TSO-DSO interaction:
An Overview of current interaction between transmission and distribution system operators and an assessment of their cooperation in Smart Grids

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An Overview of current interaction between transmission and distribution system operators and an assessment of their cooperation in Smart Grids

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Abstract:

Evolutions in the grid operation sector will require an ever closer cooperation between Transmission System Operators and Distribution System Operators.

The current interaction between TSOs and DSOs has been investigated for six specified grid operation challenges, and possible future ways of cooperation have been identified. Technical aspects as well as policy aspects have been taken into account.

The technical requirements for an evolved interaction between TSOs and DSOs can be met using available technology. However, several non-technical issues and points of discussion have been identified, of which some are related to the regulated environment grid operators are working in.

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Content

1. Executive Summary

This discussion paper is part of task 5 within ISGAN Annex 6 which focuses on Power Transmission & Distribution Systems. The main objective is to assess the future technical and market based interaction of distribution and transmission networks and to identify key challenges that deserve attention.

The report is mainly aimed at decision makers in restructured electricity markets, where a clear distinction between Transmission System Operators (TSO) and Distribution System Operators (DSO) exists, but may also be useful for decision makers considering the re-design of vertically integrated utilities.

Evolutions in the grid operation sector will require an ever closer cooperation between Transmission System Operators and Distribution System Operators. The current interaction between TSOs and DSOs has been investigated for six specified grid operation challenges, and possible future ways of cooperation have been identified:

1. Congestion of Transmission-Distribution interface
2. Congestion of transmission lines
3. Balancing challenge
4. Voltage support (TSO ←→ DSO)
5. (Anti-)Islanding, re-synchronization & black-start
6. Coordinated protection

For each case, country experts provided first-hand information about the status and expected development of TSO-DSO interaction in their respective countries. This resulted in an overview, by country, of the interaction between grid operators and provided input for the discussion about how this interaction could evolve in years to come. Technical aspects, as well as policy aspects, have been taken into account.

The technical solutions required for a closer interaction between TSOs and DSOs are very similar for most of the identified cases. New technical requirements for the DSO include a two way communication to both its flexible customers and to the TSO, and the ability to perform (quasi) real time network simulations with input from grid measurements. These technical requirements can be met using available technology, but the complexity and required skills for implementation and operation should not be underestimated.

Several non-technical issues, or points of discussion, have been identified which are closely related to the regulated environment grid operators work in; namely:

- *Maintaining a balance between infrastructure investments and use of flexibility*
  To what extent can flexibility on the distribution and transmission grid be used to support grid operation and avoid infrastructure investments? A minimum use of flexibility will be

necessary, but the impact on the processes and business cases of flexible customers will have to be limited. The use of flexibility of renewable energy sources needs to be limited to avoid a high loss of renewable energy.

- *The role of markets*
  Which grid operation challenges should be met by introducing markets and which should be managed only by technical means and appropriate bilateral contracts? In this work, it is proposed to use market mechanisms only for the balancing challenge. Coping with local grid operation challenges such as critical transformer loading, line loading and voltages, is proposed to be managed by the network operators, optimally interacting with each other. To handle such local challenges, markets would not work efficiently. Instead, a regulatory framework is required for bilateral contracts between flexible customers and network operators.

- *Setting a level playing field for flexibility*
  When using the combined flexibility of customers on the distribution and transmission grid, favoring one set of customers at the cost of the other should be avoided. For example, when facing critical line loading on the transmission grid, the use of flexibility of only distribution connected customers would be undesirable. Some mechanism, probably in discussion with the regulator, should be developed and implemented to cope with this.

- *The role of regulation*
  Should grid operation become more regulated, with clearer and stricter roles, or become more open, with guaranteed interaction between grid operators and new market players? In both cases, a clear definition of the roles and responsibilities of all participants in future grid operation will be necessary.

A clear policy framework will, in every case, encourage investments in Smart Grid solutions to deal with the identified and discussed grid operation challenges.

2. Introduction

This discussion paper is part of task 5 within IEA ISGAN Annex 6 on Power Transmission & Distribution. The main objective of this task is to assess the future technical and market based interaction of distribution and transmission networks and to develop recommendations for this future interaction. Figure 1 positions this work in the ISGAN context.

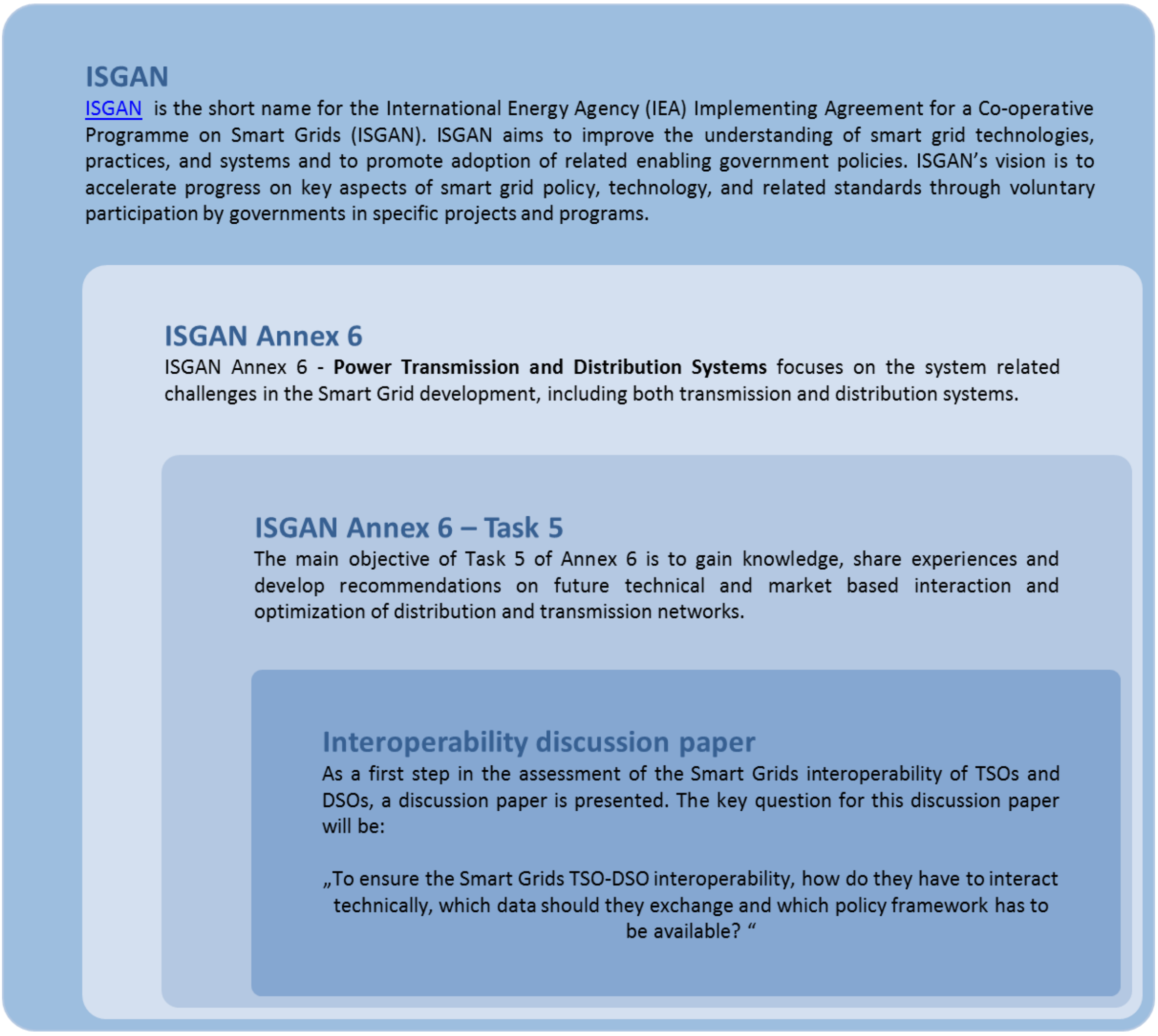

Figure 1 - Position of this discussion paper in ISGAN context

A number of emerging trends indicate that the interaction between Transmission System Operators (TSO) and Distribution Network Operators (DSO) will evolve in the coming years. One of these trends is the increasing volume of distributed generation being connected to the distribution grid. These partly fluctuating generation units change the behavior of the entire system, making it more challenging, for example, to balance generation and demand at every single point in time. Since balancing the grid is a responsibility of the TSO, it is clear that greater cooperation between TSOs and DSOs is to be expected.

