TDX-ASSIST: BEYOND STATE OF ART IN TSO-DSO INTEROPERABILITY – THE PORTUGUESE DEMONSTRATOR

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ABSTRACT

The TSO-DSO relationship is a key topic in the operation of the electricity market and is even more crucial as Europe paves its way into the constitution of a European energy market ranging from Transmission to Distribution. Following this, the subject addressed in this paper is an overview of the TDX-Assist project with a focus on the Portuguese demonstrator, which has the participation of EDPD (Portuguese DSO), INESC TEC, Nester and REN (Portuguese TSO). This project, being developed under European Union's Horizon 2020 R&I program, aims to design and develop novel ICT tools that facilitate scalable and secure information systems and data exchange between TSO and DSO.

The continuous shift from TSO connected generation to DSO connection generation is presenting new challenges to DSOs and TSOs. Keeping the system up and running in the future requires a more collaborative approach to the issue of DSO/TSO cooperation that traditionally existed in the vertically integrated network paradigm. It is possible to use IT tools to make sure both system operators have the relevant information they require to fulfil their mission.

TDX-Assist's Portuguese demo helps addressing these issues by:

1. *focusing on the provision of reactive power services by the DSO to the TSO. A new version of the Interval Constrained Power Flow (ICPF) tool, which takes into account disjoint flexibility areas as a result of the combination of discrete control variables, will be used to evaluate the range of operation points at the primary substations (Figure 1). With this information, the TSO can then select an operation point that will cause minimum impact on the transmission network.*

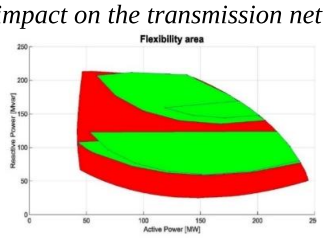

Figure 1 – Example of flexibility area computed by the ICPF tool (red area obtained considering discrete variables as continuous ones; green area obtained by considering the combination of all possible values for the discrete values).

2. *designing and implementing the information exchange needed to support other dimensions such as operational planning through nodal forecast at nodal level and exchange of maintenance plans in a defined observability area of both system operators (Figure 2).*

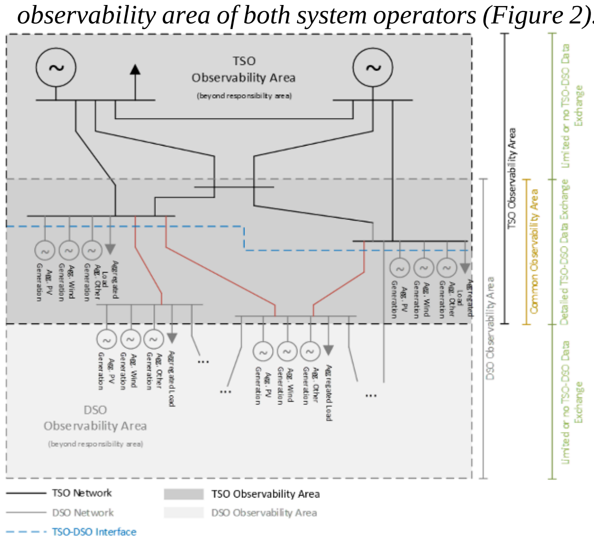

Figure 2 – Example of definition of observability area.

Furthermore, one of the main outcomes of TDX-Assist concerns the proof of concept using field tests and demonstration with industry specification at both TSO and DSO levels. The Portuguese demonstrator, particularly, will focus on:

1. *Coordination of operation planning activities between TSO and DSO. This will improve state estimation and provide valuable information for both system operators bearing in mind the results from the day-ahead market;*
2. *Improve fault location close to the TSO-DSO interface. The aim is to achieve a maximum time delay of 5 minutes to send detailed information about the type of fault and its location;*
3. *Improve system real-time supervision and control through better coordination;*
4. *Application of the Interval Constrained and Sequential Optimal Power Flow tools, demonstrating the characterization and deployment of available flexibility services and congestion management from*

two different networks.

INTRODUCTION

The electrical sector is experiencing a profound shift: on one side, consumers have started to become active market participants, either by taking on the role of prosumer or by engaging in Demand Side Response (DSR); on the other side, the distributed resources (DR) at the distribution level have experienced a significant increase in the generation mix. These trends are expected to continue and will necessitate a revision of the way TSOs and DSOs interact. TSOs and DSOs should encourage this paradigm shift by enhancing and reforming the way they interact with each other, and how they define their roles and responsibilities. Furthermore, an increasing number of European consumers (minimum 80% residential and non-residential) will have smart meters by 2020[1] thus enabling a more digital energy system of the future. In the light of this fundamental change, and proactively, rules have to be defined, governance conceived, and systems reconsidered. Effective coordination between TSOs and DSOs in both real-time and operational planning becomes increasingly important to ensure cost efficient, sustainable and reliable system operation and to facilitate markets throughout Europe. Operating the electricity system closer to its limits translates into the need for smarter grids that require a more efficient exchange of information and data, achieving more frequent updates with less human effort.

