the European transmission electricity level. An audited process may be enough to ensure the role of market facilitator, if properly implemented. However, further research can be done in order to study deeply if the coordination models need more unbundling for the DSO.

Regulation regarding allowed incomes may be changed for the distribution companies in order to incentivise DSOs to operate the grid and consider services of DER instead to invest in new grid. This issue should be studied in order to see how it affects to the coordination and which remuneration process is more efficient depending on the models.

After this technical master thesis, pilot projects can be developed considering the three different models in order to study the necessities and the adaptations from a practical point of view.

10 BIBLIOGRAPHY

50Hertz, 2012. *Requierements for a Smart Grid From the perstive of a TSO.,* s.l.: s.n.

Acer - A Bridge to 2025, 2014. *The Bridge to 2025,* s.l.: s.n.

Ahamdi, S. N. H. J., 2012. A methodology for the redesign of frequency control in modern power systems in presence of renewable energy resources.

BDEW, 2014. Smart Grids Traffic Light Concept.

California Independent System Operator and Caltech Resnick Institute, 2014. 21st Century Electric Distribution System Operations.

Ceer - Advice Demand-Side Flexibility. , 2014. CEER Advice on Ensuring Market and Regulatory Arrangements help deliver Demand-Side Flexibility.

CEER - Future role of DSOs. , 2014. *The future role of DSOs,* s.l.: s.n.

Chunyu ZHANG, Y. D. N. C. N. P. P. J. Ø., 2014. FLECH - A Danish market solution for DSO congestion management through DER flexibility services.

Delfanti, G. O., 2014. The new role of DSOs, ancilliary services from RES towars a local dispatch.. *Cired Workshop.*

Directive 2009/72 (2009).

Directive 2012/27/EU (n.d.).

DRIP Project, 2014. DRIP Project.

EDP Distribuicao & EDSO , 2015. *Brief overview on different models for the coordination of flexibility between DSOs and TSOs,* s.l.: s.n.

EDSO, Flexibility: The role of DSOs in tomorrow's electricity market, 2014. *Flexibility: The role of DSOs in tomorrow's electricity market,* s.l.: s.n.

EG3, 2015. *Regulatory Recommendations for the Deployment of Flexibility,* s.l.: s.n.

ENTSO-E, 2015. *Towards smarter grids: Developing TSO and DSO roles and interactions for the benefit of consumers ,* s.l.: s.n.

Eurelectric- Active Distribution System Management, 2013. *Active Distribution System Management - A key tool discussion paper,* Brussels: s.n.

Eurelectric -Designing fair and equitable market , 2015. Designing fair and equitable market rules for demand response aggregation.

Eurelectric, 2012. Network Codes for System Operation.

Eurelectric, 2013. *Power Distribution in Europe: Facts and firgures,* s.l.: s.n.

Eurelectric, 2014. *Eurelectric Survey.* s.l.:s.n.

EURELECTRIC, 2015. *CEER public consultation: "The future role of DSO" - A Eurelectric Response Paper.,* s.l.: s.n.

European Parliament and council 2009/713, 2009. *REGULATION (EC) No 713/2009 establishing an Agency for the Cooperation of Energy Regulators,* s.l.: s.n.

European parliament and council 2009/714, 2009. *(EC) No 714/2009 conditions for access to the network for cross-border exchanges in electricity and repealing Regulation (EC),* s.l.: s.n.

Florence School of Regulation, 2013. *Think Report: From Distribution Networks to Smart Distribution Systems: Rethinking the Regulation of European Electricity DSOs,* s.l.: s.n.

Fraunhofer IWES, ENEL Distribuzione, 3E, Union Fenosa Distribucion, EDP Distribuição, ACCIONA, 2014. *REserviceS - Report on the evaluation an conclusion of the DSO case studies,* s.l.: s.n.

GEODE, 2014. *GEODE Working Group Smart Grids,* s.l.: s.n.

Gonzalez et al, 2015. *Price-GDI: A pilot experience for the integration of distributed generation in active distribution systems,* s.l.: s.n.

Hauer, N. S. &. S., 2012. Communication Interface Requirements during Critical Situations in a Smart Grid.

ISGAN, 2014. *TSO-DSO interaction: An overview of the current interaction between transmission and distribution system operators and an assessment of their cooperation in Smart Grids.,* s.l.: s.n.

Melo, P. A. B. &. B., 2012. Network active managment for load balancing based in a intelligent multiagent sistem. *CIRED Workshop.*

Ministerio de Energía, Industria y Turismo, 2012. *P.O. 9.0 Información intercambiada por el operador del sistema,* s.l.: s.n.

Ministerio de Industria energía y turismo, 2013. *P.O. 3.2 Resolución de restricciones técnicas,* s.l.: s.n.

Ministerio de Industria y Energía, 2000. *P.O. 7.4 Servicio complementario de control de tensión de la red de transporte,* s.l.: s.n.

Ministerio de Industria, Comercio y Turismo, 2006. *P.O. 3.5 Programación del mantenimiento de la red de distribución que afecta a la operación del sistema eléctrico,* s.l.: s.n.

Ministerio de Industria, Energía y Comercio, 2008. *P.O. 15.1 Servicio de gestión de la demanda de interrumpibilidad,* s.l.: s.n.

Rivier, B., 2012. IIT Working Paper. REDEFINING THE NEW ROLE AND PROCEDURES OF POWER NETWORK OPERATORS FOR AN EFFICIENT EXPLOITATION OF DEMAND SIDE RESPONSE.

Sebatian, M. &. L., 2008. Evolution of DSO control centre tool in order to maximize the value of agregated distributed generation in smart grid. *CIRED Seminar 2008: SmartGrids for Distribution.*

SEDC - A demand reponse action plan for europe, 2013. *A demand reponse action plan for europe,* Belgium: s.n.

Silva et al., 2012. The interaction between DSO and TSO to increase DG penetration - The portuguese example.. *CIRED Workshop.*

Unión Fenosa Distribución , 2015. *White paper on Voltage Control in Active Distribution Systems,* s.l.: s.n.

Universidad de Sevilla - Unión Fenosa Distribución, 2015. *PRICE, Proyecto de Redes Inteligentes en el Corredor del Henares,* s.l.: s.n.

VDN, 2007. TransmissionCode 2007.

Wisconsing Energy Institute, 2014. The Dynamic distribution system.