To investigate the current and future cooperation between TSOs and DSOs, different cases have been identified by the ISGAN Annex 6 participants:

1. Congestion of Transmission-Distribution interface
2. Congestion of transmission lines and distribution lines
3. Voltage support (TSO ←→ DSO)
4. Balancing challenge
5. (Anti-)Islanding, re-synchronization & black-start
6. Coordinated protection

Each case represents a grid operation challenge for which collaboration between TSOs and DSOs is helpful or necessary. For each case, the current and possible future interaction between TSOs and DSOs has been investigated. Country experts provided first-hand information about the status and expected development of TSO-DSO interaction in their respective countries.

This resulted in an overview by country of the interaction between grid operators and provided input for the discussion about how this interaction could potentially evolve in years to come. Technical aspects, as well as policy aspects have been taken into account. In Figure 2, countries for which input has been provided are indicated: Austria, Belgium, Canada, China, France, Ireland, South Africa, Sweden and USA.

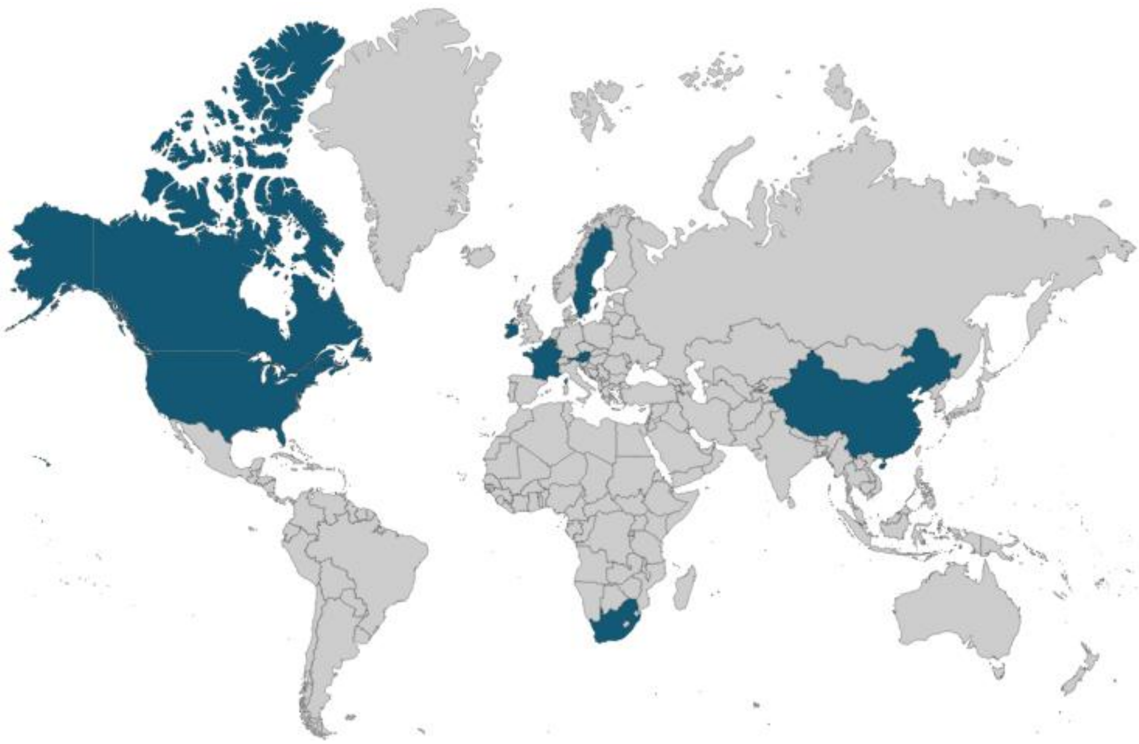

Figure 2 - Countries for which an overview of TSO-DSO interaction has been provided by country experts

A number of important observations emerge from the input provided by participating countries:

- In the discussion of interaction between distribution and transmission it is necessary to distinguish between:
    - TSO and DSO as legal entities which perform network operation
    - Transmission and distribution levels defined according to different voltage levels

  In Austria, for example, the TSO operates 110 kV networks but there are also cases where the DSO operates 380 kV lines.

- Some of the identified grid operation challenges can be handled by a single TSO or a DSO, without collaboration between them. However, this discussion paper assesses only situations in which the current and possible future TSO-DSO interaction is required in handling these challenges.

- Grid operation becomes more challenging when a larger amount of distributed generation is connected. In this analysis, situations of high penetration of distributed generation are assumed.

- Only a limited number of country experts have been asked for input. Since the electrical grid operation can differ significantly, even within one country, it cannot be guaranteed that the information by country on the following pages is fully representative.

3. Case 1 – Congestion of Transmission-Distribution Interface

3.1 Explanation of the case

The transformer between the transmission and distribution grid is located at the boundary between the operating areas of a TSO and a DSO. With an increased loading of the existing infrastructure due to both increasing loads and increasing distributed generation connected to the distribution grid, this transformer (TFO) is more likely to become critically loaded.
When this transformer is owned and operated by the DSO, the DSO can take measures to decrease its loading when a critical loading occurs (e.g. by applying demand side management, active power curtailment, the use of electrical storage or network reconfiguration). In that case, the DSO can avoid possible congestion with local measures. TSO-DSO cooperation is not necessary. However, when this transformer is owned and operated by the TSO, the TSO and DSO have to cooperate in order to reduce the loading of the TFO when an overloading threatens.

3.2 Country based assessment of TFO congestion

As stated above, this case only applies for those countries for which the TSO owns and operates the TSO-DSO transformer. Table 1 provides an overview by country of which network operator owns and operates the TSO-DSO transformer.

Country	TSO	DSO
Austria	x	x
Belgium	x	
Canada	x	
China	x	
France		x
Ireland		x
South Africa	x	
Sweden		x
USA		x

Table 1 - Operator of TSO-DSO transformer

In Table 2, the overview by country of the current TSO-DSO interaction in case of TFO congestion is given, together with the planned extension of this cooperation and the possible gap to achieve full TSO-DSO interaction in a Smart Grid context.