TDX-Assist's main objectives

The main aim of this project is to design and develop novel ICT tools and techniques that facilitate scalable and secure information systems and data exchange between TSOs and DSOs. The three main novel aspects of the ICT tools and techniques to be developed in TDX-Assist are: scalability – the tools and techniques will be able to deal with new users and increasingly larger volumes of information and data; security – the tools and techniques will ensure that overall system operation is protected against external threats and attacks; and interoperability – the information exchange and communications between the system operators will be based on existing and emerging international smart grid ICT standards.

HOW TDX-ASSIST DEMO PT ADDRESSES THE CHALLENGES

The Portuguese demo focusses in: (i) demonstrating the characterization and deployment of available flexibility services and congestion management; (ii) evaluating the Portuguese TSO/DSO information exchange in terms of co-simulation and evaluation of different ICT traffic conditions.

Business Use Cases (BUC) and System Use Cases (SUC) of the Portuguese demo

The interactions between the TSO and DSO along different timeframes lead to the identification and development of dedicated business use cases that are illustrated in the Figure 3.

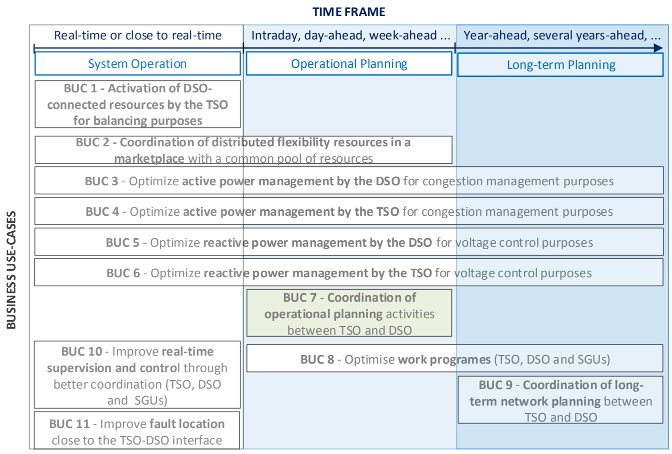

Figure 3 – TDX-Assist complete BUC's list.

In our case a specific focus was given to the coordination of operational planning activities between TSO and DSO. This allows, amid others, to improve programming of networks operation as well as a better network representation based on available forecasts of the load and generation disaggregated by technology type (wind, PV, hydro, CHP, etc.).

For the implementation of the data exchange and its design one needs to consider the following steps illustrated in the Figure 4.

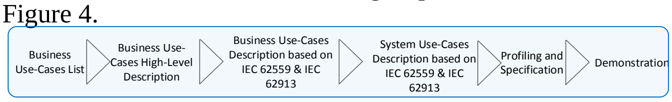

Figure 4 – Steps to demonstration.

The key issues that need to be considered are: frequency on the data exchange, type of data, protocol to be used.

In the PT demo, three main areas were addressed:

1. Exchange of short circuit power at the physical interface between TSO and DSO. This information is initially created by the TSO based on the recent market information, topology changes and sent to DSO to be complemented by the active contribution to the three-phase short circuit current it may present at each interface bus. This involves 30' granularity for the next 24h and results in a pattern similar to a load diagram.
2. Forecast of generation at bus level in the observability area presented in a disaggregated manner by type of generation (ex.: wind; hydro) and type of market player (ex.: energy market; fixed tariff). This aggregated information for all the interconnection points (about 80 points for Portuguese network) will be provided by the DSO in a 15' sampling for a period up to 72 hours and updated each 24 hours.

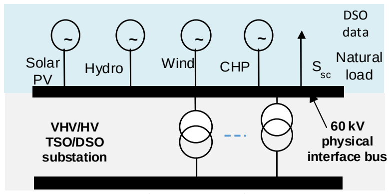

Figure 5 – Example of generation forecast use case.

3. Improve the fault location close to the TSO-DSO

1 European Commission, Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on common rules for the internal market in electricity, 30.11.2016

interface, concretely, the distribution lines owned and operated by the DSO that are directly connected to the transmission bays. The main objective is to start sending the information provided by the distance protections owned by the TSO to the DSO. The access to redundancy of measurements collected by distance protection devices at both ends of distribution lines is a DSO need in order to improve fault location accuracy. TSO exchanges in real-time the fault location data (impedance) with the DSO. Close to real time, the TSO will exchange with the DSO a report with additional information about the fault event and oscillographies details as well.

