Operational Coordination across Bulk Power, Distribution and Customer Systems

An Initial Assessment of Coordination Models in the UK, EU, Japan, Australia and the US

Prepared for the Electricity Advisory Committee
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This report includes an adaptation of a more comprehensive international review and assessment concluded in summer 2018 by a team led by Paul De Martini of Newport Consulting including Dr. Lorenzo Kristov, Dr. Jeffrey Taft of Pacific Northwest National Laboratory, Mark Higgins of Strategen, Marc Asano of Hawaiian Electric, Ezra Beeman of Energeia and Jacquie Moss. The original review and assessment involved extensive interviews with key transmission and distribution subject experts within the international locations surveyed. This report would not have been possible without the subject matter experts' willingness to participate and provide the reference documents cited – we extend our thanks for their generosity.

Disclaimer

1 Introduction

A reliable, resilient and secure power system is critical to the US economy and welfare of its citizens. The advancement in distribution energy resource (DER) technology and its adoption by utility customers, as well as policies directed at improving system resilience, are changing the operation of the electric grid for both distribution and bulk power systems. To ensure a reliable and resilient power grid today and into the future, it is essential to consider the implications of the expanded use of customer and merchant DER on-grid operations, as well as to provide critical operational services for both bulk power and distribution systems. Specifically, the growing use of DER services is driving a need for increased coordination between transmission and distribution operators, customers, aggregators and a variety of emerging participants.

Traditionally, transmission and distribution operations have been lightly coordinated as the distribution system was largely a passive extension of bulk system operational activity. Likewise, customers' use of their DER has had little coordination with distribution operations beyond initial interconnection. This is changing as opportunities for individual and aggregated customer DER to provide bulk power system services and as transmission and distribution non-wires alternatives. As such, there is a need to more actively coordinate DER functions and related operational activities across the bulk power, distribution and customer (or aggregator) systems.[1]

Operational coordination includes a wide range of activity between all participants engaged in the generation, use and management of electricity within a framework of specified roles, responsibilities, business process and technical requirements. This specifically includes information exchange and control coordination of all participants in the provision of energy and grid services to maintain and contribute to reliable system operations.[2] The transformational changes described above will require new transmission-distribution-customer (TDC) coordination frameworks to ensure reliable, resilient 21st century power systems.[3] The purpose of this report is to provide a general framework for TDC coordination and identify key issues that will need addressing in the United States to enable existing federal and states' policy regarding the use of DER services.

This report provides a comparative summary of the current status of leading global discussions regarding TDC coordination frameworks to reliably manage the integration and utilization of DER. The report draws on interviews conducted by the Newport Consortium in spring 2018 with transmission and distribution operators in the United Kingdom (UK), the European Union (EU), Japan, Australia, and the United States ISOs/RTOs in California and New York.

In Section 2, we present a set of Grid Architecture[4] principles used to assess and compare the structural relationships associated with each of the TDC coordination efforts we investigated. Section 3 describes

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[1] In this paper, we frequently apply the term "transmission" to represent the operational domain of the whole of the bulk power system, including all generators tied to the transmission system.

[2] Joint Working Group C2/C6.36, *System Operation Emphasizing DSO/TSO Interaction and Coordination*, CIGRE June 2018 Available Online: https://e-cigre.org/publication/733-system-operation-emphasizing-dsotso-interaction-and-coordination

[3] For a detailed discussion of the operational, market and regulatory implications of high penetration of DER in the power system see P. De Martini and L. Kristov, *Distribution Systems in a High Distributed Energy Resource Future,* Lawrence Berkeley National Laboratory, 2015. Available online: http://eta-publications.lbl.gov/sites/default/files/lbnl-1003797.pdf

[4] J. Taft, *Grid Architecture 2*, Pacific Northwest National Laboratory, 2016 Available online: https://gridmod.labworks.org/sites/default/files/resources/Grid%20Architecture%202%20final_GMLC.pdf

and assesses each example with respect to the architectural principles. The assessment included specifying the roles and responsibilities of the transmission system operator (TSO), the distribution system operator (DSO), and customer/aggregator with regard to the interfaces between their systems (TDC interfaces). Section 4 provides concluding observations. A glossary of the terms used by the different jurisdictions is provided in Section 5 and all reference materials are given in Section 6.

2 Grid Architecture Framework

Grid architecture is a discipline that is concerned with the structural aspects of the electric grid, the relationships among structural elements including key actors, and how systems can scale to address increased complexity. The principles and methods of grid architecture provide a framework for assessing and resolving structural changes to power system operations. This includes how to enable the use of DER services for bulk power and distribution system operations at scale. Grid Architecture adheres to reliability and resiliency constraints and respects the physical underpinnings of the electric system. A common aspect of all the DER coordination efforts reviewed here involves identifying new operational challenges and exploring new structural designs and related functional requirements.

Grid Architecture provides an effective method for comparing the DER coordination approaches being developed or considered in the several cases we examined. Specifically, we compare the different approaches using an architectural framework that is characterized by a layered structural hierarchy of interaction between the transmission system operator (TSO), the distribution system operator (DSO), the DER themselves (either directly with customers or through a DER aggregator), and other relevant actors. An architecture structural analysis enables a rigorous operational risk analysis that can inform a holistic economic assessment.

2.1 Grid Architecture Principles

Key architecture principles that should be assessed in development of TDC coordination models are defined in Table 1 below. These principles address the essential elements to ensure reliable and effective grid function in the transition to a more distributed power system.

Table 1: Summary of Key Coordination Architecture Principles

Principle	Description
Observability	Function related to operational visibility of the distribution network and integrated DER. Sufficient sensing and data collection can help to assemble an adequate view of system behavior for control and grid management purposes, thus providing desirable snapshots of grid state. The data can also be utilized to validate planning models. Observability needs of DSO and TSO depend on how the coordination framework is specified.
Scalability	Ability of system’s processes and technology design to work well for very large quantities of DER resources. Coordination architecture can enhance or detract from this desired capability.
Cyber security vulnerability	While this topic has many dimensions, the principle here is to reduce cyber vulnerability through architectural structure. Structure can expose bulk energy

	systems to more or less vulnerability depending on data flow structure, which depends on coordination framework. To be minimized.
Layered decomposition	Layered decomposition solves large-scale optimization problems by decomposing the problem multiple times into sub-problems that work in combination to solve the original problem. Used here as the basis for comparing grid architectures.
Tier bypassing	Creation of information flow or instruction/dispatch/control paths that skip around a tier of the power system hierarchy, thus opening the possibility for creating operational problems. To be avoided.
Hidden coupling	Two or more controls with partial views of grid state operating separately according to individual goals and constraints; such as simultaneous, but conflicting signals DER from both the DSO and TSO. To be avoided.
Latency cascading	Creation of potentially excessive latencies in information flows due to the cascading of systems and organizations through which the data must flow serially. To be minimized.

For more detail on system architecture, the Pacific Northwest National Laboratory's Grid Architecture website[5] is a useful reference library that contains a large number of reports and analyses relevant to TDC coordination.

2.2 Cyber-Physical Considerations

Effective cyber-physical integration of customer DER to distribution grids is central to ensuring reliability and the potential to achieve desired resiliency that DER and microgrids may provide. Cyber-physical integration refers to the information, controls and communications required to scale the interconnection and utilization of DER (and increasing number of nodes). This primarily involves several of the principles described above, including:

- The need for improved observability and related information necessary for planning and operations,
- Standards harmonization and commercial maturity to achieve desired interoperability and performance to enable the scale desired, and
- Robust communications with integral security to satisfy the availability, reliability and other performance requirements for system operations.

The overview that follows provides context to the types of issues that need to be resolved in addition to the larger structural issues presented in the international comparative review.

Distribution to Customer DER

There are many potential interfaces between customer DER and the distribution operator that need to be considered with respect to coordination processes, including the extent and timing of information exchange and requirements for control and communication. These aspects span considerations for

[5] PNNL Grid Architecture Library, available online: https://gridarchitecture.pnnl.gov/

interconnection requirements, planning and real-time distribution operations.[6] Customer DER is used here broadly to also include DER aggregators and independent DER developers. Coordination between distribution operators and customers is essential to ensure customer DER operations do not inadvertently impact system operations and safety, and that DER providing services meet the performance and communications service level required.

Several relevant standards have been developed, such as IEEE 1547-2018, to address interoperability issues. However, additional effort is required to enable the application of such standards; for example, practical implementation will require certification testing and market adoption with viable strategies for applying the advanced functionality they offered. IEEE 1547-2018 has several functionality options and, additionally, doesn't address communication[7] or cybersecurity[8] leaving significant issues to resolve to ensure effective D-C coordination. A recent report from the Association of Edison Illuminating Companies (AEIC)[9] summarizes lessons learned from several DER services demonstrations in the US. This report presents the following set of issues that require resolution in regards to coordination between distribution operators and customer DER:

- Reliability of DER communications was well below the average communication reliability of distribution supervisory control and data acquisition systems.
- Reliable measurement and verification for DER services is needed.
- Timely coordination between distribution operator and aggregator is essential.
- Harmonization of standards and related certification testing is needed.

For example, there are a variety of information, control and communications standards and rules in many states today which are employed to interface transmission operations and/or distribution operations to customer DER directly or through aggregators (Figure 1). Without applying a holistic framework, there remains the potential for operational risks that will impede scaling DER adoption and utilization as discussed in the AEIC report.