Country	Current interaction	Planned extension of cooperation	Gap to full Smart Grid interaction
Austria	In the national electricity act (Elektrizitätswirtschaft- und -organisationsgesetz) it is required to operate networks ≥110 kV according to the n-1 criterion. Therefore, congestion is avoided in the network planning phase.	None	None because congestion is already avoided by considering the n-1 criterion.
Belgium	DSO and TSO communicate manually (by phone) in case of congestion. A "Technical Code for Distribution of Electricity" and a technical code regarding transmission grid management are available.	None	The equipment is, for the greater part, not automatically or remotely operable. Each operator is informed only by the measurements at its own side of the grid. The DSO has no visibility over the schedule of distributed generation connected to its system.
Canada	In case of transformer overload: - When available, interruptible loads on MV-feeders are disconnected. Therefore, the DSO sends a signal to these loads after receiving a request from the TSO. - Entire feeders can be disconnected when no critical loads are present. Therefore, the TSO sends a signal directly to the corresponding feeders. Laws and regulations provide the necessary regulatory framework	A strategy is implemented to manage the voltage on the distribution grid. Investigations are ongoing as to how this Volt/var control affects the transformer congestion. Therefore, information about network areas with congestion is exchanged. The necessary regulatory framework has to be determined based on these investigations.	A better knowledge of the distribution feeder voltage profile can advance the Volt/var control strategy. A revenue model, beneficial to both parties, should be developed.
China	DSO and TSO communicate by phone in case of congestion. The DSO will transfer some part of loads to other feeders if capacity is available or cut some loads if no capacity is available.	The State Grid Company and South Grid Company of China will finish the building of distribution automation systems in the next 5 years. In many cities, the distribution automation system will be coupled with the dispatching automation system of the TSO. Therefore, information about congestion will be exchanged.	Volt/var control strategy for distributed generation connected to the distribution grid may conflict with integrated control to avoid transformer congestion.
France	N/A	N/A	N/A
Ireland	N/A	N/A	N/A
South Africa	Transformer device and loading alarms are sent to "Transmission Agents" who are located in the distribution control rooms. The distribution control room can take responsibility for the transformer loading. When needed telephone communications will take place	N/A	The deployment of advanced alarm processing and processing of the rate of change of the transformer analog values is planned. This will allow notification of potential congestion problems to the control staff.

	between the Transmission Agents at the distribution control room and the transmission control room.		
Sweden	N/A	N/A	N/A
USA	The distribution planning department works with the transmission planning to ensure adequate capacity and station configurations. As load grows, additional transformer banks can be placed in service and the station configuration can be re-evaluated. Also, larger transformers can be specified. This interaction takes place between the respective planning departments in the distribution and transmission businesses. Transmission system operator policy limits individual bank loading so that redundancy is ensured with the company's mobile transformer fleet. The capability of the mobile transformer fleet is not exceeded.	None	-

Table 2 - Overview by country of interaction on TSO-DSO congestion

3.3 TSO-DSO cooperation to avoid TFO congestion

For the countries in which the TSO operates the transformer, current interaction between the TSO and the DSO in the case of transformer congestion is mainly found in the planning phase (e.g. considering n-1 criteria). In the case where congestion threatens, the TSO sometimes has the ability to disconnect some feeders directly on the distribution grid or disconnect some customers through a request sent to the DSO. This process is generally not automated. An interesting approach is used in South Africa, where the cooperation between both network operators is formalized by having "Transmission Agents" working in the distribution control rooms, supervising the TSO infrastructure loading and acting upon critical loading.

Generally, there are not many plans to increase the cooperation between TSO and DSO to avoid TFO congestion. However, a higher visibility of each other's grid loading and some form of automation are identified as beneficial for future grid operation. China does have plans for the rollout of distribution system automation which would replace todays' manual actions to avoid TFO overloading.

Indeed, more decentralized generation could be connected to the distribution grid, without the need for upgrades, if a process is put in place to reduce the transformer loading as soon as this loading becomes critical, using flexibility on the distribution grid. This process would require more grid monitoring and increased data exchange between both network operators.

In Figure 3, a process is proposed which could be implemented to avoid TSO-DSO transformer congestion using flexibility on the distribution grid. The TSO monitors the TFO loading and in cases where this loading becomes critical, the TSO sends a request to the DSO to decrease the TFO loading by a certain amount. The DSO has to combine information about the distribution grid topology and its current loading with the actual available flexibility of its flexible customers. The DSO has to decide which actions have to be taken by certain flexible customers to reduce the TFO loading without violating the distribution network limits. For more complicated cases, the use of network simulations could be necessary. Finally, the DSO could send a "use-of-flexibility" request to some flexible customers. Feedback signals could be necessary.

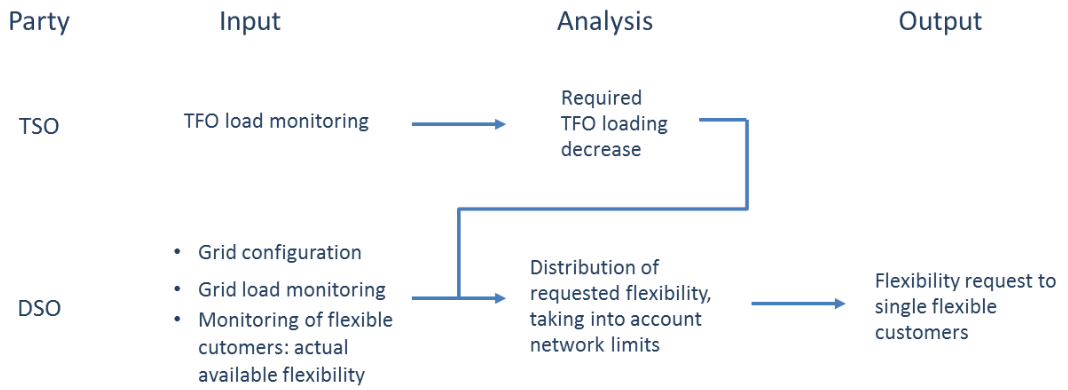

Figure 3 - Process proposal to avoid TFO congestion using flexibility on distribution grid

This proposed solution has a number of technical requirements:

- Monitoring of the TFO loading by the TSO.
- Communication mechanism between the TSO and DSO to send congestion signals.
- Overview of flexible loads and generation connected on the distribution grid to the TFO concerned.
- Monitoring by the DSO of the available flexibility of its flexible customers.
- Communication mechanism between the DSO and its flexible customers to send flexibility requests.

An important question to be considered is which customers the DSO will address when a critical loading of the transformer occurs. A pragmatic solution is to make use of the last-in-first-out principle, which is illustrated in Figure 4. As long as the transformer capacity is sufficient, it is possible to connect customers with a regular connection. This implies that these customers can make use of their full contractual power at all points in time, under normal grid operation conditions (excluding n-1 situations for example). When the limit of the transformer capacity is reached, new customers could still be connected without the need for grid reinforcement, but these customers can no longer be guaranteed the availability of their full contractual power at all times. They could therefore choose to become flexible customers. According to the last-in-first-out principle, the flexible customer who was connected last will receive the flexibility request first.

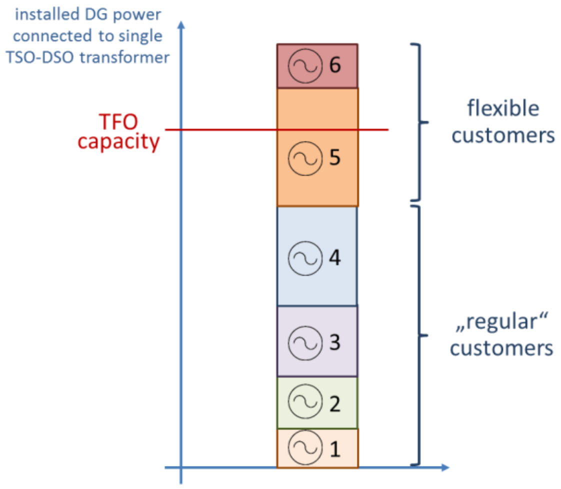

Figure 4 - Illustration of regular and flexible customers

This solution avoids retrofitting the installations of customers who were connected earlier ("regular" customers). Moreover, the contracts and business cases of flexible customers are not affected when additional, new flexible customers are connected. These new customers will have to respond to the flexibility request first.

From a legal point of view, the contracts between flexible customers and their DSO should include a requirement that these customers are obliged to respond to the use-of-flexibility request. Also from a regulatory point of view, such contracts should be accepted. These contracts will probably state limits to the use of flexibility, to have a clear understanding of the worst possible impact on the process and business case of flexible customers and to make sure that necessary network investments are not neglected.