System's Architecture

In order to allow the real-time exchange of information between REN and EDPD, a communication interface was implemented to establish a link between grid operators based on an Inter Control Centre Protocol (ICCP). The exchange of information includes real-time data concerning REN substations and EDPD substations, resulting in the visualization of the information exchanged through a real-time monitoring TSO/DSO interface.
SCADA systems of both TSO and DSO are connected to the ICCP system, allowing the visualization and analysis of real-time monitored and exchanged data between grid operators.

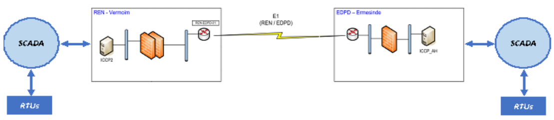

Figure 6 – SCADA system connection between both REN and EDPD.

This connection is redundant at both TSO and DSO side with two independent servers (not represented in the Figure 6). SCADA system of both REN and EDPD receives data from different sources, such as generating and demand facilities, through Remote Terminal Units (RTUs). This architecture allows a high availability, low latency ICCP service between both companies.
For non-real-time exchange of information (forecast, oscillography, maintenance plans, short circuit levels), we adopted the use of the same communication interface/architecture segregated in different VLAN's (for security and confidentiality reasons), connecting the TDX-Assist servers on both sides. Those servers are responsible for collecting the needed information from the different systems and exchange data between both TSO and DSO.

Tools to support the SUC

The tools have as main objective the improvement of cooperation between TSO-DSO through the facilitation of information and data exchange in different applications for purposes from operational planning to real-time operation. In the specific case of the Portuguese SUCs, the tools that will be tested are the SAFIR and SRAO for the fault location close to the TSO-DSO interface and a python API developed for the exchange of short-circuit levels. As mean of communication, depending on the SUC, will be used mainly the ICCP for real time information and Web-Services or SFTP for non-real time data.
About the tools that will be demonstrated for the improvement of the fault location, firstly, we have the SRAO that is a system that automatically gathers the oscillographies from the TSO side.
SAFIR is an application, which is currently under development, for the analysis of incidents through oscillography records with potentialities in the behavioural analysis of the protection systems, with capacity to respond to all the specificities related with the systems installed in the REN substations. In addition, this application is able to carry out incident analysis, behaviour analysis, network and system modelling, monitoring and information gathering, and is capable of developing interfaces and other specific applications of systems already acquired by REN. The information gathered, treated and disseminated in a short time, about an event/incident at any point in the transmission grid, will allow faster and more objective interventions of the REN or EDPD teams. The information provided by SRAO related to the oscillographies registered are submitted to the EDPD via SFTP in COMTRADE format. The SAFIR will provide in real time to the DSO, via ICCP, the information about the location of the fault if that occurs on HV lines coming out from the TSO-DSO interface in order to allow the DSO to quickly identify the location of the fault. Close to real-time is provided a report to EDPD with additional information about the incident, sent via Web-Services.
For the demonstration of the exchange of short circuit levels at bay level it was developed an automated procedure to exchange this information that involves the PF calculation and the short circuit currents taking into consideration the contribution from the EHV and HV with 30' granularity for the next 24 hours. The accumulated contribution for the short circuit levels from the TSO side is then calculated and provided to the DSO via Web-Services. Then they can add the contribution from the active HV from the distribution side. Finally, the total short circuit level, with both contributions, can be shared between operators.

ADDITIONAL FUNCTIONALITIES TO BE DEMONSTRATED

As stated before, one of the main goals of TDX-Assist project is to demonstrate advanced functionalities that enable higher levels of coordination between the TSO and the DSO in an environment of increasing renewable integration. Within the Portuguese demonstrator, improved versions of two tools, which have been firstly developed in the EvolvDSO project [1], will be used to support the operational planning of reactive power exchanges in the interface substations between the transmission and the distribution networks:

- New Interval Constrained Power Flow (ICPF);
- New Sequential Optimal Power Flow (SOPF);

The improvements on these two tools result from the limitations already identified in the EvolvDSO project, namely, the inclusion of discrete control actions (e.g. switched capacitor banks, on-load tap changers, etc.), renewable power uncertainty, and interdependencies in the TSO/DSO interface substations due to meshed connections in the distribution network.
These two tools are used sequentially to:

- decide the reactive power exchange in the TSO/DSO interface substations;

- contract reactive power reserve available in the distribution network to meet the planned exchange considering uncertainty in the distributed generation.

