FLEXIBILITY HUB – MULTI SERVICE FRAMEWORK FOR COORDINATION OF DECENTRALISED FLEXIBILITIES

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ABSTRACT

EU-SysFlex H2020 project aims at developing and testing innovative tools for the integration of high levels (above 50%) of renewable energy sources (RES) in the pan-European Electricity system. These high levels of RES will increase the need of new sources of flexibility to support the system services, since there will be a decreasing number of conventional power plants on the grid. In this context, this paper describes the Flexibility Hub (FlexHub) concept, consisting in a platform of tools managed by the DSO to facilitate market-based flexibility provision to the TSO using resources connected to the distribution system. The FlexHub is part of the systems to be tested in the EU-SysFlex project, in the Portuguese demonstrator. It includes the provision of flexibility to the TSO in terms of active power (with an extended restoration reserve market) and reactive power (in a local set market), and the provision of an equivalent dynamic model of the distribution grid for TSO dynamic grid analysis.

INTRODUCTION

The EU is undergoing a deep energy transition towards a decarbonized energy system. This entails a continuous increase of renewable energy sources (RES) and distributed energy resources (DER), as well as the progressive closures of greenhouse gas (GHG) emitting plants, with coal plants first, [1], and gas plants in later phases, [2]. Under this scenario, new strategies will need to be demonstrated in order to increase system flexibility [3] at minimum cost, while maintaining a secure and stable operation. Ancillary services traditionally provided by large conventional generation are progressively being replaced by renewable-based generation spread throughout the grid. The need for improved flexibility is, in fact, already being translated into grid codes, as it is the case of the European Union [4]. According to it, even smaller units connected to the lower voltages levels of the grid are required to participate with the provision of frequency and voltage regulation functionalities, such as frequency sensitive mode (for over-frequency phenomena) and fault ride-through (FRT) capability.

These transformations will require adapting the current power systems to deal with these new challenges. For example, improving temporal granularity of markets by approaching gate closure to real time and reducing time-duration products, [5] could contribute to better integrating RES and DER (note that there are already EU market reforms aligned with this, [6], [7]). Indeed, RES forecasts performed too much time in advance entail larger errors, pressing the TSO's to contract larger amounts of reserves (FCR, FRR, and RR, [8]), increasing reserves costs and imbalance risks. In addition, the integration of DERs also reinforces the need for shorter time products and closer to real-time markets, since many DER technologies are well suited for generating, consuming, or shifting consumption of electricity in short intervals. Frequent market sessions can provide fairer economic value of the existing flexibility, since system operation becomes more inflexible as it approaches real time, incentivizing early imbalances solving. However, too many sessions (high frequency of sessions) could also reduce markets liquidity. Incentivizing the participation of new sources of flexibility to provide dispatchable load or generation for balancing is also essential. In this sense, new types of resources should be allowed to participate in the market (see for example [9], [7]), and bids formats reviewed to adapt them to these new resources, [5], so as to allow market agents to include information about their costs and operating constraints in their bids.

In this new scenario, the increase of DER and their active participation in the system operation is also expected to transform the distribution networks, by significantly increasing the complexity of their dynamic behavior and the way they interact with the upstream transmission network. Traditionally, when assessing power systems stability, system operators (typically TSOs) represent the whole distribution chain with passive loads. However, this is no longer representative, meaning that new models able to capture the complex and active dynamics of the

distribution are needed, [10], [11], [12]. Therefore, in order to deliver a proper representation of the distribution networks while maintaining acceptable computational time and guaranteeing confidentiality issues between DSO and TSO, improved mechanisms enabling these interactions become a relevant challenge under the energy transition scenario.
This paper proposes the DSO Flexibility Hub (FlexHub) concept to address some of the above mentioned challenges (that EDP and INESCTEC are designing and implementing). The main contributions of the FlexHub are:

