Global Perspectives on TSO-DSO Coordination Models for Distributed Energy Resources Market Integration

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***Abstract*—The increasing integration of distributed energy resources (DER) like solar, storage, and electric vehicles necessitates effective coordination between transmission system operators (TSOs) and distribution system operators (DSOs). This paper reviews TSO-DSO coordination models in Europe, Australia, and North America, focusing on strategies for DER participation in electric markets. In Europe, regulatory frameworks and flexibility markets aim to enable DER integration. Australia's rapid DER growth has led to innovative approaches for grid stability, emphasizing DER management through system services and demand response. North America is developing models to address regional challenges in DER aggregation and market participation, with a focus on operational integration. Key insights include the need for adaptable market designs, clear regulatory frameworks, and flexible operational coordination to support efficient DER integration and grid reliability. The review identifies common opportunities and challenges, offering valuable insights for advancing TSO-DSO collaboration.**

***Index Terms*--TSO-DSO Coordination, Local Flexibility Markets, Distributed Energy Resources**

I. Introduction

Policy initiatives like FERC's Order 2222 in the U.S. [1], the EU's Directive 2019/944 [2], and Australia's Distributed Energy Integration Program (DEIP) [3] promote DER market integration, requiring utilities to facilitate market participation. Through aggregation, DER can collectively meet market requirements and offer services [4] such as frequency regulation and congestion management.

Additionally, decarbonization goals, climate resilience, and growing energy demand are overwhelming existing grid infrastructure, making DER valuable as non-wires alternatives (NWAs) for grid reinforcement. Customer adoption of DERs, driven by lower costs and technological advances, further necessitates modernizing grid management techniques to accommodate third-party-owned DERs and ensure effective connection and compensation mechanisms.

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Given the evolving landscape of power systems and the increasing integration of DER, various models have been proposed to enhance TSO-DSO coordination. A literature review on RES integration shows a trend towards decentralized coordination models, which facilitate DER services efficiently while reducing costs and complexities [5]. In the scope of market design, a theoretical market framework has been introduced in [6] to conceptualize and design electricity markets that integrate the TSO-DSO coordination mechanism. The proposed framework serves as a comprehensive tool, formalizing innovative market concepts and outlining fundamental categories and decisions essential to market design. A review of TSO-DSO coordination mechanisms in Europe reveals various approaches with unique features, benefits, and challenges, leading to the proposal of an innovative hybrid model to enhance coordination efficiency [7]. In the US, enhanced TSO-DSO coordination is required to enable DER participation in wholesale markets, as mandated by FERC Order No. 2222 [8]. A proposed bi-layer model has DSO managing DER aggregations while TSOs ensure grid stability, emphasizing the need for standardized communication protocols, data-sharing mechanisms, and clear regulatory guidelines. A European perspective also stresses the importance of standardized frameworks and data-driven methods for estimating flexibility to improve grid stability [9].

While the literature presents several technical solutions for TSO-DSO coordination, this paper focuses on practical perspectives from different jurisdictions. It aims to review the ongoing development and implementation efforts of TSO-DSO coordination models, addressing the specific challenges given the regulatory frameworks in various regions. The paper is organized as follows: Section II provides the foundations to understand the TSO-DSO models over the paper, Section III presents the main findings from the development of the TSO-DSO model in Australia, Europe, and North America, and Section IV discusses the main conclusions drawn from this work.

II. TSO-DSO Coordination Models

A. *Defining a TSO-DSO Coordination Model*

A coordination framework outlines the actions, responsibilities, and data exchanges between parties working together, reducing complexity and costs (Figure *1*). It breaks down high-level objectives into clear interactions for stakeholders. In the electric power system, such frameworks define relationships between traditionally siloed organizations and address multiple challenges across distribution, transmission, generation, and customers. Although the bulk and distributed power systems are electrically connected, their planning and operation have traditionally been performed independently or with minimal interaction. As DER participation grows, transmission and distribution operators benefit from structured information sharing and decision-making, facilitated by a coordination framework among the different actors.

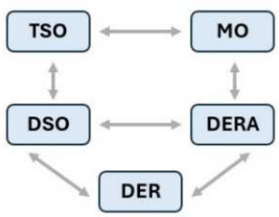

Figure 1. Actors and interactions for TSO-DSO Coordination.