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6 *Modern Distribution Grid Report, Volume III*, Pacific Northwest National Laboratory, 2017 Available online: https://gridarchitecture.pnnl.gov/media/Modern-Distribution-Grid-Volume-III.pdf

7 id.

8 Stamber, K., Kelic, A., Taylor, R., Henry, J., Stamp, J. Distributed Energy Systems: Security Implications of the Grid of the Future, Sandia National Laboratory, January 2017 Available online: http://prod.sandia.gov/techlib/access-control.cgi/2017/170794.pdf

9 The Association of Edison Illuminating Companies, PG&E, SCE and SDG&E, *Enabling Smart Inverters for Distribution Grid Services*, October 2018. pp. 10-11 Available online: https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/Joint-IOU-SI-White-Paper.pdf

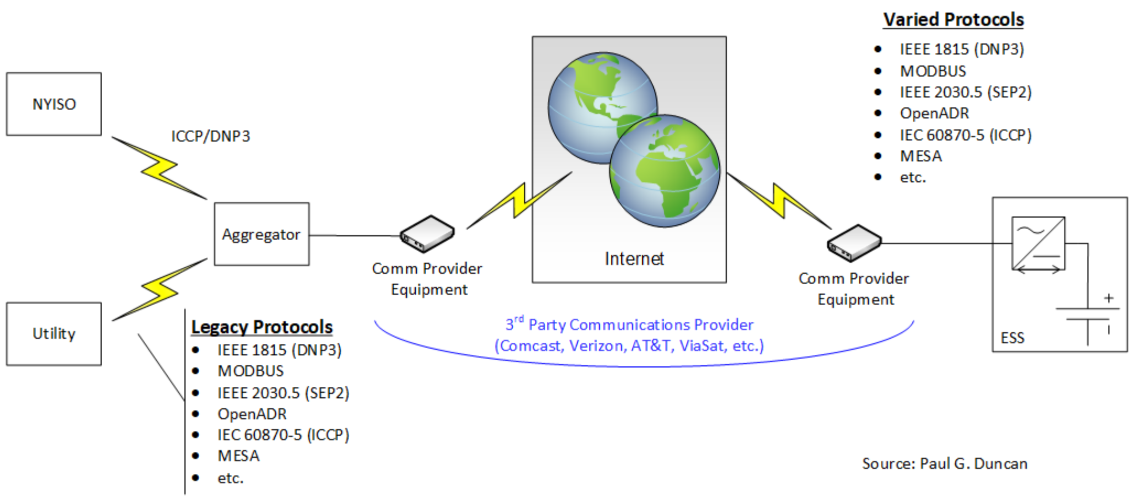

Figure 1: Current TDC Information/Control Standards and Communications

Transmission to Distribution Coordination

System operators are faced with the dual challenge of managing variable, bulk-level, renewable power generation and variable net load driven by customer DER. Customer DER poses the larger issue given the lack of visibility and controllability. A 2018 CIGRE report[10] identifies the critical issues for TSOs in managing frequency, balancing, system voltage control, and bulk power system restoration with significant DER integration and utilization. The CIGRE report discusses findings from an international survey of TSOs. The CIGRE report identifies several issues in common with the AEIC report;

- Observability,
- Effective controllability, and
- Timely operational coordination.

In addition, NERC has continued to assess the issues involving a more distributed power system. The System Planning Impacts from Distributed Energy Resources Working Group (SPIDERWG) recently prepared a draft scope document[11] that identifies "key points of interest related to system planning, modeling, and reliability impacts to the Bulk Power System (BPS)." The working group activity list includes the following actions related to T-D coordination:

- *Develop detailed guidelines related to recommended information sharing and data collection for necessary information to flow across the transmission-distribution interface effectively to support BPS [Bulk Power System] reliability needs.*
- *Develop recommended practices and guidance for assessing the performance of the BPS under increasing penetrations of aggregate DER.*

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[10] Joint Working Group C2/C6.36, *System Operation Emphasizing DSO/TSO Interaction and Coordination*, CIGRE June 2018 Available Online: https://e-cigre.org/publication/733-system-operation-emphasizing-dsotso-interaction-and-coordination

[11] System Planning Impacts from Distributed Energy Resources Working Group (SPIDERWG), *Draft Scope Document*, NERC, September 2018 https://www.nerc.com/comm/PC/System%20Planning%20Impacts%20from%20Distributed%20Energy%20Re/SPIDERWG_Scope_Document.pdf

- *Provide guidance for distribution-level monitoring to improve steady-state and dynamic modelling of aggregate DER, including the use of smart meters, dynamic disturbance recorders (DDR), phasor measurement units (PMUs), and other recording devices.*
- *Provide technical recommendations for the adoption and use of IEEE Std. 1547-2018.*
- *Provide guidelines, white papers, compliance guidance, etc. in support of NERC Reliability Standards addressing interconnection requirements.*

The SPIDERWG activities are consistent with the findings of the CIGRE report that clearly indicate that there is much work needed to address a myriad of issues related to large-scale DER integration and utilization. Although these reports do not address all the TDC coordination issues, they illustrate the importance of undertaking a thorough assessment to determine the cyber-physical and structural changes needed. An architecture-based discussion is provided in the following comparative review.

2.3 Architectural Structure Considerations

Applying architectural principles is important in the development of reliable TDC coordination structure. Such structures incorporate roles and responsibilities, information flows, and control and communication pathways. To address scaling and optimization issues, an important architectural concept is the *laminar coordination framework*[12] (layered decomposition) which organizes nodes so that they can effectively function and interoperate. This laminar coordination approach provides a common basis for comparing what might at first appear to be disparate grid architectures and allows clear identification of the key characteristics of each.

The conceptual architectural analyses in this paper applies laminar structural analysis by utilizing skeleton diagrams. Coordination skeleton diagrams are diagrams that capture aspects of industry structure, control structure, and market functions like dispatch, all of which are elements of coordination. Each diagram consists of boxes for the relevant entity classes (derived from industry structure definition) connected by lines of operational coordination flow (as distinct from physical electric power flow). A more complete analysis of architectures would entail identifying the structural elements in detail, conducting comparative assessment and performing rigorous operational risk analysis of each structure.

Coordination flow may be unidirectional or bi-directional, depending on the nature of the coordination relationship. Operational flows involve all the relevant information needed to coordinate the market functions and network operational functions, typically in real time (T) up to T minus 45 days (T-45) for certain operational engineering and maintenance coordination activities. An example of a simple coordination skeleton diagram illustrating the transmission, distribution and customer tiers is shown below in Figure 3. These diagrams are used in this report to highlight the proposed TDC coordination approaches under discussion to facilitate comparative assessments of the key aspects.

[12] J. Taft, *Comparative Architecture Analysis: Using Laminar Structure to Unify Multiple Grid Architectures*, Pacific Northwest National Laboratory, 2016 Available online at: https://gridarchitecture.pnnl.gov/media/advanced/Comparative%20Architecture%20Analysis-Final.pdf

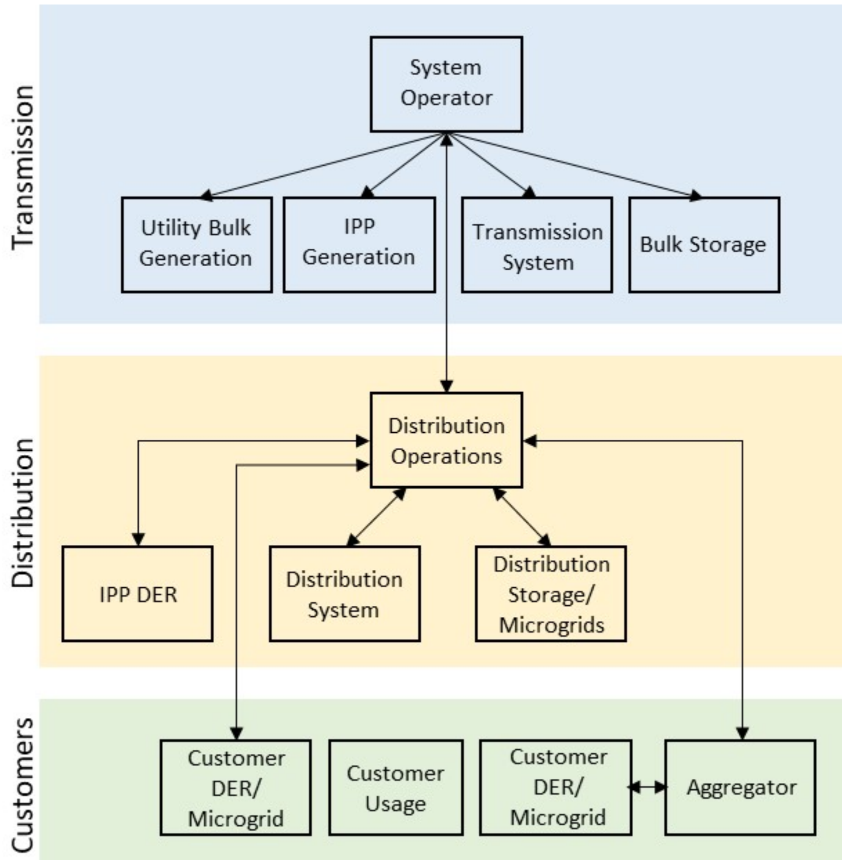

Figure 2: Example Coordination Skeleton Diagram

The diagrams in this report were either identified in source documentation or conceptually developed for each assessed location. These diagrams, and related documents, are useful tools to identify potential issues and concerns.