- A new innovative local market design to provide reactive power from resources connected to the distribution grid, to compensate for the decrease of the resources currently providing this service. The proposed market increases the temporal granularity with respect to many other current market's structures [13], decreasing the product time-duration, as well as allowing bids closer to the market gate closure. It also combines an extended delivery time with complex bids, designed according to the expected participating resources, to facilitate the adaptation of the cleared schedules to the real operating constraints of the new assets providing the service. Finally, the market designed also provides additional flexibility to the market agents, since they can correct future previously scheduled positions by participating themselves to adjust their previous positions to their future availability, strategy or needs.
- A new innovative market design to provide active power from resources connected to both the transmission and distribution grids. This market is a redesign of the current restoration reserve (RR) market [13], with increased temporal granularity (as for the previous case), reducing the time-duration of the products. It also increases the delivery horizon, so that in combination with complex bids (designed according to the resources that could provide the service) it helps market agents to adapt the clearing schedules to the real operating constraints of their assets. Finally, the market designed also provides additional flexibility to the market agents, since they can also participate to correct previously scheduled positions according to their future availability, strategy or needs.
- A new simplified equivalent dynamic model of the whole distribution grid for frequency and voltage disturbances at the TSO/DSO connection point, to provide a more realistic dynamic behavior of the grid. The increasing penetration of distributed resources is transforming the distribution grid into more complex and dynamic structures with larger impact on the transmission grid dynamics, so these models would contribute to improve TSO dynamic analysis. The proposed model allows to include a larger diversity of distributed generation technologies than existing approaches, [10], [11], [12].
- A new platform that promotes the interaction and coordination between TSO and DSO for enhanced system operation.

This paper is organized as follows: The next section reviews the general FlexHub architecture and the demonstration resources that will be available for testing. Each of the services provided by the FlexHub are afterwards described in the following sections. Finally, the main conclusions are presented.

FLEXIBILITY HUB ARCHITECTURE

The Portuguese demonstration will be developed at the distribution grid connected to Frades primary substation. Frades is a 20 MW TSO/DSO substation located at the north of Portugal, with 40 transformers that provide service to about 8000 grid connection points, 90 MW of installed RES (larger than the grid consumption), and 2 distribution high/medium voltage (HV/MV) secondary substations. Flexibilities come from 46 MW of wind active power, with reactive power ranging between -50 Mvar and +50 Mvar. Figure 1 represents a very simplified architecture of the FlexHub. It uses the updated grid configuration and the real and forecasted active and reactive power flows from DSO information systems, and the bids from the market agents, to provide the flexibility services described in the following sections, and summarized in Figure 2.

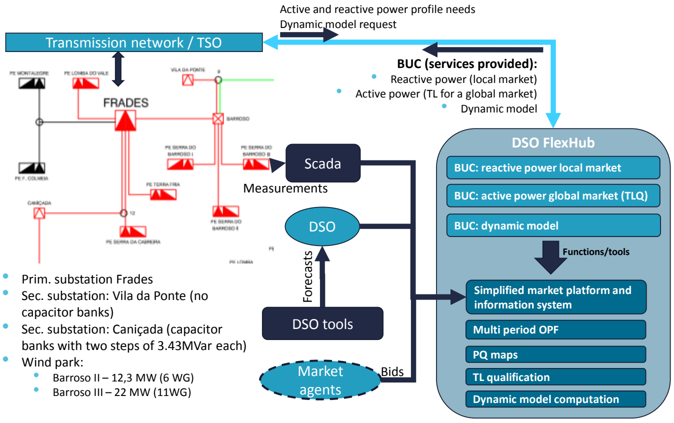

Figure 1: Flexibility Hub simplified architecture

Figure 2 represents the three business use cases (BUC) designed to provide the three FlexHub services, as well as its implementation in system use cases (SUC), corresponding to the main activities of each BUC, explained in the following sections:

- Provision of reactive power flexibility with distributed resources;
- Provision of mFRR/RR type reserves with distributed resources:
- Provision of an equivalent dynamic model of the (active) distribution grid to the TSO.