The New ICPF, which is based in the tool proposed in [2], builds reactive power flexibility maps (Figure 1) for the new 24 hours taking into account the distribution network limits (ampacity, voltage, etc.) and forecasts for the flexibility range available in each node. The reactive power flexibility maps, which are computed by the DSO, can be displayed for one interface substation of for pairs of substations. In the latter case, equivalent network models for the transmission network are required to include the electrical dependencies between adjacent interface substations. The use of equivalents for the transmission network is necessary to ensure the DSO has no access to TSO private data. The flexibility maps for the next 24 hours are sent to the TSO, which must select a profile for the reactive power exchange at the desired substations.

After agreeing on a pre-agreed 24-hour reactive power profile, the DSO runs the new SOPF tool to contract the optimal reactive power flexibility (e.g. capacitor banks, transformers with on-load tap changer (OLTC) ability, reactive power production in distributed generators, etc.) to meet the desired profile. Note that this optimization problem must include the uncertainty associated with the renewable power injection. To avoid prohibitively high simulation times, each period is optimized sequentially using the optimal value for the decision variables as an input for the next period. Hence, the New SOPF tool consists on running a two-stage stochastic reactive power management model (Figure 7) in each hour taking into account a representative set of scenarios for the distributed renewable generation, the reactive power flexibilities available, and the reactive power injection policies currently in force for the distribution network.

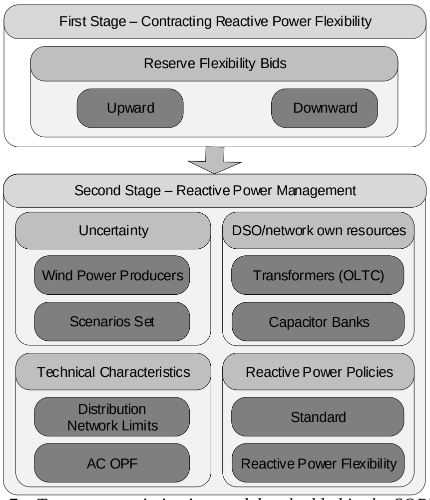

Figure 7 – Two-stage optimization model embedded in the SOPF tool.

As an example, the reactive power policy for the distributed generation in Portugal is based on the sum of inductive and capacitive reactive energy produced by a generating unit in one single hour [3]. In practice, the reactive power depends on the tan ϕ, which is a function of the active power injected by the generating units into the grid. The tan ϕ varies according to the time of the day and must be met within a range of +/- 5%, otherwise financial penalties are applied [9]. The output of the New SOPF tool is the amount and type of flexibility the DSO may need to operate the distribution system in expectation, ahead of the operating hour. More precisely, the optimal scheduling of the static equipment's (capacitor banks and transformers with OLTC) managed by the DSO, as well as the upward and downward reactive power flexibility that should be contracted to the distributed generation to maintain the reactive power profile agreed with the TSO. It's worth mentioning that the active power generation of the DER is previously dispatched, which means that the New SOPF will use the reactive power flexibility to guarantee the reactive power profile required by the TSO. Curtailment of active power from DER is allowed, but highly penalized, limiting the flexibility from DER.

EXPECTED RESULTS

Expected Demo results

Both EDPD and REN aim to fulfil the purpose of the TDX-Assist project which is to develop a framework that allows for an exchange of important information between DSO and TSO.

REN will receive most need forecasting information regarding the real load and generation at the distribution network. This will allow the TSO to have important information for carrying out balancing operations and restoration in case of an outage. Restoration is more complex in a distribution network with high DG penetration because the generation will take more time to connect than the load.

On the other hand, EDPD will receive fault location data which is of crucial importance for field teams trying to locate faults in sometimes difficult circumstances thus minimizing outage times to clients. Furthermore, the upstream short-circuit current at the interconnection point will allow for more accurate short-circuit calculation further downstream but also for more accurate power flow calculation.

ICPF results

As previously mentioned, the New ICPF and the New SOPF tools are currently under development. However, the new sequential SOPF has already been tested for academic distribution network considering the Portuguese policies for reactive power generation [3]. For this purpose, a 11kV distribution network with 37 buses connected to the high voltage network through two power transformers of 10 MVA each was considered. This network supplies 1908 consumers of which 1850 are domestic consumers, 2 industries, 50 commercial stores and 6 service buildings [4]. Consumption characteristics and profiles of each type of consumer and by bus were taken from [5]. The network contains distributed energy resources, namely combined heat and power (CHP) and wind power plants. Generators data is available on [6], where scenarios of wind power generation can be found in [7], [8]. In addition, the study has been modelled considering the Portuguese policies for reactive power generation. Thus, the reactive power production of all DER must be within the limits imposed by the legislation [9]. More precisely, renewable power producers have a tan ϕ equal to 0 in off-peak hours, and tan ϕ equal to 0.3 in peak hours, with allowable variation of +/-5% [9].