Note that while the coordination diagrams don't illustrate the physical interfaces and flows, it is essential for any coordination architecture to understand and address the physical interfaces as a foundational consideration as described earlier.

2.4 Conceptual TDC Coordination Models

This report uses a set of three reference conceptual TDC coordination models[13] that illustrate a spectrum of potential coordination architectural models as illustrated in Figure 3 below. These conceptual models are useful for evaluating potential structures that may emerge for TDC coordination and the related the architectural trade-offs between the models. The various potential TDC coordination models under discussion globally fall within this spectrum and will be discussed in more detail the following section.

[13] These models are discussed in detail by P. De Martini and L. Kristov (2015); note that De Martini & Kristov refer to the Hybrid DSO model as the "Minimal DSO" model since it involves minimal DSO functionality and role in coordinating DER. The Hybrid DSO represents a range of potential hybrid structures.

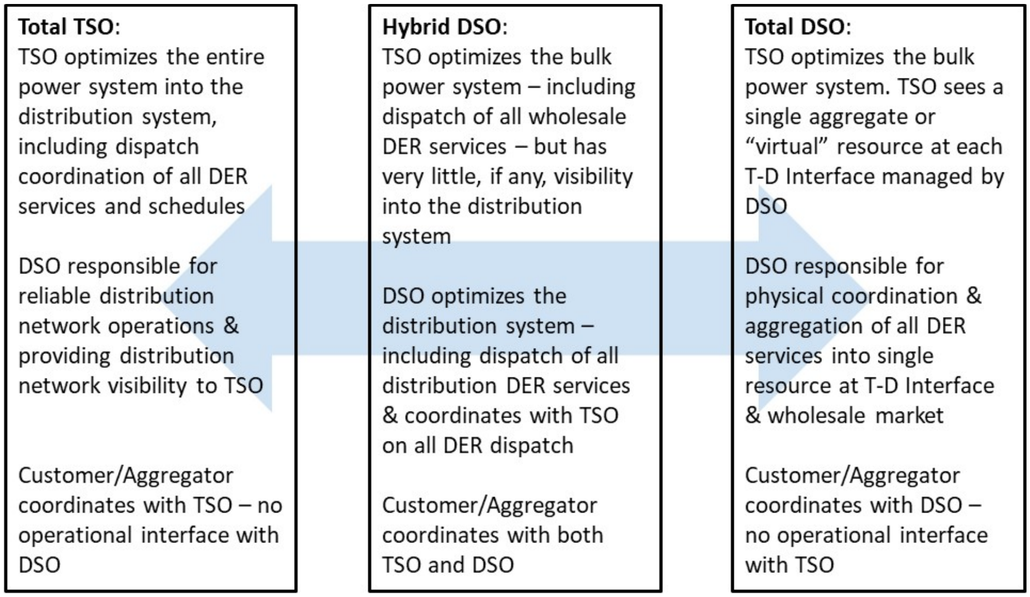

Figure 3: Spectrum of Conceptual Models of TDC Coordination

Simple conceptual TDC coordination skeletal diagrams for each of the three reference conceptual models are shown in Figure 4 below. These are offered as a means to initially understand the fundamental relational structure of proposed coordination architecture before diving into the more complex architectural issues as described above.

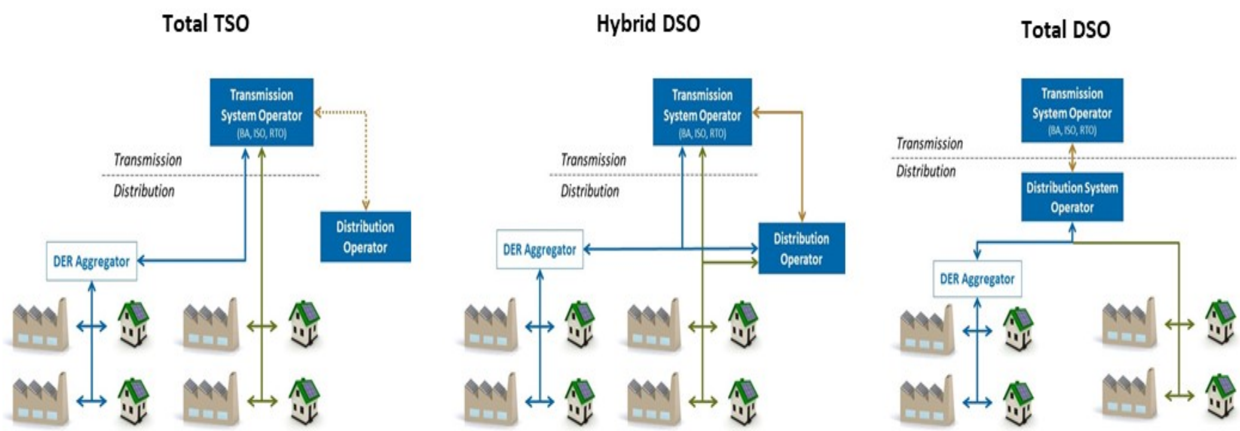

Figure 4: Conceptual Reference TDC Coordination Models

Development of future TDC coordination structures will need to address the Grid Architecture principles to ensure reliability and resiliency. Specifically, in relation to coordination and optimization of significant amounts of DER participating in both wholesale markets and distribution network services, while simultaneously respecting/mitigating transmission and distribution level constraints. This will require high levels of visibility into the operation of the distribution network, including physical switching coordination and distribution-level, nodal state estimation and short-term forecasting. Any TDC coordination model will also need to address:

- Distribution tier bypassing,

- Hidden coupling of operational controls,
- Scalability of inherent operational processes and related technological designs, and
- Cybersecurity vulnerability from or through DER with unknown protection.[14]

The direction of discussions globally suggests that future architectures will likely be variations of the Hybrid[15] model oriented to be either more TSO-centric or DSO-centric with regard to primary DER coordination responsibility. As such, it is very unlikely that a full conceptual Total TSO or Total DSO will be fully employed in any region within the next decade.

The Hybrid DSO model, while attempting to minimize significant structural changes, introduces complexity in structure, roles, responsibilities and coordination processes. This is manageable at lower levels of DER participation but will face scalability issues as DER participation grows. Therefore, we anticipate that many of the international efforts will begin with a Hybrid DSO type approach and ultimately evolve toward either a TSO dominant centralized structure or a more layered DSO dominant model. This evolution will depend on how the hybrid structure coordination challenges (involving market coordination, information flows, and controls) can be satisfactorily resolved – meaning good enough as opposed to perfect.

3 International Comparative Review

The seven international locations reviewed for this report represent the vanguard in addressing TDC coordination architectures for significant utilization of DER services. However, it is important to note that all these efforts are at early stages of development and there is not yet consensus on the respective future architectures. A key question under discussion is the extent to which the evolution of TDC coordination structures must be constrained by legacy industry, market-control and information structures to ensure reliability and resiliency while achieving desired market efficiency. Also, how much freedom exists to pursue structural modifications in order to address the architectural considerations described earlier in Section 2?

Determination of the choice of predominantly centralized (Total TSO centric) or layered (Total DSO centric) structure is an early architectural decision that has significant impact on the downstream decisions for architecture, market design, implementation of market mechanisms, control systems, communication networks, organizational roles, responsibilities, and industry structure.

The current discussions as described below involve resolving two contrasting two schools of thought regarding TDC coordination structure: 1) a centralized approach where the TSO performs all DER and operational coordination versus 2) layered approaches where a DSO has a significant role in DER coordination. Important to note that each of these US and international discussions is rooted in ensuring reliable and resilient bulk power and distribution grid operations. The order of the review of each of the seven locations is based on the relative maturity of the discussions.

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[14] K. Stamber, et al. *Distributed Energy Systems: Security Implications of the Grid of the Future*, 2017 Available online: https://prod.sandia.gov/techlib-noauth/access-control.cgi/2017/170794.pdf

[15] De Martini and Kristov (2015) describe a "Minimal DSO" as one variant of the Hybrid DSO model. The Minimal DSO involves the minimum addition of new functional capabilities beyond today's distribution utilities in order to maintain reliable distribution service with high volumes of DER, but no foray into major new roles such as operating a distribution-level market.

3.1 United Kingdom

The UK is pursuing the use of DER services to support both bulk power system and distribution grid operations, in particular, a need for operational flexibility services arising from more renewable generation on the system. Distribution grid operators (referred to as distribution network operators in UK) are also seeking to utilize DER services to support their operational needs. Additionally, DER services providers (aggregators) are pursuing multi-use applications (MUA) that stack various bulk power and distribution grid services to maximize the revenue potential for their services. Also, DER services providers are concerned about having direct access to the wholesale market without having to go through a DSO intermediary. The UK term for this concept is "alternative routes to market," i.e., the idea that a DER aggregator can have multiple options for market access. These drivers are similar to those in the US as well as other countries in this review. As such, the UK analysis is very helpful for any jurisdiction pursuing these questions, as the fundamental structural issues to address exist irrespective of nuances in existing system structure, market operations and electric grid configurations.