4. Case 2 - Congestion of transmission lines

4.1 Explanation of the case

Due to increased loading and/or distributed generation on the distribution grid and the transmission grid, transmission grid lines may become critically loaded. This congestion case is comparable to the former. However, line overloading may be caused by the loading of several TSO-DSO transformers and TSO customers.

4.2 Country based assessment of line overloading

Table 3 gives an overview by country of the TSO-DSO interaction to avoid critical transmission line loading.

Country	Current interaction	Planned extension of cooperation	Gap to full Smart Grid interaction
Austria	In the national electricity act (Elektrizitätswirtschaft- und Organisationsgesetz) it is required to operate networks ≥110 kV according to the n-1 criterion. Congestion of transmission lines is avoided in the network planning phase. In case of faults and maintenance, the DSO partly supports the TSO line loading (switching measures at DSO level).	None	None because congestion is already avoided by considering the n-1 criteria
Belgium	The TSO solves issues concerning transmission lines without the support of the DSO. This is done through re-dispatching of units. A “Technical Code for Distribution of Electricity” and a Technical code regarding transmission grid management are available.	The use case for solving congestion through DSO-TSO cooperation has been proposed within a joint project (ATRIAS). The impact of including flexibility at the distribution level in the management of the electricity system is being investigated. However, congestion management through interaction is not the first project priority.	Interoperability of TSO & DSO systems. Increased visibility, for the DSO, over the actions of grid users (schedules, and forecasts). Specifications over roles, priorities, and responsibilities of the system operators with respect to cooperation.
Canada	-	-	-
China	The TSO solves issues without the support of the DSO. In case of critical transmission line loading, The TSO will cut some TFOs according to their respective importance.	In many cities, distribution automation systems at the DSO will be coupled with the dispatching automation system at the TSO. Information will be exchanged to transfer loads to other feeders and the cutting of TFOs may be avoided.	Full interaction between TSO and DSO concerning the control of RES, both active and reactive power, need to be considered.

France	A request is sent from the TSO to the DSO to adapt the power flows at the TSO-DSO transformer. Depending on the available time to react (20, 5 or 1 minute), the DSO can take appropriate measures. In case of emergency, load shedding is automatically requested by the TSO. This signal goes automatically through the DSO control centers, following predefined patterns. No specific rules and regulations apply.	Ancillary services of renewable generation to manage the loading of transmission lines. Necessary exchange of data between TSO and DSO: - Measurements of RES production - Forecast of the RES production - Level of congestion Necessary regulations are in discussion.	Full interaction between TSO and DSO concerning the control of RES (both active and reactive power) Therefore, a definition of the mandatory and appropriate ancillary services from RES has to be defined and financial aspects have to be thought over.
Ireland	The TSO is responsible for the active power control including the generation and the demand side on both the transmission and distribution systems.		
South Africa	The SCADA system is used to monitor congestion problems and notify the transmission control staff in the distribution control room of problems on the transmission system. Changing conditions of the transmission grid are taken into account and both critical transmission line loading and voltages are communicated.	None	None
Sweden	No interaction takes place.	None	A more coordinated operation could help in relieving congestion. Grid planning and operational data would need to be exchanged.
USA	TSO uses DSO to execute load curtailment when required. TSO determines the amount, DSO determines the particular load blocks. The load curtailment information is provided manually from the TSO to the DSO. Industry policies are determined by the North American Electric Reliability Corporation (NERC). Furthermore, regional TSO policies apply.	None	Future capabilities to allow for distribution backfeed to transmission are needed. Need for enhanced and advanced metering, need for more accurate load modeling. Missing protection coordination. At present, utilities cannot backfeed transformers with high-side Delta configurations due to loss of effective grounding and complication of insulation coordination should the transmission system become an island.

Table 3 - Overview by country of interaction to avoid TSO line overloading

4.3 TSO-DSO cooperation to avoid TSO line overloading

The current TSO-DSO interaction is quite different for the investigated countries. In Ireland, for example, the TSO is responsible for the control of demand and generation on both the transmission and distribution level. More common is the situation where the TSO can send a request to the DSO to curtail loads in the case of critical line loading. Sometimes this procedure is automated, for example in emergency cases.

A more intense collaboration is planned in some cases, for example in Belgium and France, where the use of renewable distributed generation to manage transmission line loading is being investigated. In China, the planned distribution automation system will be capable of transferring loads to other feeders in the case of critical line loading.

Identified topics of discussion are the roles and responsibilities of all actors in future grid operation and mandatory requirements for renewable generation connected to the distribution grid.

As stated before, to avoid line overloading when using flexibility on the distribution grid, an extra technical challenge arises: the combined use of the flexibility of multiple TSO-DSO transformer stations with the flexibility of TSO customers may be necessary. To make this possible, the TSO has to combine information about the available flexibility from his own customers with the available flexibility on the concerned DSO networks.

A possible process is proposed in Figure 5. The TSO has information about the transmission grid configuration and monitors its loading. The TSO also needs information about the available flexibility of flexible customers connected to the transmission grid. The same monitoring is necessary for the distribution grid, performed by the DSO. Based on actual grid loading, the DSO can calculate the total available flexibility, aggregated per point of connection with the TSO, taking into account the distribution network loading limits. This information is necessary for the TSO to decide which flexibility can be utilized on the transmission grid and on the distribution grid to decrease the transmission line loading.

Once the TSO has determined which flexibility per TSO-DSO point of connection will be utilized, the technical solution could be the same as in the TFO congestion case concerning the requests-for-flexibility to flexible distribution connected customers. Therefore, similar legal and regulatory issues apply. This solution is also applicable in case the DSO is operating the TSO-DSO transformer.

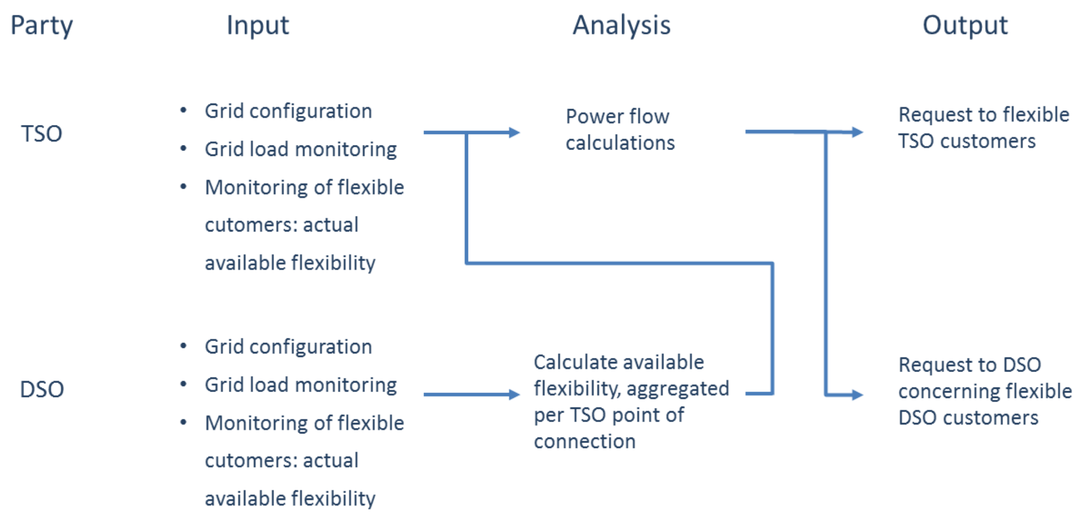

Figure 5 - Process proposal of TSO-DSO interaction to avoid line overloading

The technical requirements concerning the interaction between TSO and DSO are the same as in the case of transformer congestion.

From Figure 5, an important issue arises: the TSO has the choice to address flexibility on the transmission grid and on the distribution grid. Some mechanism should be put in place to avoid a situation where the flexibility of one of those groups is favored. Traceability of the choices made and transparency about the reasons why, will have to be provided. This is definitely a topic of discussion with the regulators. In cases where remuneration for the use of flexibility is foreseen, the least expensive flexibility will be preferred.