Note that the DER active power production is fixed according to a previous forecast of the energy dispatched in each hour. For the wind power plants, a point forecast for the next 24-hours is assumed as well as 10 assimilate scenarios for each hour, as shown in Figure 8.

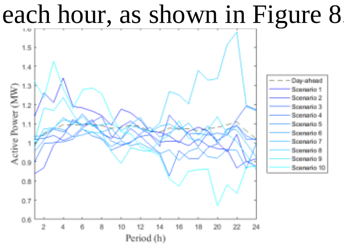

Figure 8 – Point forecast and scenarios of wind power plant throughout 24h.

Taking the wind active power as input, the New SOPF determines the expected reactive power production for each operating hour taking into account the flexibility limits. Figure 9 shows that the New SOPF keeps the tan ϕ of this wind power plant within the +/- 5% range in every scenario.

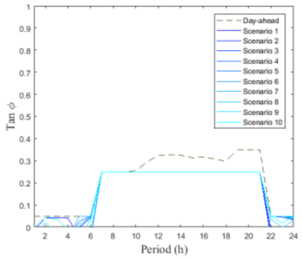

Figure 9 – Forecasted & realized tan ϕ of the wind power plant throughout 24h.

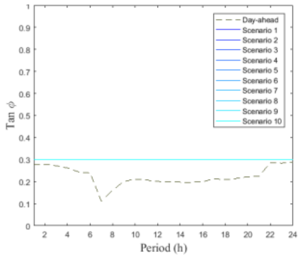

Figure 10 – Forecasted & realized tan ϕ at the main substation throughout 24h.

For simplicity of illustration, the reactive power profile imposed by the TSO assumes a fixed tan ϕ of 0.3. This means that the tan ϕ at the primary substation must be within +-/ 5% of 0.3 in every scenario, otherwise the DSO is highly penalized. Figure 10 depicts the tan ϕ profile at the substation. As expected, the tan ϕ is as close as possible to 0.3 in every scenario to ensure no penalty for the DSO. To this result contributes the reactive power generation of the DERs, as well as the capacitor banks and transformers with OLTC ability.

The reactive power production of the capacitor banks at the main substation is shown in Figure 11. Note that the tap level is at the maximum position in most of the hours and scenarios since the New SOPF relies on these resources as the first to provide and correct reactive power. Still, one can see that the tap position in all scenarios do not change more than four times per day, therefore limiting the equipment degradation.

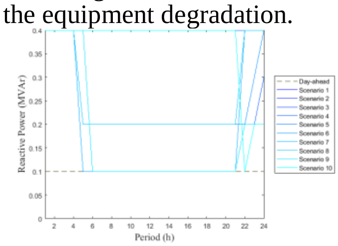

Figure 11 – Tap changer of capacitor banks throughout 24h.

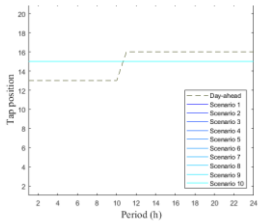

Figure 12 – Transformers with OLTC ability throughout 24 h.

Similarly, the use of the OLTC tap is minimized, maintaining the same position throughout the 24 hours. Note that the optimization taking into account only for the point forecast (day-ahead) leads to a modification on the OLTC tap position during the day as shown in Figure 12. In summary, these results show that the SOPF can effectively reduce the number of tap changes for OLTCs and capacitor banks depending on the costs associated to the use of these resources and also to the costs of the flexibility provided by DER. Moreover, the New SOPF successfully dispatches enough reactive power flexibility from DER to follow the reactive power profile required by the TSO at the upstream connection (main substation) of the distribution grid, enabling the DSO to participate in new services of reactive power provision to the TSO.

CONCLUSION

The exchange of bi-directional information between DSO and TSO is already important and it will be ever more important in the future as the generation increases in distribution side. A reliable future grid operation will be based on information exchanged between DSO a TSO.
Portugal's demonstration in the TDX-Assist program will demonstrate the exchange of several types of relevant information for both DSO and TSO. Furthermore, several tools, already under development by INESC-TEC, will also be assessed to determine distribution network reactive power supply, or absorption, capabilities at the DSO/TSO interconnection point in high DG penetration environment.

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