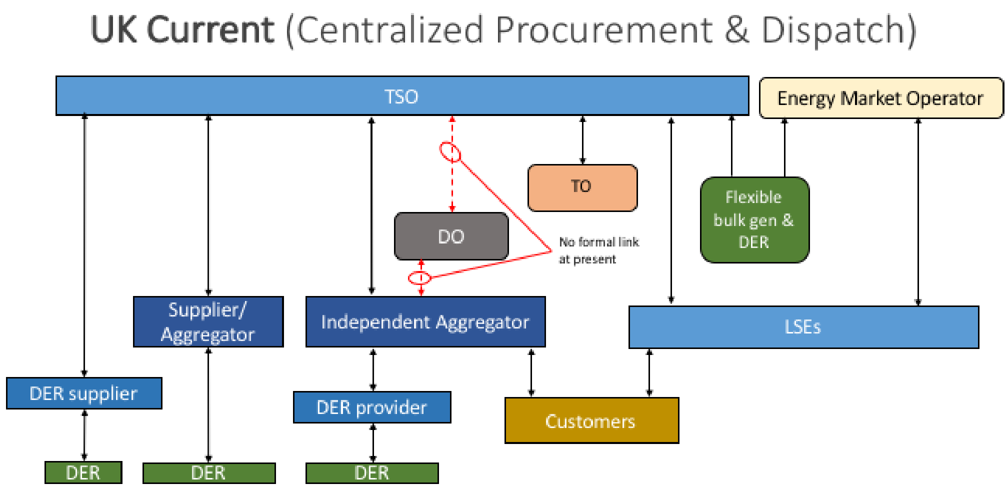

Figure 5: Current UK Coordination Structure

The UK Open Networks Project has identified five potential future TDC coordination architectures for evaluation.[16] The starting point for the UK is the present architecture shown in Figure 5, which is close to a Total TSO model. Among the future models, two approaches shown in Figure 6 below illustrate architectural considerations that should be addressed and reflect the structural discussions underway in other locations to specify the roles and responsibilities of the TSO, DSO, and DER aggregator.

[16] Open Networks Future Worlds (31 July 2018) by Energy Networks Association (ENA) Open Networks Project (2017), available online: http://www.energynetworks.org/electricity/futures/open-networks-project/future-worlds/future-worlds-consultation.html

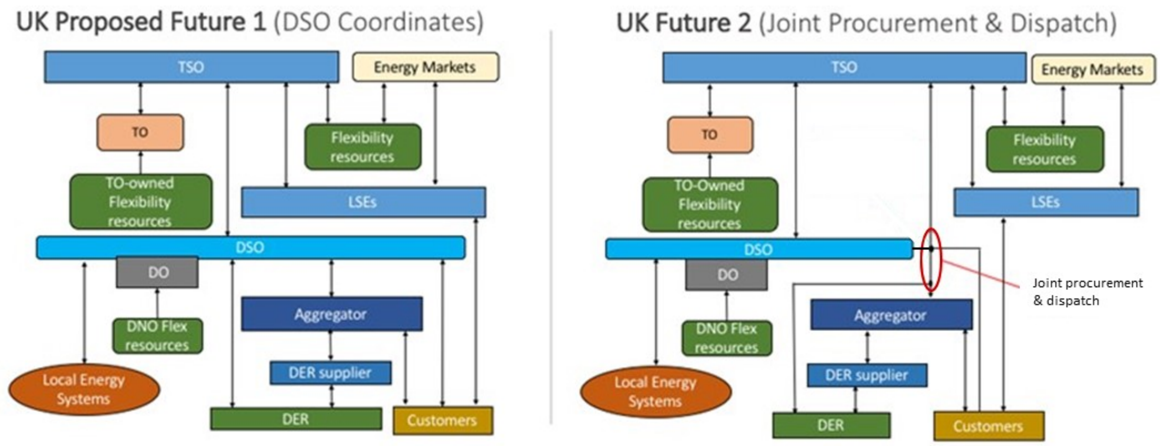

Figure 6. Two of UK's Five "Future Worlds" TSO-DSO Architectures

UK Future 1 above is close to a Total DSO model: DER coordination flows entirely through the DSO to the TSO. Consequently, the model makes good use of layered decomposition and has few issues with tier bypassing or hidden coupling, except for the way in which DSO flexibility resources are managed (see Table 1 above for definitions). The arrangement for connecting DER via a DER supplier and then an aggregator to get to the DSO introduces the possibility of some cascading latency issues. Because of the layering and use of the Total DSO approach, scalability is good while cyber vulnerability of the bulk energy system due to DER connectivity is relatively small.

In UK Future 2, the DSO and TSO share the responsibility for DER coordination. This shared responsibility leads to a more complicated arrangement involving these parties and the aggregators in particular because the sharing mechanism is not currently clear. This structure leans toward a Total DSO model, but the sharing arrangement results in a blending of roles that will require extra coordination to perform. Future 2 partially degrades the layered decomposition structure and allows for some tier bypassing, although the proposed function-sharing ("joint procurement and dispatch") may prevent that from being an issue.

The effect of the Future 2 structure is to increase the coupling between the TSO and DSO, *not* hidden in this case, since the DSO cannot manage the DER in its service area alone while interfacing to the TSO in a modular fashion. The joint arrangement results in data flow complexity involving the DSO, the TSO, the aggregators, the customers, and DER. This is a result of the structure, shown in the red oval highlighting "joint procurement and dispatch", which comes about due to the definition of joint roles instead of clean separation of functions.

Also noteworthy is the fact that UK's two largest distribution network operators, UK Power Networks (UKPN) and Western Power Distribution (WPD), both of whom are participating in the Open Networks Project, have separately issued strategic plans for their own evolution to become DSOs, specifically focusing on DER coordination and obtaining flexibility services from DER. WPD's December 2017 Transition Strategy[17] describes and compares four DSO models along the spectrum of Figure 1 above and concludes that the "DSO Led" market model (i.e., the Total DSO end of the Figure 1 spectrum) will deliver the most efficient whole-system outcomes with high volumes of DER. WPD characterizes the

[17] https://www.westernpower.co.uk/our-network/strategic-network-investment/dso-strategy

DSO role in this model as "neutral market facilitator" for DER flexibility services. UKPN's August 2018 Flexibility Roadmap[18] does not explicitly compare DSO models, but emphasizes the same themes as WPD including neutral market facilitation and collaboration with the TSO to use DER flexibility to maximize whole-system benefits. This suggests a substantial role for the DSO in DER coordination towards the Total DSO end of the spectrum.

The UK Open Networks assessment approach is focusing on many key strategic issues (cost, complexity, customer satisfaction, regulatory compliance, and network performance). However, the UK effort unfortunately is not employing a grid architecture structural comparative analysis with respect to associated operational risks such as those identified by CIGRE. Instead, the UK is using the Smart Grids Architecture Model (SGAM)[19] framework. SGAM, based on GridWise Architecture Council's interoperability framework[20], is a framework for identifying the information and operational technologies (IT/OT) and related interoperability needed as part of developing conceptual designs and cost estimates. However, these frameworks do not enable assessment of grid architectural structural issues or related operational risks.

3.2 Australia

Australia has been discussing TDC coordination as part of the Electricity Networks Transformation initiative, a joint effort of Energy Networks Australia (DSO organization) and CSIRO (national science and innovation lab), over the past three years. A key focus was on the means to coordinate DER given the large growth in DER adoption over the past few years. The Electricity Network Transformation Roadmap released in April 2017[21] discusses the Grid Architecture issues that need addressing.

Following this roadmap, AEMO and Energy Networks Australia (ENA) released the Open Energy Networks Consultation Paper[22] (June 2018) to invite stakeholder input and initiate more concrete activities to develop "a coordinated approach that facilitates integration of DER, considering both transmission and distribution constraints, [that] will deliver the best outcomes for customers."

The AEMO-ENA paper illustrates the present framework for DER participation in the wholesale market (Figure 7), which is based on direct relationships between AEMO, the DER aggregators and retailers without any involvement of the distribution network services providers (note: Australian DNSPs, as in Texas, provide only wires services, not retail electricity). This structure is seen as workable with small numbers of DER but not feasible as the numbers continue to grow and are used for bulk power system and distribution grid services.

[18] http://futuresmart.ukpowernetworks.co.uk/wp-content/themes/ukpnfuturesmart/assets/pdf/futuresmart-flexibility-roadmap.pdf

[19] CEN-CENELEC-ETSI Smart Grid Coordination Group, Smart Grid Reference Architecture, November 2012. Available online at: https://ec.europa.eu/energy/sites/ener/files/documents/xpert_group1_reference_architecture.pdf

[20] GridWise Architecture Council, GridWise® Interoperability Context-Setting Framework, March 2008

[21] https://www.energynetworks.com.au/sites/default/files/entr_final_report_web.pdf

[22] https://www.energynetworks.com.au/sites/default/files/open_energy_networks_consultation_paper.pdf

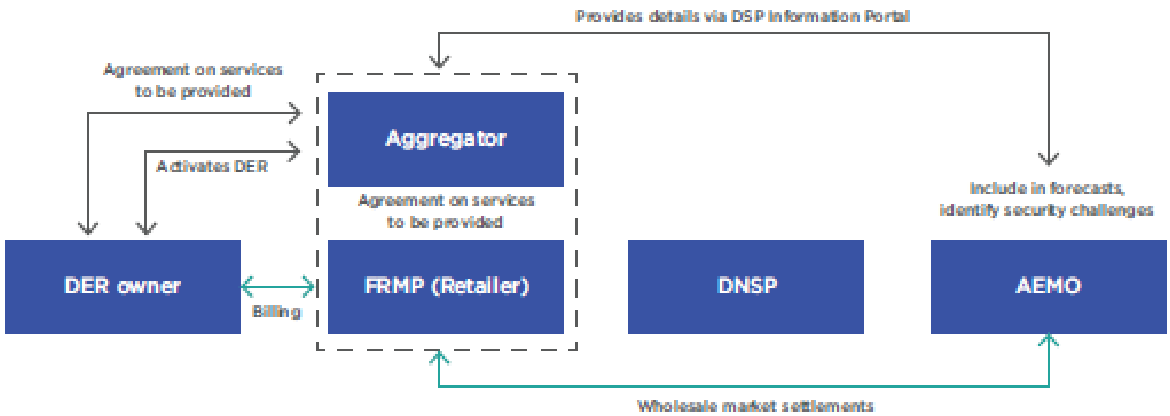

Figure 7: Current DER Dispatch Framework (source: AEMO-ENA)

The consultation paper proposes three TDC coordination models to frame the stakeholder discussions under the Open Networks initiative. The paper summarizes key advantages and disadvantages to each model consistent with the Grid Architecture principles described in Section 2 of this report. The first model (Figure 8) resembles Total TSO, with AEMO operating a central platform as well as optimizing DER dispatch while taking into account both transmission and distribution network constraints.

