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Identification of Conflicts between Transmission and Distribution System Operators when Acquiring Ancillary Services from Electric Vehicles

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***Abstract*—Distributed energy resources are able to provide services to grid operators, possibly with competing objectives. With the development of active distribution grid management, various market designs arise. Here, a reference market framework is considered, which allocates the available flexibility products according to requests coming from both distribution and transmission system operators. The goal of this paper is to provide an identification procedure that is able to detect, identify and catalogue possible conflicts among the involved stakeholders that take place when requesting and/or acquiring ancillary services from flexible units. The investigation is carried out considering a 3-area power system which allows to take into account local constraints as well as system-wide needs. As outcome, this paper identifies the conflicts from both a theoretical and a practical point of view, by means of descriptions/identification procedure and by visual examples, respectively.**

***Index Terms*—Ancillary services, Distribution system operator, Electric vehicles, Transmission system operator.**

I. Introduction

With the increasing penetration of intermittent distributed energy resources (DERs) in modern power systems, the need for additional ancillary services is evident, especially for balancing purposes. Furthermore, the displacement of traditional large power plants due to increased decentralization of generation poses challenges to transmission system operators (TSOs). In fact, they need to control the power system without access to conventional ancillary services from a few large power plants. This calls for replacing the traditional service providers with aggregated units mostly connected to low voltage (LV) grids.

By contrast, distribution system operators (DSOs) are facing technical challenges in accommodating the increasing amount of new electrical loads, e.g., electric vehicles (EVs), while searching for solutions that defer investment in grid reinforcement.

Since grid balancing is a responsibility of the TSO, whereas respecting the local grid constraints needs to be assured by the DSO, it is clear that greater cooperation between TSOs and DSOs is needed [1], [2].

Within this context, if managed properly, EVs become flexible resources that can improve the system operation, making them an attractive asset for both transmission and distribution system operators. In fact, EVs can be considered as distributed energy storage systems with large potential for network regulation [3], [4]. EVs can be capable of adjusting the battery charging process in order to provide different ancillary services for supporting the power grid, such as primary frequency control or voltage control [5]–[7].

It is clear that flexibility provided by EVs can match different needs and could potentially create conflicts dependent on which stakeholder uses flexibility and for what purpose. Flexibility products should be allocated based on technical and economic optimization, i.e., flexibility should be used where its potential is the highest [8]. Many possible market frameworks are proposed in the literature [9]–[13], defining roles and responsibilities of the involved stakeholders in different situations. In this work, a framework similar to the '*Common TSO-DSO Ancillary Service market model*' presented within the SmartNet project [13] is introduced. As a specific trait, it has a single flexibility platform, which has to cope with all the flexibility requests presented by the system operators, as well as the flexibility offers received by the aggregators.

The goal of the paper is to propose a catalogue of possible TSO/DSO conflicts that can take place when it comes to acquiring flexibility products. Furthermore, the work presents the logical assessment employed for the identifications of such conflicts, with highlighted research questions for future investigations. A simplified 3-area power system is taken as a reference for the investigation in order to consider both the local constraints and the system-wide needs. It is worth mentioning that the definition of an internal multi-objective optimization algorithm that would be implemented by the flexibility platform operator is out of the scope of this work.

II. EV Flexibility Characteristics and involved Stakeholders

Distributed energy resources are potential providers of flexibility services. This Section aims at defining a "flexibility product" when providing services either to DSOs or TSO, similar to the ancillary services for the TSO. The flexibility product can be defined as *the power adjustment sustained from a particular moment for a certain duration at a specific location* [10]. Among the various types of DERs, EVs are alleged to have special potentials that make them one of the most prominent sources of flexibility. Indeed, EVs are relatively large loads which are expected to be grid-connected and available for long periods of time (high degree of flexibility), and claim quick-response (even lower than 0.5 s [4]) potentially with bi-directional power flow capabilities (V2G) [3]. In this respect, the grid services that they can provide are presented in Table I [3].