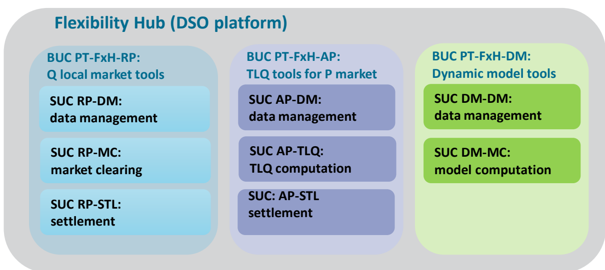

Figure 2: Flexibility Hub BUC and SUC

REACTIVE POWER LOCAL MARKET

For this market, the time interval between two deliveries (and duration-time of the product) is 15 minutes, and the market is cleared 10 minutes prior to each delivery. The delivery horizon is up to 7 hours (28 time intervals, see Figure 3).

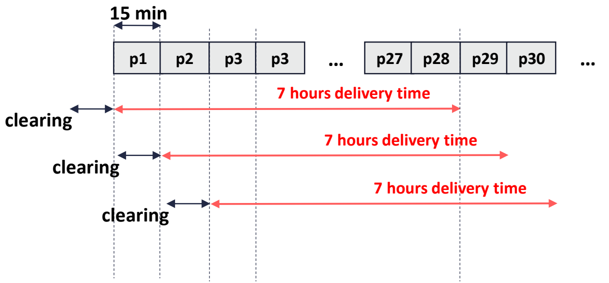

Figure 3: Time intervals and delivery horizon in a time-frame

Figure 4 shows the sequence of activities for a unique market session.

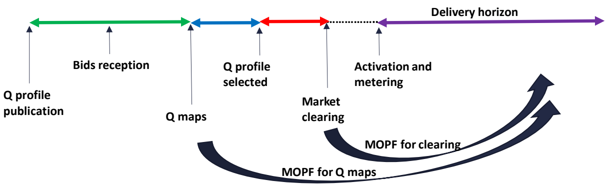

Figure 4: Activities sequence for a unique reactive power market session

The TSO publishes the reactive power profile needed for the next time delivery horizon (corresponding to an inflexible bid) or directly bid with the desired price to deal with market uncertainty. Market agents can send their bids for each delivery period to supply the needs of the TSO or to balance their own position to modify previously assigned schedules. A multi-period optimal power flow (MOPF) is used to inform the TSO of the available reactive power for a set of predefined cost ranges (Q-maps, according to the methodology described in [14]), and to perform the market clearing for the final profile selected by the TSO after considering the cost ranges availability of the Q-maps.

The length of the delivery horizon allows avoiding excessive switching of particular assets (for example for capacitor banks), by using the complex conditions of the bids. Bids include the amounts of reactive power offered for each time-period and its price (see for example [15] or [16] for the cost assessment of providing reactive power), and also accept the possibility of not curtailing individual time-periods (for example for discrete steps assets), or not curtailing any of the offered quantities (to avoid switching during the whole delivery period). Since market sessions are continuous, positions can be adjusted in following sessions, if market liquidity is large enough.

Market is cleared by maximizing the social welfare with network constraints. Cleared bids with complex conditions not holding are iteratively discarded until all the complex conditions of the cleared bids hold. To make use of existing DSO resources for reactive power control, these resources (being paid with non-market regulated mechanisms) are used first by the clearing algorithm, and it is the remaining residual reactive power demand that is supplied with market bids.

EXTENDED RESTORATION RESERVE MARKET

This market is an extension and improvement of the current Portuguese RR market by increasing time granularity with a same time-frame as shown in Figure 3, and allowing bids with distributed resources. To avoid distribution grid constraints problems, bids containing distributed resources are marked for future checking. As Figure 5 shows, the TSO selects bids iteratively to fulfil its active power needs for the next delivery horizon. In case a bid containing resources in a distribution grid is selected, the FlexHub associated to the corresponding distribution network is called to compute the traffic light qualification (TLQ) before the bid is cleared. The TLQ indicates if the resources offered can be activated totally (green light), partially (yellow light, which also informs on the quantities that could safely be activated) or cannot be activated (red light) and must be discarded due to violations of distribution network constraints. The process of selecting bids and performing the TLQ when needed is repeated until the TSO's needs are met.