B. *Actors*

The roles and needs of the key actors involved in TSO-DSO coordination are illustrated in Figure *1*. These actors and interfaces are referenced in text and sequence diagrams throughout the following sections and identify how each could interact to inform the others and to help optimize the DER utilization. In this section, one also reviews the different terminology that is used throughout the following for clarity and to provide additional context:

- **DER:** A DER refers to any resource situated on the distribution system, any of its subsystems, or behind a customer meter. This encompasses resources located in front of or behind the customer meter, such as energy storage resources, small generation, controllable loads, and electric vehicles along with their supply equipment.
- **DER Aggregator (DERA):** An entity that combines one or more distributed energy resources into one or more DER aggregations to participate in a wholesale market, ancillary services, or flexibility market.
- **TSO/DSO:** These terms refer to the actors responsible for planning and operating its transmission/ distribution systems, including the active management of DERs and other technologies.
- **Market Operator (MO):** The entity that operates the bulk power system in organized electricity market jurisdictions and administers the wholesale electricity market in that region. In the US, these entities are typically known as Independent System Operators (ISOs) and Regional Transmission Operators (RTOs)

III. Global Perspectives on the TSO-DSO Models

A. *Australia*

The "Open Energy Networks Project" by Energy Networks Australia [10] focused on integrating DER into the electricity grid through effective TSO-DSO coordination and explored various models for TSO-DSO coordination [11], including the Single Integrated Platform (SIP), Two-Step Tiered Platform (TSTP), Independent Distribution System Operator (IDSO), and Hybrid Model.

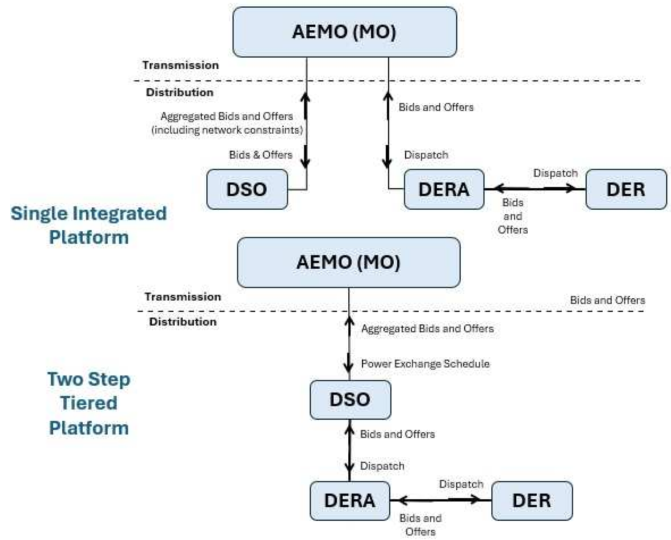

Figure 2. Single Integrated Platform (at the top) and Two Step Tiered Platform (at the bottom).

The SIP model proposes a unified platform where both TSO and DSO coordinate DER integration, aiming to streamline processes and ensure seamless communication between all stakeholders (Figure 2 on top). This model centralizes interactions with market participants through the Australian Energy Market Operator (AEMO), ensuring standardization and moderate regulatory changes. AEMO manages the procurement, dispatch, and settlement of DER for system services. The model offers several advantages, including streamlined processes, improved efficiency, and reduced complexity due to a single, independent, and transparent market facilitator. The regulatory changes required are moderate, as AEMO already performs similar roles for wholesale and frequency control of ancillary services markets. However, the expanded role for AEMO may necessitate adaptations to its funding model and pose challenges due to AEMO's lack of distribution network experience. The DSO lacks direct control over DER, potentially leading to conflicts. The complexity and cost of single-entity system planning are significant and will be passed on to all customers. In turn, the TSTP model involves a two-tiered approach where DERs first interact with the distribution system operator (DSO) before being aggregated and coordinated at the transmission level, helping manage local grid stability while ensuring broader system reliability (Fig. 2 at the bottom). In this case, DSOs take full responsibility for managing DER within their networks, promoting a more decentralized and active operation of distribution networks.

DSOs prequalify, procure, dispatch, and settle DER from aggregators and energy retailers to resolve network constraints, giving them priority over DER procurement and dispatch to address local issues. This local market approach can reduce barriers to entry for DERs and provide smoother integration. Nevertheless, DSOs lack experience with real-time dispatch processes and would need to develop this capability. The model requires seamless and coordinated dispatch between DSOs and AEMO, which can be challenging. Additionally, DSOs may not be perceived as sufficiently independent, and they will incur costs for operating a local market.

Concerning the IDSO model, it features an independent entity managing the distribution system, separate from the traditional utility, to coordinate DER integration and market participation, ensuring neutrality and efficiency. The model offers the advantage of acting as an independent, neutral, and transparent market facilitator, which helps eliminate concerns about conflicts of interest. This neutrality ensures unbiased decision-making and fosters trust among stakeholders. Nonetheless, the model also presents several challenges: establishing seamless interfaces between the IDSO and the DSO for exchanging network status and constraints, as well as between the IDSO and AEMO for resource co-optimization, can be complex and costly. In addition, new independent IDSOs would need to be established in each distribution network area, adding an extra layer of complexity.