TABLE I. EV Grid Services Adapted from [3]

System-wide services	
Name	***Description***
Primary Frequency Regulation	It keeps the frequency in an interval around 50 Hz
Secondary Frequency Regulation	It restores the frequency to 50 Hz after deviations
Tertiary Frequency Regulation	It replaces secondary regulation
Synthetic Inertia	It aims at emulating the mechanical inertia of the traditional rotating synchronous generators
Adaptive Charging	The charging is delayed or advanced in time based on, e.g., energy cost or renewable contents
Distribution grid services	
Name	***Description***
MV/LV Transformer and lines congestion management	It helps to mitigate over-loading of distribution transformers and cables
LV over-/under-voltages management	Massive penetration of small RES units as well as EVs could lead to over- or under-voltages
LV grid phase balancing	Single-phase EVs could help to mitigate the phase unbalances in LV distribution networks
Islanded microgrid and black start	One or a set of EVs able to sustain a small power system could be a valuable resource

The main stakeholders involved in the trading of EV flexibility products are listed below [11]:

TSO - responsible for the transmission system operation stability. It needs services, among others, for frequency control (from primary to tertiary reserve) and voltage support for the transmission grid.

DSO - responsible for the distribution grid operation and thereby for ensuring power delivery to customers at all times, without disturbing the transmission system. It needs services, among others, for peak-shaving (MV/LV transformer or lines congestion management) and local voltage control.

Balance Responsible Party (BRP) - financially responsible for the energy acquired from the power market. In case of deviations from the purchased energy, the BRP has to pay for imbalances to the TSO, since the TSO is forced to activate additional regulation in order to correct the imbalances.

EV owner - willing to offer flexibility to the EV aggregator within certain comfort and technical boundaries.

EV aggregator - collects all the flexibility offers from the EV owners of his fleet, makes correspondent contracts with them, and bids in the market. Based on individual EV capabilities, flexibility products are grouped and offered to the market.

III. Today DSO's role and Proposed Market Framework

Nowadays, in many European countries the TSO ancillary service provision from flexible DER units connected at LV levels is already possible. On the other hand, DSOs cannot acquire local services from the same DERs, since there is not yet a role for DSOs in the market [13]. Therefore, in the current market setup, the TSO/DSO conflicts that could take place mostly concern the local technical constraints of the distribution system infrastructure. In fact, since connected at a distribution level, DERs' adaptive management aimed at providing a TSO service may lead to local grid constraints violations. In particular, the induced technical issues that the DSO is supposed to face would mostly be congestions or under/over voltages. A possible mean to reduce these conflicts as much as possible is the enhancement of TSO/DSO cooperation. This can be achieved by information and data exchange in the grid expansion planning phase (long term), for congestion management contracts (long/medium term), as well as for the real time operation (short term) [8].

This work assumes a possible future DSO role as an active market player. In [14], several key attributes essential for the successful operation of future flexible distribution systems are identified, along with the possible DSO designs. The considered future European DSO model is called *evolvDSO* [15] and is expected to take the following responsibilities: network planning and operation processes, contracting of flexibility services and market facilitation with cooperation between system operators. Within this framework, it is clear that – compared to the contemporary situation – new issues will arise: not only technical but also economical and political when considering remuneration schemes and potential conflicts of interests. Thus, in order to catalogue such conflicts between TSO and DSOs when acquiring flexibility products, the prominent flexibility market framework is taken as a benchmark [13]. It includes all the listed stakeholders and defines a new day-ahead market dynamics in fact such a framework is analyzed with respect to the day-ahead trading of EV grid services. As a specific trait, it has a single flexibility platform that has to cope with all the flexibility requests presented by the system operators as well as the flexibility offers received by the aggregators. In this way, it is expected that grid constraints are implicitly taken into account, since the flexibility operator would manage both information about the location of flexible sources and the DSOs' needs for flexibility in different areas. The DSOs' flexibility requests are formulated according to the forecasted demand profiles that each DSO receives from the suppliers. Moreover, such a platform is supposed to allow flexibility procurement without jeopardizing the grid operation or creating extra costs [13]. A scheme of the