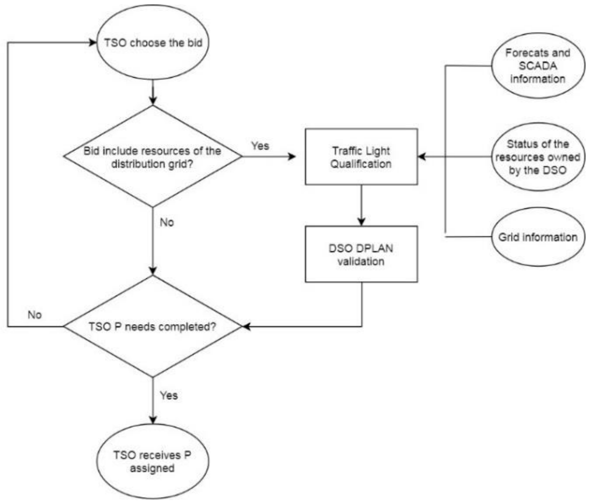

Figure 5: Traffic light qualification

As for the reactive power market proposed, bids format also accepts complex conditions. In this case, in addition to the non-curtailability conditions that were also accepted in the reactive power market, additional conditions such as ramp rates or maximum energy (to facilitate bidding storage) are also accepted.

Figure 6 shows the sequence of activities for a unique market session.

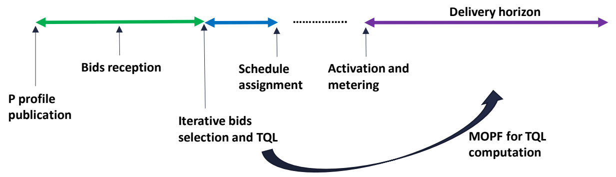

Figure 6: Activities sequence for a unique active power market session

Since bids assignments may involve curtailments, a MOPF is used to determine the final assignment per individual resource according to the grid constraints by minimizing the total curtailment.

EQUIVALENT DYNAMIC MODEL

This service is to provide an equivalent simplified dynamic model of active distribution grids, to be used by the TSO when assessing network's transient stability, suited for frequency and voltage disturbances. It is based on a general model structure designed to represent most Portuguese HV distribution grids operated in a meshed configuration, shown in Figure 7.

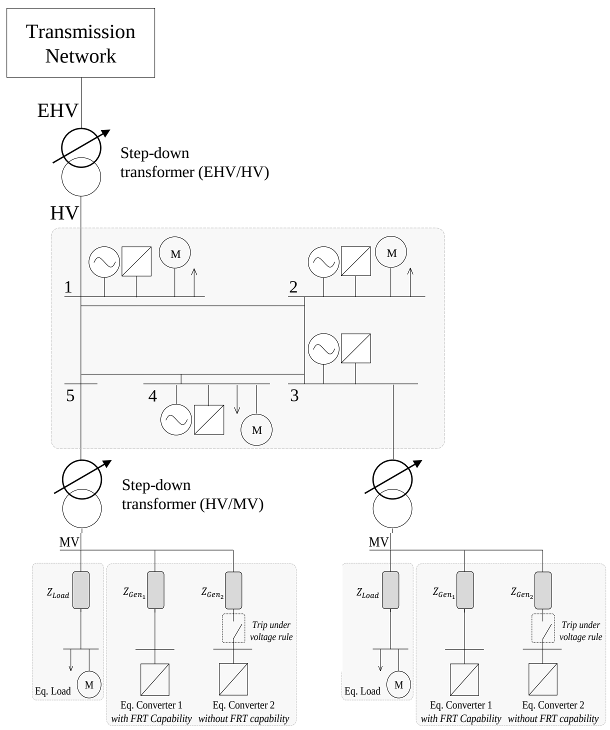

Figure 7: Equivalent dynamic model structure

The model is built by adding the dynamic contribution of each type of component connected to the grid. The main components considered are synchronous generation, converter-connected generation (for RES and storage representation), composite loads, and MV (radial) networks equivalent. The latter follow the same rationale, by considering the addition of converter-connected generation (small RES and storage, with and without FRT capability) and a composite load. These components are connected in parallel to the HV/MV power substation using equivalent impedances, for voltage drop representation.