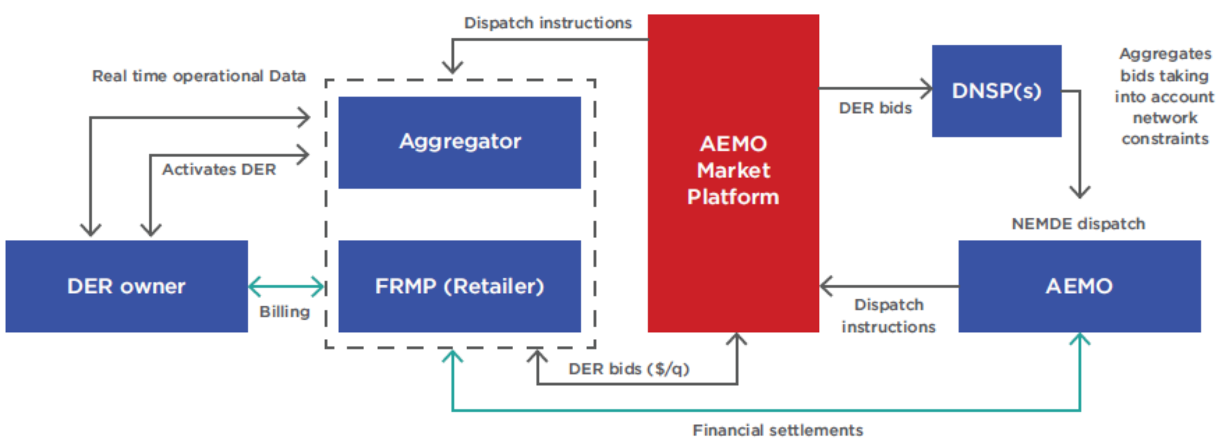

Figure 8: Single layer centralized structure (source: AEMO-ENA)

A second model (Figure 9) is described by AEMO-ENA that is effectively a Total DSO approach.

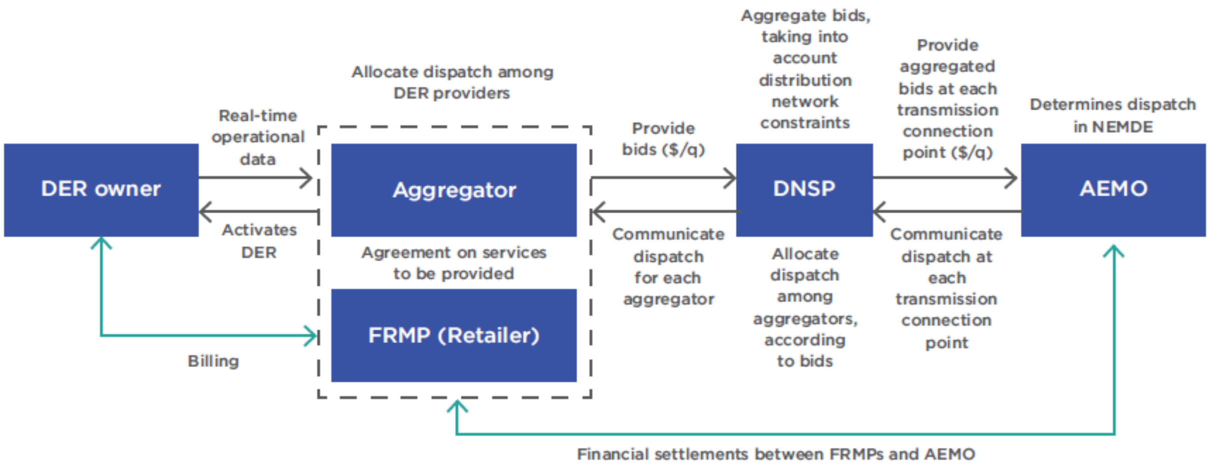

Figure 9: Layered Structure (source: AEMO-ENA)

The third model (Figure 10) is an adaptation of the Total DSO concept incorporating DSO independent (iDSO) of the distribution utility.

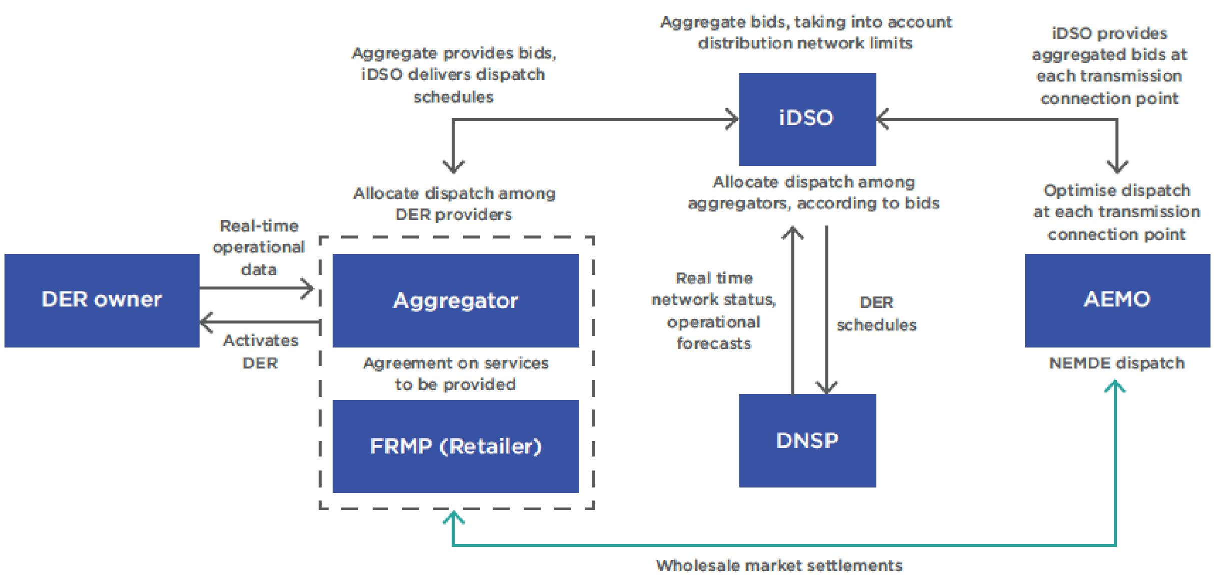

Figure 10: Layered, 3-way operational coordination structure (source: AEMO-ENA)

These models and related considerations are introduced as a means to frame discussions about the evolution of the needed structural changes to TDC coordination in Australia. The paper recognizes the structural change issues raised elsewhere and is following a process similar to the UK to engage stakeholders in an assessment of the options and trade-offs to develop an effective roadmap. However, like the UK effort, Australia is not conducting a comparative grid architectural structure risk assessment. Australia is also using the SGAM framework which will enable a conceptual design of the IT/OT systems and needed interoperability which in turn supports development of an implementation cost estimate.

3.3 European Union

High penetration of distributed generation connected at the distribution level in Europe along with increased utilization of DER for grid services, is creating a need for greater T-D coordination. The CIGRE report[23] highlights "*two main dimensions of the TSO-DSO relationship:*

> *(1) operational changes required resulting from the presence of distributed energy resources (DER) at the end of the grid in terms of coordinated (a) planning, (b) operations, and (c) information exchange between DSO and TSO;*
>
> *(2) potential impact of DER related to the above operational changes with respect to (a) frequency management and balancing, (b) voltage control, and (c) system restoration.*"

These issues, similar to the UK, lead to the same architectural issues regarding DER coordination requirements and related changes to the current structures. The present TDC coordination architecture in Europe is in its early stage in regard to DER, and for the most part resembles the Total TSO model.

EU proposals for future TDC coordination architectures have initially been prepared by the European TSO[24] (ENTSO-E) and DSO organizations[25] (DSO Committee) respectively. The proposed DSO Committee approach, which is the most detailed proposal to date in the EU discussions, involves the ability to:

- Offer flexibility and aggregated DER services up to TSOs
- Utilize DER for congestion management for their own systems
- Provide some simplistic signals up to the TSO to inform optimization equations and when the DER can and can't participate in markets
- Prioritize distribution system reliability needs in the event that a TSO dispatch of DER conflicts with such needs.