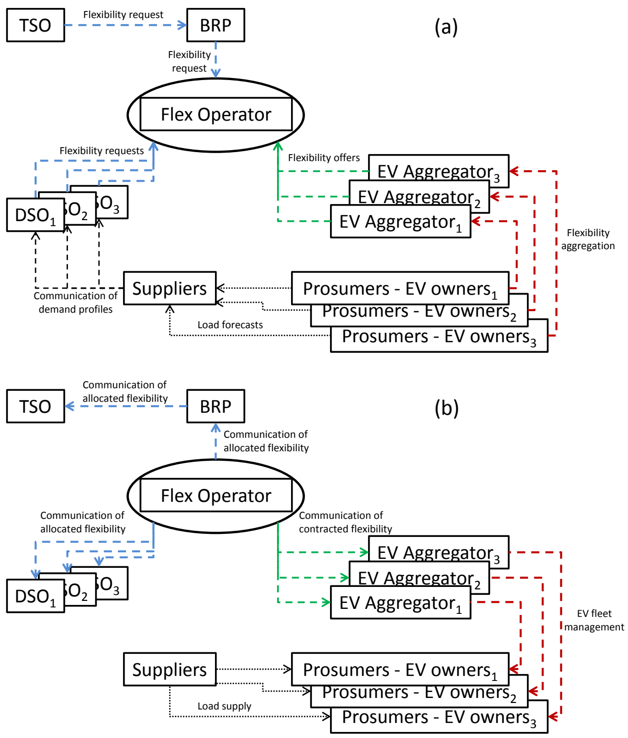

Figure 1. Proposed flexibility market framework for the day-ahead trading of EV grid services. (a) and (b) show the interactions among the involved stakeholders before and after the clearing process, respectively.

considered market framework is depicted in Fig. 1. It operates in several phases:

Phase 0 – Before the clearing process: the suppliers communicate to the DSOs the forecasted load profiles of their customers. EV aggregators contract flexibility with the EV owners in their fleets. The TSO trades flexibility through the BRP. (Fig. 1-a).

Phase 1 – Before the clearing process: DSOs and BRP present flexibility requests to the Flex Operator according to the information received by the suppliers and the TSO, respectively. EV aggregators offer flexibility according to the contracted aggregated availability from their EV fleets. (Fig. 1-a).

Phase 2 – The clearing process: the Flex Operator performs an evaluation based on multi-objective optimization algorithms that aim at optimally allocating the available flexibility products from a technical and economical point of view (e.g., respecting the technical needs while minimizing the total costs). The evaluation naturally considers that DSOs' local flexibility needs are linked to a particular localized congestion problem, whereas the TSO needs flexibility to maintain the system stability independently on the location of the resource. Eventual conflicts are identified and addressed according to the methodology proposed in Section IV.

Phase 3 – After the clearing process: the Flex Operator communicates the obtained optimal flexibility profiles to DSOs, BRP and EV aggregators, who will properly manage corresponding EV fleets. (Fig. 1-b).

IV. TSO/DSO Conflicts and Proposed Method for Identification

Different needs for flexibility services of each involved stakeholder can raise potential conflicts between two or more stakeholders with opposing needs. In fact, the activation of a given service could have a negative influence on other stakeholders or there could be a limited availability of flexibility, thus, only one stakeholder could acquire it. Within the market framework proposed in Section II, this kind of conflicts will be taken into consideration by the Flex Operator platform, which will detect them and then address them accordingly.

The goal of this Section is to provide an identification procedure, which is able to detect, identify and catalogue possible DSO/TSO conflicts that take place when requesting and/or acquiring flexibility products.

Since the complexity of the problem brings enormous amount of different potential conflicts, the here-presented analysis focuses on conflicts coming from TSO and DSOs flexibility requests for acquiring two specific services, namely primary frequency regulation and transformer congestion management, respectively.

Within this context, four conflicts have been identified:

Conflict (a): Need for compensating imbalances caused by activation of flexibility for solving a local distribution issue. The need for activating a service to solve a local DSO problem in a particular area may cause a problem at a system level in terms of balancing. In fact, considering a system in balanced operating conditions, a consumption decrease for preventing congestion at a distribution level would force the BRP to increase the consumption elsewhere. In this way, the balance would be guaranteed and the local congestion would be prevented.