Lastly, the Hybrid Model combines elements of the other models, allowing for flexibility and adaptability based on regional needs and regulatory environments, aiming to balance local and system-wide benefits while minimizing risks and costs to consumers. The Hybrid Model allows all market participants to interact with a single entity, the AEMO, via a two-sided platform that acts as an independent, neutral, and transparent market facilitator. This model centralizes the procurement, dispatch, and settlement of DER for system services under AEMO. Moreover, the DSO computes dynamic operating envelopes based on direct access to network operation data and constraints, ensuring efficient management. However, the expanded role of AEMO, requiring a broader range of resources, may necessitate changes to its funding model. The DSO does not have direct control over DER connected to the distribution network, as they are procured and dispatched by AEMO, potentially leading to conflicts. Furthermore, a seamless interface is required between the DSO and AEMO for exchanging real-time network status, distribution network constraints, and operating envelopes, which can be complex and costly to achieve.

B. Europe

In the European context, the report [12] from ENTSO-E and E.DSO provided a first input on establishing a suitable TSO-DSO framework, focusing on congestion management, balancing services and flexibility. The report highlights the need for common European principles for data exchanges and recommends regular information sharing and decision-making between TSOs and DSOs.

Apart from that, in the scope of several European Union-funded research and innovation projects, such as CoordiNet [13], OneNet [14] and SmartNet [15], several models and market architectures for the coordinated TSO-DSO procurement of flexibility services have been proposed and tested in the scope of pilots.

In the scope of those projects, the Local Market Model emphasizes DSOs procuring flexibility services directly from local providers to manage grid constraints, fostering localized solutions and direct interactions. Meanwhile, the Central Market Model establishes a single platform where both TSOs and DSOs can procure flexibility services, aiming to optimize system efficiency through centralized transactions and coordination. In turn, the Common Market Model integrates elements of both local and central markets, allowing for coordinated procurement by TSOs and DSOs via a common platform, which facilitates better alignment and resource sharing. The Integrated Market Model envisions a fully integrated market where flexibility services are procured seamlessly across different market layers, ensuring optimal coordination between TSOs and DSOs. Conversely, the Multi-level Market Model involves multiple market layers (local, regional, national) with coordination mechanisms in place to ensure efficient flexibility procurement across these layers, allowing for a more granular and tailored approach. On the other hand, the Fragmented Market Model operates with limited coordination between TSOs and DSOs, as each entity runs its market, potentially leading to inefficiencies due to the lack of integrated planning and resource optimization. Lastly, the Distributed Market Model emphasizes a distributed approach where multiple decentralized market platforms operate independently but are interconnected, promoting resilience and adaptability through a network of platforms.

In the Great Britain (GB) context, the Energy Networks Association (ENA) Future Worlds document [16] outlines five potential future scenarios for the GB energy system, focusing on the roles of DSOs and TSOs in a decarbonized, digitized, and decentralized energy landscape. These scenarios, referred to as "Future Worlds," explore different approaches to managing the evolving energy system. World A (DSO-Driven) envisions DSOs taking a leading role in managing local flexibility and balancing services, with TSO coordinating at a higher level. World B (TSO-DSO Coordination) involves enhanced coordination between TSOs and DSOs, with shared responsibilities for flexibility procurement and system balancing (Figure 3). World C (Independent DSO) sees DSOs operating independently, managing local flexibility markets and balancing services without direct TSO involvement. World D (TSO-Driven) has TSOs taking a leading role in managing flexibility and balancing services, with DSOs supporting at the local level. World E (Market-Driven) envisions a market-driven approach where independent market operators facilitate flexible procurement and system balancing, with minimal direct involvement from TSOs and DSOs. A comprehensive cost assessment and impact assessment were performed to evaluate the viability of different future energy scenarios [17].

On the one hand, the qualitative assessment suggests that Worlds A and B are better positioned to evolve quickly without requiring substantial changes. In contrast, Worlds D and E will take longer to evolve and need significant organizational changes to progress to advanced stages. Implementing these changes during a period of accelerated DER growth could add significant complexity to an already challenging situation. Worlds B and E require complex coordination across multiple actors, leading to substantial real-time data exchange. This increases the resources needed for operation and the rules governing it, potentially leading to operational issues. World D appears to be the lowest-cost option to implement and operate. Although it may not deliver the same near-term benefits as Worlds A and B, it could be effective if DER uptake is lower than expected, focusing on coordinating distributed generation rather than demand flexibility at lower voltage levels. Although all scenarios can provide neutral markets with appropriate mitigation processes, World E naturally facilitates a neutral market without additional safeguards. It allows flexibility coordinators to take a whole system view, being the only scenario where a neutral party sees the value of flexibility to both TSO and DSO.