The DSO Committee proposal includes a traffic light concept to coordinate markets across the TSO-DSO interface with distribution grid operations. The DSO traffic light concept provides one way of managing this interaction: a green signal from the DSO at a given TDC substation informs the market that there is no limitation on sourcing services from the DSO, while a red signal prevents use of the DER in the optimization because distribution system stability is jeopardized and sourcing services is not possible.

The report states that, in today's power grid, there is only a green phase (operation dictated by the wholesale market) that can, in extreme situations, suddenly become red (operation dictated by distribution grid needs). As the transition from one phase to the other becomes increasingly significant in the future, it is important to provide for an amber intermediate stage. The amber phase, the interaction of market and distribution grid, is entered if a potential distribution system bottleneck exists in a defined local area. In the amber phase, distribution system operators can call upon the flexibility

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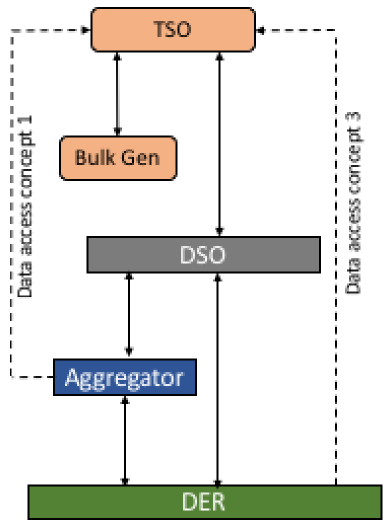
[23] CIGRE (2018)

[24] See the ENTSO-E position paper, *Distributed Flexibility and the Value of TSO/DSO Cooperation*, available at: https://docstore.entsoe.eu/_layouts/15/WopiFrame.aspx?sourcedoc=/Documents/Publications/Position%20papers%20and%20reports/entsoe_pp_DF_1712_web.pdf -- as well as the earlier working paper of the same title, available at: https://docstore.entsoe.eu/Documents/Publications/Position%20papers%20and%20reports/170809_Distributed_Flexibility_working-paper_final.pdf

[25] See DSO Committee on Flexible Markets (2018), *Flexibility in the Energy Transition: A Toolbox for Electricity DSOs* available online: https://www.edsoforsmartgrids.eu/wp-content/uploads/Flexibility-in-the-energy-transition-A-tool-for-electricity-DSOs-2018-HD.pdf The DSO Committee is comprised of the various European associations representing DSOs.

offered by DER aggregators in that local distribution area to prevent a red phase situation. This will



generally be affected indirectly through measurements agreed to with suppliers/aggregators or in exceptional cases, should such measures be lacking, by direct control as allowed by contractual arrangements.

The essential future coordination structure proposed by the DSO Committee is shown in Figure 11.

Figure 11: E.U. DSO Associations' Proposed Future Architecture

The future architecture proposals in Europe are not very well developed so there are not too many possible observations. The structure proposed by the DSO Committee is layered and the main model is very close to the Total DSO model. This arrangement avoids tier bypassing and hidden coupling issues, because the DSO is instructing the aggregator so that there is no bifurcation of DER dispatch authority.

The DSO Committee proposal includes two additional options for data flows to the TSO that imply a degree of tier bypassing. These options are shown in Figure 11 as dashed lines labelled "Data access concept 1" and "Data access concept 3" (Data access concept 2 is via the DSO).[26,27] Since no instructions to DER are intended to flow back along these lines, there is no actual hidden coupling issue from a control point of view. However, there can be a race condition[28] with the same information flowing along different paths to different destinations and potentially arriving at different times due to differing latencies. For Data access concept 3, this is not likely to be an issue. However, depending on the latency in the aggregator, it could become a problem for Data access concept 1. In this case, the TSO and DSO could end up with differing views of grid state potentially leading to conflicts in DER coordination. The problem could likely be resolved at the DSO, but this is something for which a solution must be specifically designed. The issue is more severe if there are many aggregators involved since each may have a different latency.

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[26] DSO Committee on Flexible Markets (2018), *Flexibility in the Energy Transition: A Toolbox for Electricity DSOs* (2018).

[27] *TSO-DSO Data Management Report* (2016), available online: https://cdn.eurelectric.org/media/2061/tso-dso_dm_rep-2016-030-0382-01-e-h-E471F48A.pdf

[28] Race condition is a condition in which an outcome depends on the actual order of arrival of data that should be considered simultaneously.

The DSO Committee model provides a foundation to develop more sophisticated DSO operations and TDC coordination approaches, informed by pilots and demonstration projects. Common-sense simplifications, such as the green-red traffic light concept, may allow flexibility and congestion management services to be provided across the TSO-DSO interface while maintaining ownership, control and responsibility in each jurisdiction. This would represent an evolution towards a Hybrid DSO model, with DSOs and TSOs both playing a role in coordinating DER services and operations.

The ENTSO-E position paper and working paper cited earlier state a definite preference for a “single flexibility marketplace,” a centralized market platform in which both TSO and DSO may procure flexibility services offered by “distributed flexibility resources” (DFR). Such a marketplace would initially be implemented at the national level and could over time evolve into a broader regional market. Figure 12 illustrates this model.[29]

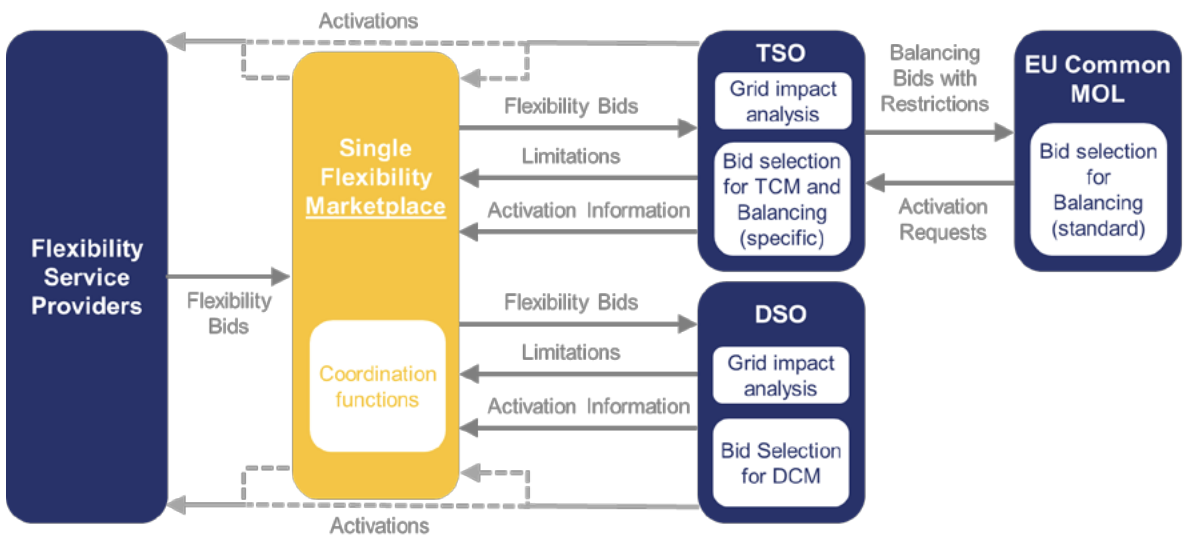

Figure 12: ENTSO-E’s proposed flexibility marketplace for balancing and TSO and DSO congestion management processes

This model may be considered a variant of the Hybrid DSO, except for the lack of any pathways for TSO-DSO direct coordination except through the marketplace. Depending on how TSO-DSO coordination is implemented, this approach could raise concerns about tier bypassing and hidden coupling. ENTSO-E’s position paper does acknowledge the importance of addressing TDC coordination.

However, ENTSO-E explicitly opposes architectures where DFR interact only with the DSO for bidding and dispatch, as in the Total DSO conceptual model. “Such scheme leads to fragmentation of liquidity, places unnecessary barriers to aggregation, unnecessarily reduces the pool of options for grid operators, increases communication costs, limits the use of DSO connected flexibility to solve congestions in the TSOs’ network and vice-versa, and obliges distributed flexibility providers to bid in different platforms, one for the TSO and one or more for each DSO to which their assets are connected.” Such concerns

[29] See https://docstore.entsoe.eu/Documents/Publications/Position%20papers%20and%20reports/170809_Distributed_Flexibility_working-paper_final.pdf

should be weighed against the significant architectural considerations related to system operations discussed here, including tier bypassing and hidden coupling.

The ENTSO-E argument against Total DSO model highlights a central issue in all the international discussions - the trade-off between desires for more efficient market structures versus a desire for more robust system operational structures.[30] This tension is why many of the coordination discussions lead initially to proposed compromise structures that are variants of a Hybrid model.

3.4 California

California's current coordination structure is also closer to a Total TSO model. The current structure is a continuation of the California ISO (CAISO) and distribution utility roles in which the CAISO optimizes the dispatch of resources to execute wholesale spot-market energy trades and balance the system in real time, while the distribution utility provides reliable power distribution services. However, the role of distribution operators is changing as the interest in using DER services to provide distribution grid services has begun and is expected to increase. Also, DER are expected to play a more significant role in providing bulk power system services to address the flexibility needs similar to those described in the UK and Europe.

The present California architecture in Figure 13 reflects DER services provided directly to the TSO as well as the existing demand response (DR) programs that distribution utilities operate for the benefit of wholesale market operations. The resulting complexity involves a large number of entities and a somewhat ad hoc coordination structure. For context, the UK and Europe do not have distribution utility run demand response programs.