Conflict (b): To solve a TSO request, activating the only available flexibility product causes distribution overloading. It concerns the prioritization problem between DSOs and TSO. When activating the only available flexibility to satisfy a TSO request would cause distribution overloading.

Conflict (c): The available flexibility can satisfy either the DSO request or the TSO request. It concerns the prioritization problem between DSOs and TSO. The offered flexibility would not be enough to satisfy all the needs.

Conflict (d): One flexibility product can solve several problems. Rather than a technical conflict, c*onflict (d)* presents an economical conflict that the Flex Operator may face mainly when remunerating aggregators. In fact, one offered asset could have all the necessary capabilities to concurrently satisfy both a TSO and a DSO need. Thus, it is important to define a fair way to remunerate the aggregator.

The flow-chart diagram in Fig. 2 shows step by step the proposed procedure that the Flex Operator is supposed to follow when managing flexibility requests and offers.

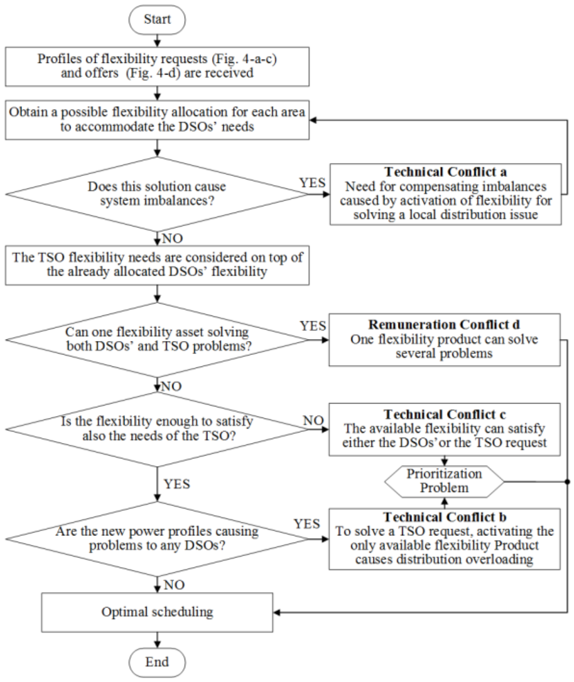

Figure 2. Flow-chart of the DSO/TSO conflict detection methodology.

First, the Flex Operator receives flexibility requests from DSOs and TSO as well as the offers profiles from the aggregators. Then, a possible allocation of flexibility over time for each location is formulated to accommodate the DSOs' needs. So, the Flex Operator checks whether the new power profiles (original DSOs' demand profiles over time with the addition/subtraction of the activated flexibility) would introduce problems from a balancing point of view. In this case, *conflict (a)* would be identified, and a new resource allocation would need to be obtained. Once a solution that does not introduce imbalances is found, the flexibility needs of the TSO are considered on top of the already allocated shares for the DSOs' needs. At this point, the methodology proposes to check whether with the same flexibility product both DSOs' and TSO's problems are solved. If yes, the best solution from a social point of view would be found, as it would involve the least possible amount of flexibility to satisfy all the needs. Though, the remuneration *conflict (d)* would be identified, which needs to be addressed while – in parallel – formulating the optimal solution. In case *conflict (d)* is not detected, the check on the presence of the other eventual technical *conflicts (b)* or *(c)* needs to be done. In particular, they concern the prioritization problem between DSOs and TSO when the offered flexibility is not enough to satisfy all the needs

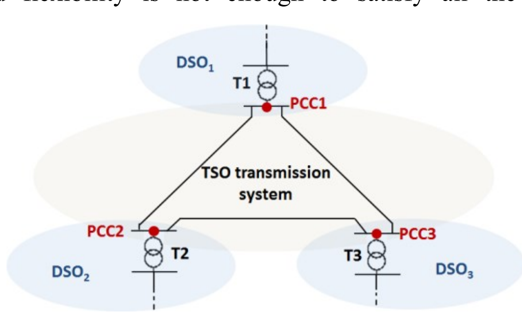

Figure 3. 3-area power system.