5. Case 3 - Voltage support (TSO ←→ DSO)

5.1 Explanation of the case

TSOs can support the voltage on the distribution grid, as can DSOs support the voltage on the transmission grid.

The voltage level at the distribution grid can be controlled with the TSO-DSO transformer tap setting. DSOs could support the voltage at the transmission level activating flexibility on the distribution grid.

5.2 Country based assessment of voltage support

Table 4 gives an overview by country of the TSO-DSO interaction to support grid voltages.

Country	Current interaction	Planned extension of cooperation	Gap to full Smart Grid interaction
Austria	The setting of the transformer (tap position) is negotiated between the two control rooms (TSO and DSO) and performed manually in order to satisfy the needs of the DSO and TSO. An automated control is used sometimes, but not widely implemented at the moment.	Some more automation of tap changers is expected.	
Belgium	Not a current practice.	None	
Canada	The TSO supporting DSO voltage is governed by law. Capacitor banks on the DSO side and on the industrial client side are for voltage control on the DSO side.	The evolution of the situation could be that in the case where the DSO capacitor banks are not necessary for voltage control on the DSO side, they could be used to contribute to the TSO voltage control. This would require knowledge of the distribution network voltage and signals from the DSO. It would also require a revenue sharing scheme that is not yet in place.	
China	The TSO solves the issue without the support of the DSO, and vice versa.	None	In case of a high penetration of RES, an optimization of the voltage set point needs interaction between DSO and TSO.
France	No exchange between TSO and DSO, except in the case of an emergency. Occasionally, possible voltage support from the DSO level (DSO compensators in substations) is investigated via phone calls.	Ongoing discussions to achieve an optimized way to operate the whole system (including RES that has an impact on the voltage profile). No conclusion yet.	Optimization of TSO-DSO-RES voltage management by appropriate interaction. Flexibility at the DSO grid (including RES capacities) is not operated, although possible.

Ireland	None. For some generation connected to DSO, the Distribution Code sets a power factor range.	The use of sources of reactive power on the distribution system to support the voltage on the transmission system. The TSO may issue a reactive power, power factor or voltage setpoint to the DSO at the TSO-DSO interface based on the capability at that point. The DSO will control the reactive power generation / absorption of distribution-connected generation to meet that setpoint while maintaining distribution system voltage and line-loadings within limits. Necessary data exchange may include reactive power capability at TSO-DSO interface, setpoint transmit and acknowledge. A "Voltage Control Protocol" at the TSO-DSO interface will be agreed by the TSO and DSO.	Development of a 'Nodal Controller' to control reactive power flow of distributed generation connected at specific transmission system nodes for the benefit of the transmission and distribution system. Real time ability of TSO to send a setpoint instruction to instruct DSO/distribution-connected generators and receive a confirmation. "Voltage Control Protocol" at the TSO-DSO interface agreed by the TSO and DSO.
South Africa	As is the case for critical line loading, critical voltages on the transmission grid are communicated to the transmission staff in the distribution control room. It is their responsibility to take appropriate measures.	None	None
Sweden	Zero reactive power flow is maintained on TSO-DSO interface. The TSO operates the capacitor banks installed on the distribution grid (called "reversed power control"). An agreement is set up for this operation process. No regular exchange of data, but statistics and special grid events are exchanged.		Increasing variations in generation and consumption have to be handled appropriately. Good forecast systems with proactive cooperation between TSO and DSO have to be established. Coordinated investments in reactive power support. More interaction is needed in sharing and understanding existing problems and limitations of both grids. Clear regulation has to be provided for smart grids functionalities.
USA	TSO performs switching of DSO substation capacitors and tap changers. DSO station voltage measurements are used to manage capacitor controllers with the Energy Management System (EMS) and Distribution Management System (DMS). Tap changers operate autonomously, as do regulators. The TSO manages all voltage support needs. At present, a program for switching distribution line capacitors is non-existent.	None	Joint research on integration of renewable technology; specifically renewable voltage information, could be useful. Real time metering New rate structures and research concerning new rate structures.

Table 4 - Overview by country of interaction to support grid voltages

5.3 TSO-DSO cooperation to support grid voltages

Generally, current approaches to keep the voltage within its required limits are network planning, reactive power provision of classic generators, tap changers, capacitor banks and line voltage regulators. Moreover, TSOs have the opportunity to re-dispatch generators to manage the voltage.

The current interaction between TSOs and DSOs on grid voltages is therefore rather limited. The TSO supports the DSO grid voltage by means of the on-load tap changer on the TSO-DSO transformer (in case the TSO operates this TFO). The DSO can use capacitor banks to support the distribution grid voltage.

The TSO-DSO interaction is closer in the USA, where capacitor banks are controlled by the Energy Management System of the TSO and the Distribution Management System of the DSO, using DSO station voltage measurements. Different from other countries investigated, a set power factor for distributed generation is already in place in Ireland. In South Africa, transmission staff is located at the distribution control room. These people have to take appropriate measures on the distribution grid to support the transmission grid voltage.

Although the current bilateral voltage support is limited, there is a general tendency to strengthen the role of the DSO in supporting the voltage, resulting in a more integral approach to manage the grid voltage at all voltage levels. Several possibilities are investigated:

- The use of the DSOs' current capacitor banks to actively support the TSOs' grid voltage.
- The use of reactive power from distributed generators to support the transmission system voltage.

An interesting combination is given by the approach of Ireland, currently under investigation and illustrated in Figure 6. In this case, the DSO would support the voltage at TSO level by managing the reactive power flows at distribution level. A power factor, reactive power flow or voltage setpoint may be issued by the TSO at the TSO-DSO interface. Reactive power provision capabilities of distributed generation can be used to meet the requested reactive power flows, while respecting the distribution system level voltage and line-loading limits. At the TSO-DSO interface, both parties can agree on a reactive power flow range which should be met. Such an approach could be combined with a management of the TSO-DSO transformer tap changer setting, to optimally support the DSO grid voltage.

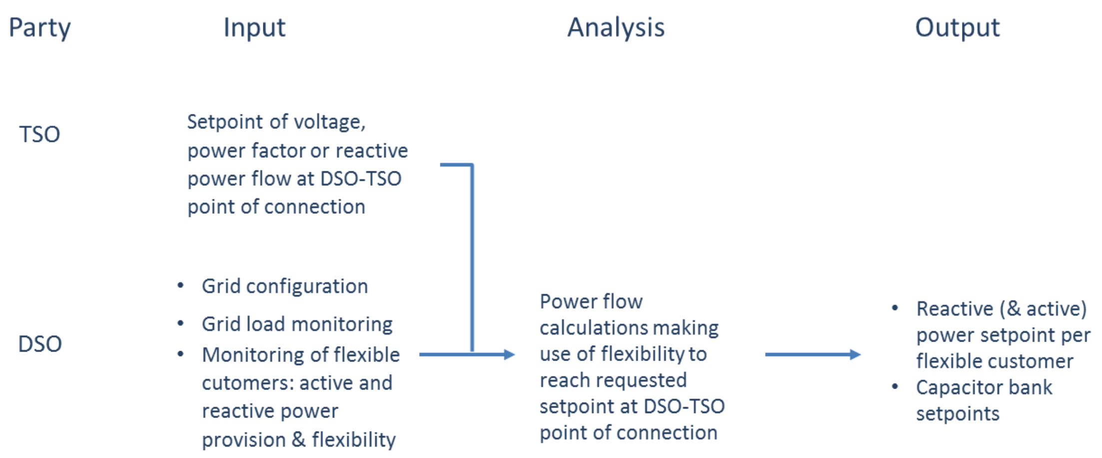

Figure 6 - Process proposal of TSO-DSO interaction to support grid voltages

The technical requirements to implement this solution are very similar to the previous cases. Grid monitoring has to be implemented, communication between TSO and DSO has to be established and communication means between the DSO and its flexible customers have to be available.