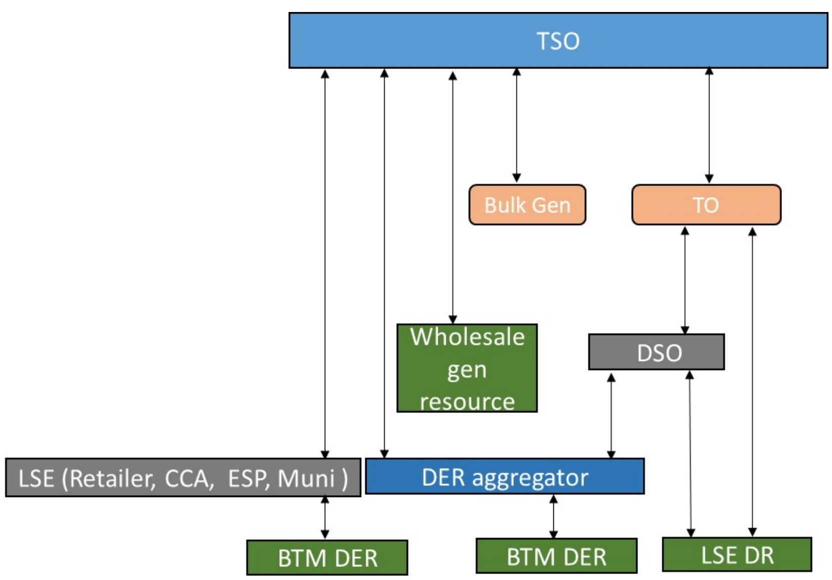

Figure 13: California's Current Coordination Framework

[30] De Martini and Kristov (2015), p. 16

Note, in particular, that there are no coordination links between the CAISO (TSO) and the DSO. Even when the CAISO dispatches a demand response resource that participates in a utility program, the dispatch goes to the transmission owner (TO) who dispatches the demand response. As a result, considerable tier bypassing exists in the present system.

In 2016 FERC approved a CAISO-proposed wholesale participation model for DER aggregations, but thus far no aggregators have opted to use this model and instead use the demand response model to aggregate behind-the-meter DER. One factor that seems to be a deterrent to the new model is the uncertainty for all key actors – the CAISO, the DSO and the DER provider – created by the lack of coordination procedures between the CAISO and the DSO to address real-time distribution conditions that may constrain DER performance. The CAISO DER aggregation model even allows an aggregation to include multiple TDC interface nodes (locational pricing nodes), a feature which the other US ISOs and RTOs have argued strenuously against at FERC.

Beginning in 2016, a working group considered TDC coordination needs for higher levels of DER wholesale market participation that ultimately led to a 2017 joint report by the CAISO and investor-owned distribution utilities focused.[31] This report focused on immediate coordination issues due to participation of DER in wholesale markets, and identified near-term mitigation measures.

One coordination aspect that California addressed, was a change to the Rule 21 interconnection rule regarding utility interface protocols. The change will require utilities to use IEEE 2030.5 (SEP2) as the protocol for direct link with customer DER. Also, the utility-to-aggregator interface will become a uniform set of protocols, but the aggregator to customer DER remains random, as identified in Figure 14 below. However, the continued lack of protocol harmonization on the customer DER will pose integration challenges to scale and potential operational risks due to the potential for poor integration as noted in the AEIC report.[32]

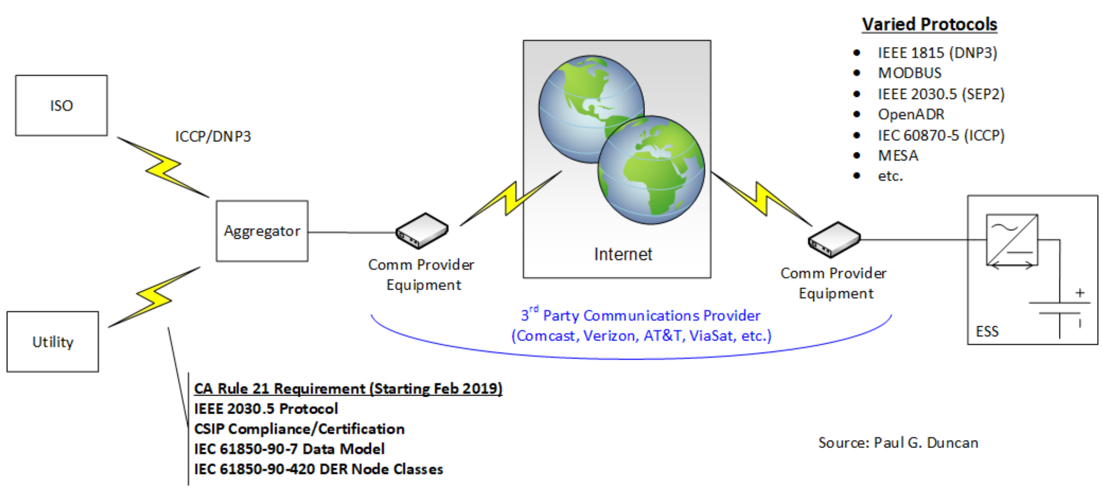

Figure 14: California TDC Information & Control Standards and Communications Options

California has begun to consider regulatory and implementation needs to enable multi-use applications (MUA) of energy storage and other DER, i.e., provision of services by the same resource for both the

[31] See More Than Smart (2017), *Coordination of Transmission and Distribution Operations in a High Distributed Energy Resource Electric Grid.*

[32] AEIC, PG&E, SCE and SDG&E (2018)

bulk power and distribution systems. Discussions continue in California on a future TDC coordination structure and significant near-term control and communication issues to resolve.[33] Based on early direction of the discussions, the future TDC coordination structure in California will likely evolve over the next decade from the current structure toward a version of the Hybrid DSO model as shown in Figure 15. This is largely because until there are meaningful markets for distribution services, DER developers generally insist on the need for direct access to wholesale markets.

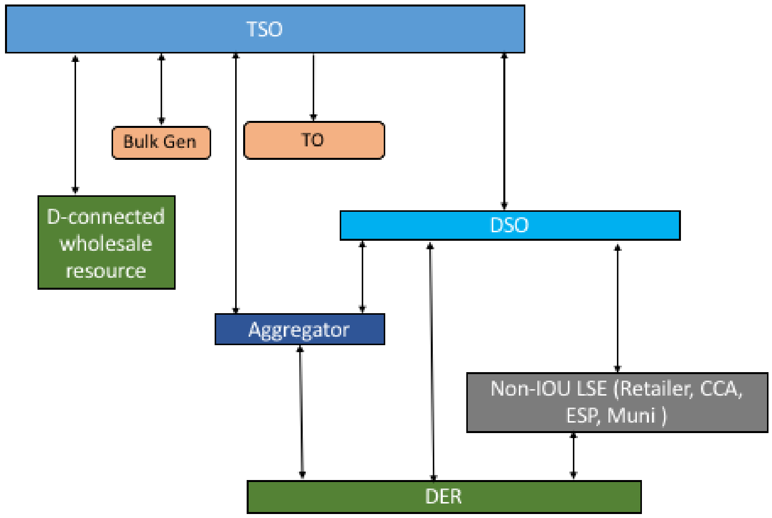

Figure 15: California's Potential Future Architecture

The California TDC coordination issues now involve, for example, the need to define measurement and compensation schemes for DER engaging in MUA, and rules for dispatch prioritization when the bulk power and distribution systems need different responses from the same distributed resource. The 2018 California Public Utility Commission (CPUC) decision D.18-01-003, and the CPUC-CAISO Joint Framework attached as Appendix B to that decision, reflect the current state of development of MUA matters and identify some of the yet-to-be-resolved implementation issues.

Further, there is recognition that a more complete discussion of a TDC coordination structure is needed to address the increasing significance of real-time distribution system conditions potentially constraining access to wholesale markets. Also, CAISO dispatches of DER to which the DSO has no visibility can create unexpected service quality and potentially reliability and safety issues on the distribution grid.

A simple Hybrid DSO based model, as illustrated in Figure 15, will continue to exhibit tier bypassing due to the path from DER to aggregator to TSO that bypasses the DSO. In addition, the potential for hidden coupling exists, with some aggregators, LSEs and the DSO all connecting to DER. The DSO may be able to mitigate part of this but not the hidden coupling involving the TSO/aggregator tier bypass unless some coordination mechanism is worked out between the TSO and DSO specifically for this. The presence of the direct aggregator-to-TSO connection also presents a moderate cyber vulnerability to the bulk energy system. Overall scalability is good due to the near Total DSO structure, which is well layered. If the DSO is handling DER coordination for the DER in its service area, then latency cascading is possible but limited.

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[33] id.

3.5 New York

New York's current TDC coordination structure, like California, is the result of legacy structures evolving over time to incorporate independent aggregation, utility programs and direct participation of customer demand side resources in wholesale markets. Discussions are underway to improve coordination and streamline interfaces as a part of the ongoing stakeholder processes at the NYISO, the Joint Utilities, and the state Public Service Commission. The starting point for these discussions is the current architecture in New York (Figure 16) that is essentially a Total TSO model.