(*conflict (c)*), or in case the activation of the only available flexibility would cause distribution overloading (*conflict (b)*). Once one of these two conflicts is detected, an appropriate multi-objective optimization algorithm would be necessary to find an optimal solution, which will finally be communicated to all the involved stakeholders.

Within the contemporary market situation, it is clear that the proposed conflict detection methodology may change. In fact, the Flexibility Operator would have to manage requests for flexibility coming only from the TSO, so the only possible conflict would be *conflict (b)*. Thus, after receiving requests and offers, the Flexibility Operator would have to check whether problems are caused to DSO. If yes, then *conflict (b)* would be detected, and the optimal solution would be decided by the prioritization agreement and finally communicated to the involved stakeholders.

V. TSO/DSO Conflict Identification Examples

The proposed analysis is based on the investigation of possible dynamics in which the listed conflicts could take place. The investigation is carried out considering the simplified 3-area power system shown in Fig. 3. TSO's transmission lines link the DSOs' areas to each other through three transformers (T1, T2 and T3), whose points of common coupling are named PCC1, PCC2 and PCC3, respectively.

As aforementioned, for the sake of simplicity, the analysis considers only the need of preventing overloading of T1, T2 and T3, while all the others DSOs' technical needs (such as line congestion, under/over-voltages, or phase unbalances) are neglected. Regarding the TSO needs for ancillary services for primary regulation, a certain profile is assumed to be requested. Note that the TSO needs reserve, i.e., availability of flexible units to solve a problem that could potentially take place. On the other hand, for the DSO the flexibility product represents a real need for power to solve a concrete forecasted congestion problem.

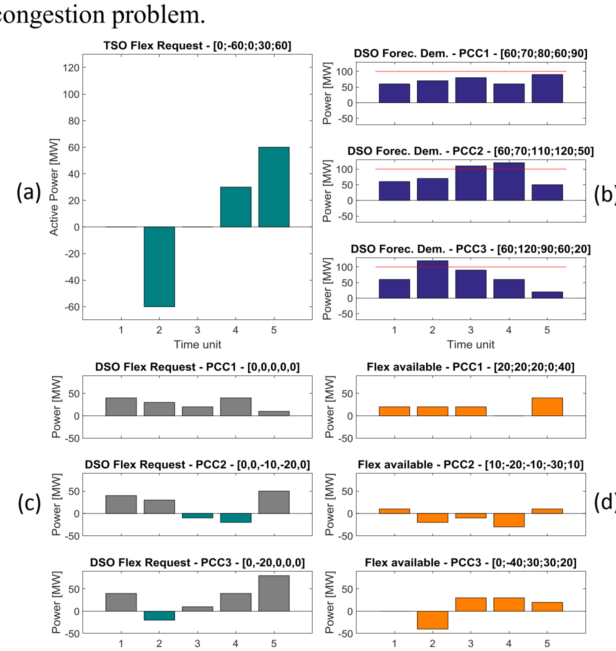

Figure 4. TSO (a) and DSO (c) flexibility requests over the time, DSO forecasted demand (b), and flexibility available in each area (d).

In order to allow a visualization of the involved forecasted/requested/available flexible power sets, a schematic representation is given. For each area, bar plots over the time represent the amount of flexibility (in this case positive or negative active power) that is requested by DSOs and TSO as well as the available flexibility offers, as in Fig. 4.

Fig. 4-a shows the TSO request of flexibility over the time, here expressed in Time Units of 15 minutes. It can be seen that at Time Unit 2, there is a need for up-reserve, which would mean power consumption curtailment due to a possible excess of generation. Whereas for Time Units 4 and 5 there is a need for down-reserve, which would mean total power consumption increase. In case of Time Units 1 and 3 no flexibility is requested. Fig. 4-b reports the power demand profiles at PCC1, PCC2 and PCC3 forecasted by the DSOs. Accordingly, each DSO will formulate correspondent flexibility requests to prevent transformer congestion, as shown in Fig. 4-c. It can be seen that for T1 no congestion situations are forecasted, whereas for T2 and T3, congestions are forecasted for Time Unit 3 and 4, and Time Unit 2, respectively. An example of possible flexibility offers is reported in Fig. 4-d which shows the available flexibility over time at the three points of common coupling.