Parameters fitting (training process) is performed with an evolutionary particle swarm optimization (EPSO) algorithm, [17]. This process minimizes the frequency-domain quadratic error between the real (or coming from a detailed grid model) aggregated active and reactive power flows at the transmission/distribution power substation, and those obtained with the simplified model, for voltage and frequency disturbances scenarios occurring at the transmission level. The model is tested with new scenarios to validate its robustness. This process is represented in Figure 8.

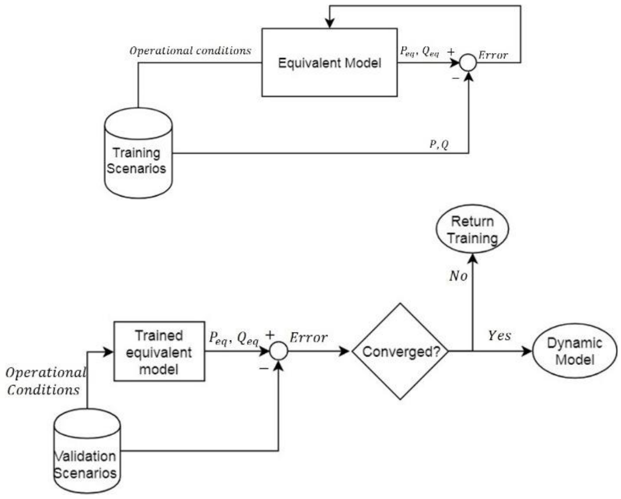

Figure 8: Training and validation process of the equivalent dynamic model

CONCLUSIONS

This paper presents the Flexibility Hub concept, an ambitious set of tools to help the DSO to provide flexibility services (active and reactive power flexibility) and grid dynamic information (by means of the equivalent dynamic model) to the TSO. The Flexibility Hub is being develop in the H2020 Eu-SysFlex project (LCE-04-2017) and will be demonstrated as part of the Portuguese demonstrator. Being an ongoing research project for the provision of services under a high RES scenario, there are many uncertainties, complexities and limitations to be considered. Some of them are:

- The high RES integration scenario assumes that many resources will be located at the distribution grids, making feasible the possibility of developing local markets in these distribution grids. However, liquidity could be a serious drawback which could entail the need of an alternative regulated procedure to provide the service or market supervision.
- Reactive power markets are frequently questioned due to the complexity of pricing reactive power. Some argue that prices could be extremely low in most hours (due to the very low variable costs of providing reactive power, mainly associated with losses), so that

investments costs of sizing resources to provide this service would need to be recovered in few hours of scarcity with high prices, with the corresponding disincentivizing uncertainty. However, this pricing problem could also happen soon in energy markets with high RES expected, and solutions (such as capacity mechanisms, bidding with long term variable costs, etc.) will also be needed.

- For both reactive and active power markets, designed times are exigent, and algorithmic computation, information exchanges and resources activation will need to fit in short time-periods. The demonstration will allow to test the validity of the proposed duration-time products and activation times, or the convenience of extending this times by losing part of the temporal granularity of the current designs. In addition, the detailed implementation and further testing will surely impose additional constraints and design improvements to the current proposals.
- Further research will help to see if more simplified structures can be used for the dynamic model, while maintaining a good level of representativeness and robustness, being part of an ongoing INESCTEC's PhD thesis.

Future works are the real implementation and testing process in the Portuguese demonstration to assess the feasibility of the proposed approaches. The developments will also provide software platforms for further markets performance analysis, which could contribute to assessing the main benefits and drawbacks of the proposed approaches.

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