Similar policy and legal issues cases apply as in the previous cases. In case the DSO wants to activate flexibility, the DSO has to be allowed to take this action in order to support the transmission grid voltage. This would require appropriate contracts with customers.

There is also the important aspect of the priority of actions to be taken: the TSO has the opportunity to activate flexibility from its own customers or ask the DSO to support the transmission grid voltage, activating flexibility on the distribution grid. Favoring one over the other should be avoided.

6. Case 4 - Balancing challenge

6.1 Explanation of the case

Instantaneous generation and consumption have to be in balance at all times. Increased penetration of fluctuating decentralized generation results in increased errors in the production forecast and therefore makes it more challenging to balance the grid. For this reason, it is expected that necessary balancing power actions will increase significantly in the coming years.

The TSO could, via the DSO, use flexibility on the distribution grid to reduce imbalances. As a reminder, the focus in this work is on the TSO-DSO cooperation, so other measures to reduce imbalance have not been taken into account.

6.2 Country based assessment of the balancing challenge

Table 5 gives an overview by country of the TSO-DSO interaction concerning grid balancing.

Country	Current interaction	Planned extension of cooperation	Gap to full Smart Grid interaction
Austria	From a policy and regulatory perspective, it is possible that generators and loads connected to the distribution grid act in balancing markets, if they fulfill the pre-qualification criteria. The DSO is not involved in the prequalification process. The Austrian TSO is in charge of the prequalification. There is no interaction between TSO and DSO in this case.	None	
Belgium	Some distribution customers offer flexibility, in the form of available capacity, to the TSO. The DSO is involved in the prequalification process of applying customers. The customers' available flexibility is assessed using real metering data, measured by the DSO and communicated to the TSO. Bilateral contracts are made between the parties involved.	Real-time balancing platform ("Bid ladder") that will allow the TSO to contract flexibility. Increased visibility, for the DSO, over the actions of grid users (schedules, and forecasts) is planned. A discussion has taken place over the imbalances in the planned schedules due to the activation of flexibility. There is a need to change the contracts for the delivery of ancillary services by a 'dynamic profile provider'.	The mentioned flexibility platform for bids and offers has to be put in place, together with profile management and aggregation services. From a regulations point of view, the DSO should be allowed to participate in the contracting of ancillary services through market mechanisms.
Canada	The TSO is the balancing authority. Production is dispatched as load fluctuates. Generation is hydro up north and loads are concentrated in the	The DSO could reduce its demand to enable exports when the southern market is very good. There would need to be a signal, since the price is fixed in	

	south, where some smaller hydro is available. When there is available transit, energy is exported to the south. Otherwise the national load is solely supplied. There is little distributed generation except for large wind farms which have a must buy contract.	advance for the internal market. A revenue sharing mechanism would need to be developed.	
China	Only the TSO is responsible for the grid balancing. The DSO is not involved.	None	None
France	Balancing is performed at the national level. In case of a balancing problem, appropriate signals are sent by the TSO (manual or automatic) to get back to normal situation. These signals are sent by the TSO to the market to solicit appropriate offers, but in the case of an emergency, automatic load-shedding is the solution. Therefore, signals are sent from the TSO to the DSO.	Pilot projects investigate to what extent "local" measures can be taken by the DSO to get some kind of balance. The outcome is unsure and the interaction with the TSO still has to be defined. In the case of demand response involving resources at the distribution level, interactions between TSOs and DSOs are under discussion. Future policy and regulations are not yet defined.	No clear answer yet.
Ireland	The TSO has full responsibility for balancing and therefore is responsible for active power control including generation and demand side, on both the transmission and distribution systems.		
South Africa	None	None	None
Sweden	None	None	Information exchange about balance in distribution grids and status of distribution customers actively participating in grid balancing. Ongoing discussions on how this should be implemented.
USA	Only load curtailment is performed by the DSO on request of the TSO. TSO determines the amount, DSO determines the particular load blocks. The load curtailment information is provided manually from the TSO to the DSO. Industry policies are determined by the North American Electric Reliability Corporation (NERC). Furthermore, regional TSO policies apply.	Current activities focus on the development of protection standards, power quality assessment, and voltage support requirements. Presently, data management solutions are explored – mostly focused on distribution (no two-way communications with Transmission)	Two-way data exchange between TSO and DSO: data exchange needed from DSO back to the TSO. TSO presently has a better real time view than DSO. Managing VARs at DSO level for aggregate TSO level benefits is presently not possible without enhanced data exchange. Enhanced rate signal required to stimulate investment on DSO level.

Table 5 - Overview by country of interaction to balance the grid

6.3 TSO-DSO cooperation in balancing the grid

Generally, the TSO is responsible for balancing the grid. Under normal grid operating conditions, the DSO is not involved in grid balancing. Nonetheless, distribution customers can already take part in the balancing process, as is the case for some countries. For those cases in Belgium, the DSOs are involved in the prequalification process and communicate metering data to the TSO.

Similarly to the previous interaction cases, the situation in Ireland is somewhat unique. The TSO also manages the flexibility on the distribution grid for balancing purposes. The situation in Canada is also unique, with large amounts of hydro power and only small amounts of distributed generation. Flexibility on the Canadian distribution grid could be used to maximize transit to other markets when this is financially viable. This input was given by a vertically integrated company and it is acknowledged that applying flexibility in this manner is probably harder to implement for companies which are not vertically integrated.

In Europe, different extensions to the current balancing mechanisms are being investigated. For example, the implementation of a real-time balancing platform has been explored, which would allow the TSO to contract flexibility when needed. In France, an approach is being investigated which includes DSO-taken “local” measures, which could result in a more balanced distribution grid.

Assuming that there is interaction between the TSO and DSO to cope with the balancing challenge, there will be a need for some aggregation of flexible customers on the DSO grid. This pool of flexible generators or loads will need to go through the prequalification process to prove they have the required availability, reliability and flexibility necessary to take part in the balancing market. Most likely, the requirements for prequalification should be revised in the light of new participants entering the balancing market. Various parties could fulfill the role of aggregator: the TSO, the DSO or a separate company. However, the market mechanisms which include DSO customers in the balancing process can only be operational as long as the distribution grid loading is not critical. This is a role which can only be fulfilled by the DSO: only the DSO knows the actual grid configuration and its current loading. Grid operation signals to flexible customers should always overrule market signals, when necessary.

An important issue to be considered, as raised by Belgium, is the impact of the use of flexibility on the imbalances in the planned schedules. By using flexibility, forecasts of generation or consumption are disturbed, which causes imbalances in the planned schedules of Balance Responsible Parties (BRP). These BRP would therefore have to pay a fine to the TSO because the TSO has to ensure the balance in the whole control area. The importance of this issue for the other countries has still to be investigated.

A number of important issues regarding regulation arise in relation to the grid balancing discussion. One such point is how grid operation should evolve: more regulated, with clearer and stricter roles, or more open, with guaranteed interaction between grid operators and new market players. For example, should the role of aggregator be performed by the DSO, who can combine market based signals and grid operation signals to use flexibility efficiently? Or should new market players be allowed to perform the role of aggregator, in close interaction with the DSO ensuring that market based signals to use flexibility do not compromise safe and secure grid operation?

7. Case 5 - (Anti-) Islanding, re-synchronization & black-start

7.1 Explanation of the case

As more distributed generation is connected, the chance of instantaneous balance of generation and load in a certain grid section increases. When, at any point in time, this grid section is separated from the rest of grid, islanding occurs. Clearly, the chance of this occurring is very small.