Herein, examples of each one of the identified conflicts that the Flex Operator could face are presented. In particular, Fig. 5 to Fig. 8 report the new area-by-area power profiles that the Flex Operator obtained following the methodology proposed in Section III. Graphically, bar plots show the DSOs forecasted demand profiles over time at the three PCCs, with the activated flexibility, which is added (orange) or subtracted (dashed white) in order to satisfy the requests.

An example of system imbalances caused by flexibility activation for solving a local distribution issue (*conflict (a)*) is schematized in Fig. 5. It can be seen that at Time Unit 3, congestion of T2 is solved. Nevertheless, as noticeable from Fig. 4-a, the system was already balanced. Therefore, the BRP would need to rely on other flexible products located in other areas (in this case in area 1), to maintain the system balance.

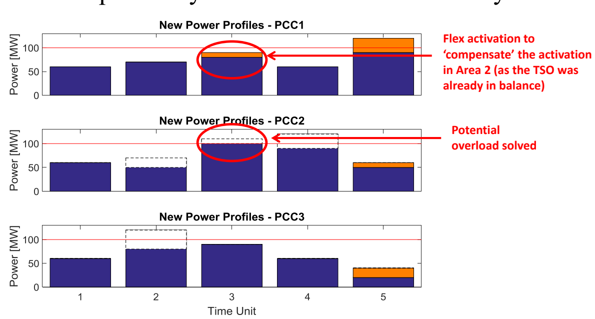

Figure 5. New profiles for each area: original DSOs demand profiles over time with the addition/subtraction of the activated flexibility. Example of compensation of activated DSO flexibility, to keep the system balanced.

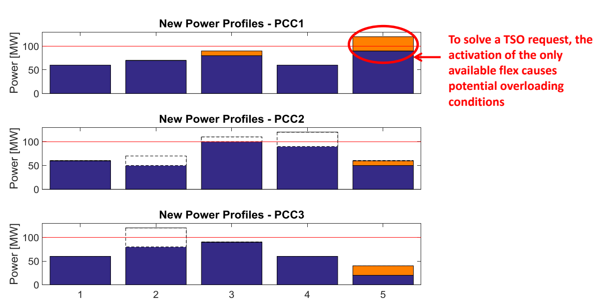

Figure 6. Example of induced congestion problem to DSO, due to the activation of flexibility to provide a service for the TSO.

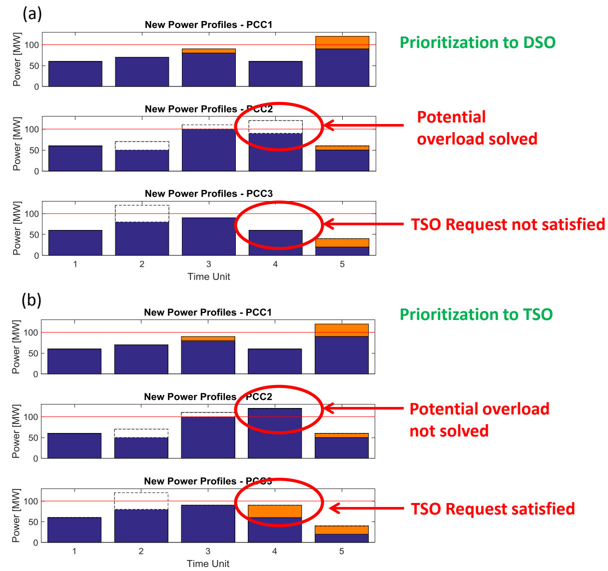

Figure 7. Example of prioritization problem when acquiring the available flexibility: it is possible to solve either the DSO (a) or the TSO (b).