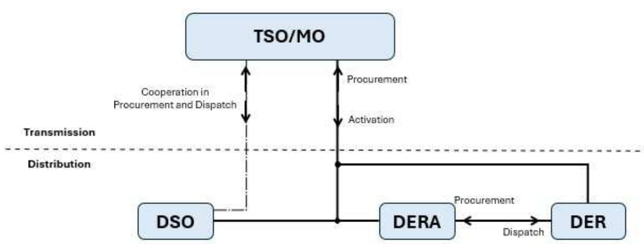

Figure 3. World B – Coordinated TSO/DSO procurement and dispatch for the UK case.

On the other hand, the cost assessment reveals that the standalone investment costs for World E are likely to be higher than the other Future Worlds. Worlds A and B have similar costs, with World A slightly higher due to the need for additional DSO investments. World D is lower cost due to centralized DSO functions under a single entity, while World C is the lowest cost but lacks the scope of system operation of other scenarios. For World E, the operating costs may be underestimated, as much of the information exchange is assumed to be internalized within the flexibility coordinator. In turn, World D benefits from economies of scale, making it relatively lower cost.

C. North America

Similar to the developments in Australia and Europe, North America is also making significant strides in developing TSO-DSO coordination models. In the US, driven by FERC Order 2222, which enables the participation of small-scale DERs and conventional generating units in wholesale markets, four models have been proposed to address this integration [8]. The TSO Model involves direct coordination between the TSO and DER, without considering local-level congestion management, and flexibility is procured solely by the TSO. The DSO Model procures flexibility at the local level, and any unused resources are then made available to TSO. The Hybrid TSO-DSO Model allows for a coordinated approach where flexibility is procured by the TSO for transmission systems and by the DSO for distribution systems. Lastly, the Common TSO-DSO Model involves joint management of flexibility procurement by both the TSO and DSO, with flexibility being provided to the entity with the highest priority.

In California, an evaluation of four alternative models [18] was performed to prepare the future grid scenarios with the increasing integration of DER. Extending centralized, open-access markets of an RTO/ISO to the distribution system, the Total TSO model consolidates the market for both wholesale and distribution grid services. In contrast, the Total DSO model creates separate markets for distribution services, with DERs balanced by the DSO, optimizing the distribution and transmission systems in layers. Further separating distribution system ownership from market operations, the Independent DSO model assigns an independent organization to manage distribution services. Hybrid models (A, B, C) combine elements of these approaches, with varying levels of coordination and market improvements, aiming to enhance DER participation and grid efficiency. Hybrid A maintains the status quo with nascent DER coordination, Hybrid B improves distribution services without layering markets, and Hybrid C introduces an independent organization for distribution services without layering wholesale and distribution markets.

In Canada, IESO (Independent Electricity System Operator) conducted a similar study for Canada, examining the coordination of high volumes of DERs [19]. The idea was to assess whether to maintain the centralized structure for coordinating high volumes of DERs or to transition to a more decentralized layered structure. According to the analysis, the choice must be grounded in the operation of the physical system and the traditional objectives of reliability, efficiency, and safety. This analysis focused on two distinct models: one where the distribution system is overseen by the TSO and the other where it is completely overseen by the DSO. The Total DSO Model shifts DER coordination from the TSO to the DSO, preventing direct DER/DERA participation in the TSO market. Instead, the DSO manages all wholesale market services for DER/DERA, submitting a single aggregated bid for each transmission-distributed interface. This requires the DSO to have advanced capabilities to establish transparent market mechanisms and optimize resources below each T-D interface.

IV. Conclusions

This paper has reviewed various TSO-DSO coordination models from Europe, Australia, and North America, highlighting the diverse approaches and strategies employed to facilitate DER market participation and ensure the secure and reliable operation of the grid. Across different jurisdictions, TSO-DSO coordination models are being investigated, and various terminologies have been employed. The hybrid model emerges as a promising approach, where TSOs and DSOs coordinate the participation of DERs in wholesale markets and flexibility services. Given that DERs are primarily connected to distribution grids, a more decentralized approach is required to manage DER at a local level. This necessitates improvements in DSOs' visibility and dispatch capabilities. Cost assessments and qualitative evaluations are crucial components of this process, as demonstrated in jurisdictions like Australia and the UK. These assessments help in understanding the financial and operational impacts of different coordination models, ensuring that the chosen approach is both effective and economically viable. Further developments in this area should focus on the registration and pre-qualification of DER assets to provide services to TSO and DSO, value stacking assessments of DER participating in both wholesale and distribution markets, activation and dispatch processes, real-time monitoring, and the settlement of these services. Understanding how DER's participation in local distribution markets aligns with its participation in wholesale markets is essential. Additionally, operational rules between DSOs and TSOs for normal and contingency operations will be needed. These rules should cover coordination protocols, data exchange requirements, and response strategies to ensure seamless operation during both regular and emergencies. DSOs, in particular, need to develop experience in managing markets to facilitate this process. The common opportunities and challenges identified across different regions offer valuable lessons for advancing TSO-DSO coordination.

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