Focusing on the TSO-DSO interoperability, the distribution grid could be disconnected locally from the transmission grid at the TSO-DSO transformer at a point in time at which the distribution grid was balanced, with a zero power flow over the TSO-DSO transformer. Measures should be taken to detect this situation or to ensure a flawless reconnection from the distribution grid to the transmission grid (resynchronization).

A severe case of islanding and resynchronization is a black-start. A black start is needed after a black-out, which can be considered as the consequence of the failure of all other measures to keep the grid stable.

7.2 Country based assessment of (anti-)islanding, re-synchronization & black-start

Table 6 gives an overview by country of the TSO-DSO interaction dealing with (anti-)islanding, re-synchronization and black-start.

Country	Current interaction	Planned extension of cooperation	Gap to full Smart Grid interaction
Austria	Some Austrian distribution network areas can practically be operated in islanding mode but due to the high availability of the transmission system, this is almost never used. Usually, black start capability cannot be widely found at DSO level since the provision of the service is not rewarded by the Austrian network tariff system. It is only foreseen at TSO level. Black start capability is considered as one of the basic services provided by the TSO.	Not expected for the near future	
Belgium	Islanding is not allowed due to safety reasons. Black start services are only used at the transmission level. A “Technical Code for Distribution of Electricity” and a Technical code for the transmission grid management are available.	None	

Canada	None	Islanding is a current subject of research. Since there is limited distributed generation, the grid support of this generation in the case of islanding or black-start is less relevant.	
China	In most cases, black-start is done by the TSO using some generation units connected to the transmission network.	None	None
France	None	Assessment of the protection settings at DSO level (following European Grid Codes)	
Ireland	None In the case of an island all distribution-system generation disconnects using anti-islanding protection. Once supply is restored distribution system generation can reconnect.	None	None
South Africa	None	None	None
Sweden	Regular exercises with participation of both network operators. Grid data is exchanged amongst them. Instructions and agreements have been set up to cope with emergency situations.	Customers are being classified in order of importance to be able to disconnect selectively in case of disturbance. An order chain will be established starting at TSO level down in the hierarchy. This planning involves both grid operators. Large amounts of information are shared. New regulations have been written or are under construction.	The possibility to control in-home appliances will make it easier to deal with emergency situations.
USA	DSO helps balance loads for black-start loading. Human interaction is the method of data exchange during black-start. TSO develops protection standards, performs protections studies and policies to prevent islanding, which is prohibited.	Investigations were made concerning microgrids at government installations. Enhanced network modelling is being investigated.	During islanded operation, there is a risk of customer equipment damaging other customer equipment. For the infrastructure owned by the TSO, liability limits prohibit certain islanding configurations. The penetration of generation at DSO level can create voltage issues for customer's equipment, oversaturation of transformers, lack of sufficient fault current for proper relay operation, issues with frequency regulation, etc. that must be resolved in a distribution islanding mode. Liability to the utility while customers use network for islanding – need process for limiting liability of utility during this mode of operation.

Table 6 - Overview by country of interaction dealing with (anti-)islanding, re-synchronization & black-start

7.3 TSO-DSO cooperation dealing with (anti-)islanding, re-synchronization & black-start

Islanding situations are prohibited and avoided by using appropriate protection settings, mainly for safety reasons. Generally, distributed generation is disconnected from the grid when islanding occurs. Therefore, decentralized generation has the functionality to detect islanding and, in that case, to reduce power injection to zero. Although intentional islanding is a topic of research, there is no tendency to operate distribution grids (partly) as islands. Perhaps some exceptions may apply, as is the case for the USA.

A second reason why islanding is avoided is liability in case of islanded operation. Indeed, in the case of damaged customer equipment, it is unclear which party is liable.

From a network operation point of view, islanding situations are not beneficial. However, there are some situations where self-provision can be necessary, as is the case for critical loads (e.g. hospitals) during outages. Since these emergency situations are already covered in current grid operation practices, there is no need to explore these further.

Black-start procedures, even today, demand close cooperation of the TSO and DSO. TSOs and DSOs work out a procedure on how reconnection should be performed after a black-out. It usually involves the disconnection of distribution feeders before reconnection to the transmission grid after power is restored. Distribution feeders will be switched to the grid in a certain order, giving priority to feeders which connect important customers (e.g. hospitals).

It can be beneficial to reconnect distribution feeders with a high volume of distributed generation early in the procedure, because they can support the power provision. This approach can be integrated into the existing plans to restore the grid. To make use of decentralized, fluctuating generation to support rebuilding of the grid, a forecast of these generation units is necessary, together with the possibility to curtail these generation units when new loads are connected to the grid. This would require similar technological features as required for previous cases, although the reaction of distributed generation to signals could be more time-critical.

Despite the possibilities mentioned, the use of distributed generation to support the grid during a black-start is not indicated as a common practice today; and none of the countries indicate this as a planned implementation.

8. Case 6 - Interoperability for coordinated protection

8.1 Explanation of coordinated protection

In the case of a fault on the transmission grid, measurements in the distribution network can set off alarms or even cause certain protections in the distribution grid to trip. Conversely, in the case of a fault on the distribution grid, the transmission network operator may receive an alarm from its own measurement devices or have false trips on its infrastructure. Coordination between TSOs and DSOs in these cases may be helpful.

When decentralized generation is connected to the grid, faults may be fed with fault currents from multiple directions. In this case, operators and technicians are blind to the fault location. Coordination between TSOs and DSOs helps in resolving this.

8.2 Country based assessment of coordinated protection

Table 7 gives an overview by country of the TSO-DSO interaction dealing with coordinated protection.

Country	Current interaction	Planned extension of cooperation	Gap to full Smart Grid interaction
Austria	Currently, there is no interaction considering coordinated protection	None	
Belgium	Currently, the CIGRE guidelines are followed. No coordinated protection actions are taking place.	None	
Canada	None Protection at the DSO level is provided by pole top circuit breaker with settings based on local short circuit depending on their position on the feeder. There is no coordination with the TSO.	None	
China	Protection coordination of TSO and DSO is implemented through protection functionality: a fault occurring along a feeder will cause tripping of the feeder protection at the substation. This feeder protection is operated by the TSO.	None	The penetration of distributed generation at DSO level impacts the short circuit power of the system. Protection settings of both the TSO and DSO will need to be adapted.
France	None	None	
Ireland	There is generally very little interaction between TSO and DSO for protection coordination. There is typically a single relay on which the DSO provides a	None	

	subset of settings and the TSO sets the remainder. For instance, for a typical transmission-distribution transformer there will be an overcurrent protection relay with two current trip settings. The TSO sets one to trip for faults on the transmission side of the transformer and the DSO provides a setting for the other in order to provide time-delayed backup protection for distribution-side faults. Where there is appreciable penetration of distribution-connected generation, additional protection devices may be installed on the transmission side of the DSO/TSO interface. The TSO specifies and sets these schemes. Trip commands are provided to the DSO as required or requested. There is no real-time data exchange on settings. Guidelines are included in the "DSO-TSO Protection Policy" and "DSO-TSO Data Exchange Protocol".		
South Africa	None	None	None
Sweden	Considering busbar protection, both grid operators are involved and take coordinated actions. Therefore, information about protective relay settings is exchanged.	None	A better insight into each other's grids would allow the construction of special protection schemes, which would result in better protection of the sub-transmission grids.
USA	TSO applies slower protection to allow for distribution automation. Circuit information is exchanged between TSO and DSO. Coordination studies are performed together.	None	With conventional technology, self-healing means slower protection which leads to more stress on Transmission equipment in the form of longer voltage dips, longer fault currents through transformers, etc. Fiber pilot/fiber communications systems can allow for faster protection. The ability of a utility to own a fiber communications network for appropriate pilot protection is a first needed step. However, present regulatory structures prohibit electric utility fiber build outs in some cases.