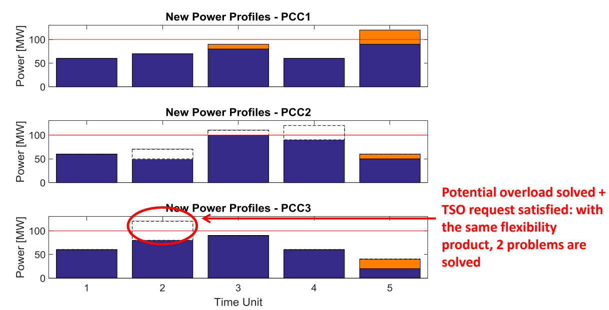

Figure 8. Example of satisfaction of needs of both DSO and TSO, by exploiting the same flexibility product.

Fig. 6 depicts one possible situation which could lead to *conflict (b)*, i.e., when solving a TSO request, the activation of the only available flexibility causes distribution overloading. It can be seen that at PCC1 at Time Unit 5, an overloading condition is caused.

As an example of a possible situation of *conflict (c)*, the need for prioritizing a DSO request over the TSO's and vice versa is presented. Fig. 4 shows that at Time Unit 4, the TSO needs an increase of the power consumption, while the DSO in area 2 requests a power reduction to solve a forecasted congestion of T2. Fig. 4-d shows that the available flexibility at Time Unit 4 allows to satisfy either the TSO or the DSO need. The two possible cases of prioritization to TSO or DSO are reported in Fig. 7-a and Fig. 7-b, respectively.

As said, *conflict (d)* represents an economical conflict that the Flex Operator may face mainly when remunerating aggregators. The example reported in Fig. 8 shows that congestion of T3 is solved, while at the same time this power reduction can also satisfy the TSO need for frequency up-regulation at Time Unit 2, as deducible from Fig. 4-a.

VI. Conclusions and Future Works

This paper identified the TSO/DSO conflicts when acquiring flexibility from EVs both in the case of the actual typical European DSO design and in case of the newly proposed European DSO model *evolvDSO*. Assuming an active DSO market role in managing distribution grids by relying on flexible resources, it is clear that new technical and economical conflicts may appear. Here, the potential conflicts have been defined, described and visually presented from both a theoretical and a practical point of view with a proposal of respective conflict identification procedure.

Within the considered market framework, day-ahead trading process of ancillary services provided by EVs is analyzed. The investigation focused on the potential conflicts arising when acquiring services for component (e.g., transformer) congestion management and primary frequency regulation. The following conflicts have been identified:

(a) Need for compensating imbalances caused by activation of flexibility for solving a local distribution issue

(b) To solve a TSO request, activating the only available flexibility product causes distribution overloading

(c) The available flexibility can satisfy either the DSO request or the TSO request

(d) One flexibility product can solve several problems.

Considering a 3-area power system, each of the analyzed conflicts was presented through appropriate case studies that allowed to visually appreciating the nature of the conflict.

The authors point out that, within the considered example and time units of 15 minutes, the distribution grid needs would need to be prioritized over the TSO's. In fact, as a larger, more flexible and more controllable system, the transmission system would be able to rely on more traditional sources for reserve, possibly most of the time. In this way, in case the acquirement of a flexibility product for a TSO service would potentially cause congestion problems to the DSO, the TSO would be invited to procure reserve relying on alternative sources. On the other hand, in case of frequency dynamics (i.e., within the intraday market) the TSO's needs may have to be prioritized over the DSOs'.

In conclusion, the authors recognize that each one of the identified conflicts raises debates, whose resolutions are out of the scope of this work, but are expected to cover a broad interest within the scientific power engineering community. Thus, as a final remark, the following open questions are proposed for future works:

- When the activation of a DSO service causes system imbalance, the BRP needs to provide compensation in order to maintain the balance. Is the BRP compensated for this? If yes, by whom?
- When the activation of a flexibility product would cause problems to another stakeholder, or in case of limited availability of flexibility, how does the Flex Operator proceed? Who would be prioritized and why?
- In case one asset has the capabilities to satisfy at the same time both a TSO and a DSO need, will the aggregator be remunerated twice? If not, which service will it be remunerated for? Is it realistic to expect the same price although the required performances could be different?

Acknowledgment

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