Table 7 - Overview by country of interaction on coordinated protection

8.3 TSO-DSO cooperation on coordinated protection

Based on the country specific assessments, current interaction considering coordinated protection is rather limited. Generally, protection selectivity is assured by a faster tripping of protection devices installed on the distribution grid and slower settings for such devices on the transmission grid. Therefore, some degree of cooperation is necessary: technical information is shared between TSO and DSO and in some cases, protection settings are discussed jointly.

There are no plans to increase the interaction on the topic of coordinated protection. However, in the USA, the ownership of a fiber communications network is an issue. If network operators were allowed to own such a network, faster protection would be possible.

Nonetheless, a closer cooperation between the TSO and DSO may make it easier to interpret alarms or explain the unexpected tripping of feeders for both grid operators. A first step could be setting up a connection between the systems of both operators to exchange information about protection measurements or outages. This information could also be useful to identify the location of a fault in case this fault could be fed from multiple directions. Proper communication protocols would have to be agreed on. In the case of changes in grid topology, possible effects on the data interpretation have to be investigated.

9. Closing discussion

As demonstrated above, some trends indicate an evolving interaction between transmission system operators and distribution system operators in the years to come.

The current interaction between TSOs and DSOs has been investigated for the specified six grid operation challenges, and possible future means of cooperation have been identified.

An overview of the discussions in the body of this paper is given in Table 8. As this table provides a high level summary, not all situations or exceptions are covered.

	Today	Future
TFO congestion	• Avoided in many countries by considering n-1 criteria in the network planning • Cooperation mostly during the planning phase • Emergency situations: TSO disconnects distribution feeders, possibly through a request to the DSO	• More grid monitoring and intensified data exchange would allow using flexibility on the distribution grid to reduce transformer loading when necessary. • A request could be sent from the TSO to the DSO to decrease the transformer loading. The DSO could translate this request to use-of-flexibility requests to flexible customers connected to the distribution grid.
Line congestion	• Mostly avoided by considering n-1 criteria in the network planning phase • In some cases the TSO is responsible for the control of demand and generation at both the transmission and distribution level. • Generally, curtailing of loads on the distribution grid is applied in case of critical transmission line loading. Sometimes this is performed manually, sometimes automated.	• The use of flexibility on the distribution grid to manage transmission line loading. • DSO could provide information about available flexibility on the distribution grid, aggregated per TSO-DSO point of connection. The TSO could use this information and his own grid monitoring to calculate the required use of flexibility. Resulting requests for flexibility could be sent to the DSO and to flexible customers connected to the transmission grid. • Some mechanism has to be implemented to decide between the flexibility of transmission customers and distribution customers.
Voltage support	• Most often, the TSO supports the DSO grid voltage only by means of the tap changer on the TSO-DSO transformer. • The distribution grid capacitor banks are possibly used to support the transmission voltage. • There are examples of distributed generation being used to support the voltage, as they are required to operate at a fixed power factor.	• (Intensified) use of the DSOs' current capacitor banks to actively support the TSOs' grid voltage. • The coordinated use of reactive power from distributed generators to support the transmission system voltage. • Both solutions can be combined when the TSO could request a voltage, power factor or reactive power flow setpoint at the TSO-DSO point of connection. The DSO could use flexibility on the distribution grid to reach this requested setpoint without violating distribution network loading limits.
Balancing	• Generally, the DSO is not involved in grid balancing. • Sometimes, distribution customers take part in the balancing process. Possibly, but not	• (Aggregated) distribution customers could be part of the balancing process. Which entity should get the role of aggregator has to be discussed. • DSO with local balancing responsibility is investigated.

	necessarily, the DSO is involved, for example in the prequalification.	• Market-based signals should not interfere with grid operation signals to use flexibility. • Issue about roles in the energy market opens discussion about a more regulated system or the entry of new market players.
Islanding, re-synchronization, black-start	• Islanding situations are prohibited and avoided by using appropriate protection settings, mainly for safety reasons. • Distributed generation is disconnected from the grid when islanding occurs. • Liability in the case of islanded operation is an issue to be discussed. • Black-start procedures, even today, demand close cooperation of the TSO and DSO. Procedures on grid restoration are set up in close cooperation.	• Use of distributed generation can be included in existing plans for grid restoration. For example distribution feeders with a high amount of distributed generation could be reconnected early in the procedure. • This would require forecasting possibilities of the concerned distributed generation and the possibility to curtail these units during grid restoration.
Coordinated protection	• Coordination of protection is limited to interaction on protection settings, assuring selectivity in case of failure.	• Exchange of information about protection measurements could lead to easier interpretation of alarms or unexpected tripping of feeders. • Fault localization could also be more effective if protection measurements could be shared amongst both network operators.

Table 8 - Summary of current and future TSO-DSO interaction

The technical solutions required for a closer interaction between TSOs and DSOs are very similar for most of the identified cases, except for the case of islanding & black-start. From a high level viewpoint, grid monitoring has to be implemented, communication between TSO and DSO has to be established and means of communication between the DSO and its flexible customers have to be available.

The roles and tasks of the DSO are expected to evolve more than the role of the TSO, based on the possible future interaction proposals. New tasks include intensified data management and flexibility management. New technical requirements for the DSO include a two way communication to its flexible customers and to the TSO, and the ability to perform (quasi) real time network simulations with input from measurements on the grid.

Such technical requirements should not be underestimated regarding implementation and operational cost, complexity and skills required; which could be a challenge, especially for smaller distribution network operators. Nonetheless, only the distribution grid operator has information about the actual grid configuration and grid loading. This means that even when other entities take up certain roles, for example the role of aggregator, the distribution network operator will always be responsible for monitoring the grid and will need to implement communication solutions to one entity or another.

With the current status of technology, technical requirements for an evolved interaction between TSOs and DSOs can be met. However, several non-technical issues, or points of discussion, have been identified which are closely related to the regulated environment grid operators are working in.

- *Maintaining a balance between infrastructure investments and use of flexibility*
  To what extent can flexibility on the distribution and transmission grid be used to support grid operation? To avoid increasing investments costs, use of this flexibility will be necessary. On the other hand, the impact on the processes and business cases of flexible customers should be limited. Necessary network investments should be carried out and they should not be avoided at the cost of, for example, severely reduced renewable energy production.

- *The role of markets*
  To what extent should new rate schemes be implemented? Which grid operation challenges should be met by tariffs and which should be managed only by technical means and appropriate bilateral contracts? In this work, it is proposed to use market mechanisms only for the balancing challenge. Coping with local grid operation challenges such as critical transformer loading, line loading and voltages is proposed to be managed by the network operators, interacting optimally with each other. To handle such challenges, markets would not work efficiently without intervention. Instead, a regulatory framework is required to address bilateral contracts between flexible customers and network operators.

- *Setting a level playing field for flexibility*
  When the combined flexibility of customers on the distribution and transmission grid is used, favoring one set of customers at the cost of the other should be avoided. For example, when facing critical line loading on the transmission grid, the use of flexibility of only distribution connected customers would be undesirable. Some mechanism, probably in discussion with the regulator, should be implemented to cope with this.

- *The role of regulation*
  Closely related to the previous statement, is the discussion point on how grid operation should evolve: more regulated, with clearer and stricter roles, or more open, with guaranteed interaction between grid operators and new market players? In both cases, a clear definition of the roles and responsibilities of all actors in future grid operation will be necessary.

A clear policy framework will, in every case, push forward investments in Smart Grid solutions to deal with the discussed challenges that grid operators are facing.

10. Acronyms and Abbreviations

BRP	Balance Responsible Party
CIGRE	International council on large electric systems
DG	Decentralized generation
DMS	Distribution management system
DSO	Distribution system operator
EMS	Energy management system
NERC	North American Electric Reliability Corporation
RES	Renewable energy sources
TFO	Transformer
TSO	Transmission system operator
USA	United States of America
var	Volt Ampère Reactive

Table 9 - Acronyms and abbreviations