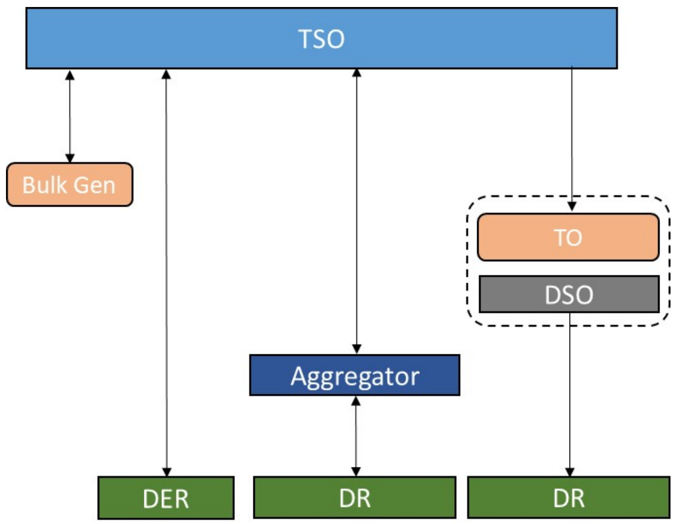

Figure 16: New York Current Coordination Framework

At present there is no consensus in NY on the long-term coordination model. The NYISO in its DER Roadmap concept paper[34] described two simple alternative conceptual models, as shown in Figure 17. The TSO centric hybrid type approach (Alternative 1 below) involves the aggregator interfacing directly with both the NYISO and the DSO (known as distribution system platform provider or DSP in New York), including separate communications and information requirements.

Alternative 1 is a minor evolution from the present structure: layered decomposition is not used, and tier bypassing is extensive. Consequently, the potential for hidden coupling is also large and scalability, both in terms of communications and computational needs at the TSO, is problematic. Cyber vulnerability for the bulk energy system is high in this model because of the direct connection of DER to the TSO. Cascading latency is a concern in some of the coordination paths. The potential ability of aggregators or customer DER to participate at the TSO level and/or the DSO level is a source of potential issues due to hidden coupling at the distribution grid. For these reasons, the NYISO and the DSOs view this hybrid model as becoming more problematic as DER penetration and market participation increase over the coming years. Neither entity in the hybrid model will have a sufficiently accurate picture of

[34] NYISO (2017), *Distributed Energy Resources Market Design Concept Proposal,* available online: http://www.nyiso.com/public/webdocs/markets_operations/market_data/demand_response/DER_Roadmap/DER_Roadmap/Distributed-Energy-Resources-2017-Market-Design-Concept-Proposal.pdf

what is happening with DER aggregations and individual customer resources to be able to manage the collective effects DER will have on markets or physical transmission and distribution security.

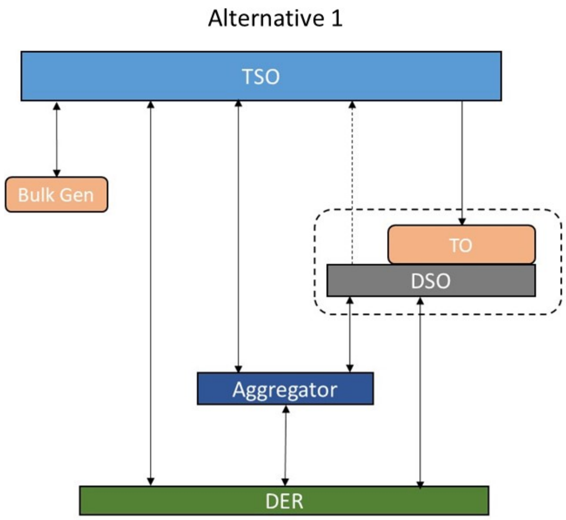

Figure 17: Options for New York's Future DER Coordination Framework

In alternative 2, removing the link between the aggregator and the TSO moves closer to the layered decomposition structure by eliminating one source of tier bypassing, the ability of aggregators to participate directly at the TSO level. The presence of a link from DER to the TSO, however, still allows for tier bypassing, hidden coupling, scalability issues, and cyber vulnerability at the TSO level. In alternative 2, the DSO is better prepared to manage the DER and, if coordination between TSO and DSO is well organized, the tier-bypassing problem may be mitigated. However, DER that are bidding into the wholesale markets and providing DSO grid services could then add the potential for mis-coordination. The hidden coupling problem remains but likely at a low level.

It is clear in both options that the intent is for most DER to be orchestrated through aggregators. NYISO anticipates enabling aggregations as small as 100 kW to participate in wholesale markets for energy, ancillary services, and capacity.[35] Unlike the California aggregation model, however, NYISO plans to require these aggregations to be entirely within a single TDC interface or pricing node. The NYISO and DSOs have also had discussions to implement rules for DER service hierarchy to ensure that the responses to competing signals DER may be receiving are well orchestrated.[36]

The Joint Utilities developed an evolutionary framework for the role of the DSO.[37] This framework (Figure 18) includes two coordination models and refers to a potential future third end state. “DSP 1.0” is the current DSO development in New York. “DSP 2.0” refers to an evolutionary second phase with enhanced integration, information, and market services.

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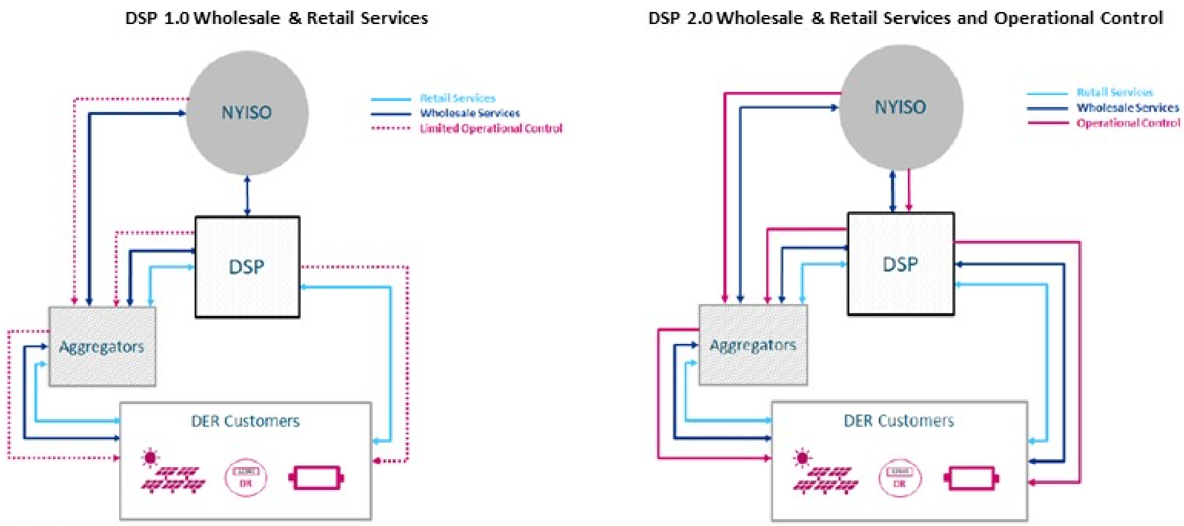
[35] NYISO and PJM operate centralized wholesale capacity markets that clear most capacity, whereas in California the majority of capacity is bilaterally contracted.

[36] New York has an open stakeholder engagement process to address a range of detailed issues including DER coordination. The Joint Utilities of New York stakeholder engagement website with materials is here: http://jointutilitiesofny.org/joint-utilities-of-new-york-engagement-groups/

[37] Joint Utility’s framework is described in Consolidated Edison’s *Distribution System Improvement Plan*, 2018, pp. 15-17 Available online at: http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7bDE23C0BF-CF5C-4D31-BF9A-E9AC36FD659B%7d

Currently, under DSP 1.0, DSOs provide retail settlement and billing services to customers based on a value of DER tariff, and wholesale settlement and billing services to aggregators for NWA procurement. DER aggregators and their customers can also access wholesale settlement and billing services through the NYISO. This approach includes rules for joint participation in utility NWA procurement and the NYISO markets that form the basis for operational coordination with the NYISO.



Source: ConEdison

Figure 18: Joint Utilities of New York TDC Coordination Models

DSP 2.0 is intended to increase visibility and operational control over DER to enable integrated markets for wholesale and distribution services. In DSP 2.0, DSOs, as an option, would offer wholesale scheduling and dispatch services. This is proposed to enable customers and aggregators to maximize the value of their resources across NYISO wholesale markets and distribution markets. In DSP 2.0, aggregators can still access wholesale markets directly through the NYISO. The NYISO would also need enhanced capabilities to monitor and control DER. The Joint Utilities' DSP 2.0 is similar in structure to the NYISO's Alternative 1. Additionally, the Joint Utilities suggest that a third evolution, called "DSP 2.x", which is a possible longer-term phase of TDC coordination development that may develop in response to transactional distribution markets. DSP 2.x, while not discussed in any detail, may in concept look similar to the NYISO's Alternative 2. In this conceptual model, aggregators would no longer interface with the NYISO and instead the DSO would coordinate transactions across distribution and physical interchange across the T-D interface. The few direct interfaces between DER and the NYISO would involve distribution connected bulk power system resources.

3.6 Japan

Japan is in the midst of reforming the electric industry comprised of ten vertically integrated electric utility power companies (EPCOs), nine of which regionally serve mainland Japan and the tenth EPCO serves the islands of Okinawa. The first round of electricity market reform commenced in 2013 with the establishment of the Organization for Cross-Regional Coordination of Transmission Operators (OCCTO). OCCTO is the TSO for mainland Japan responsible for the countywide network planning and operations.

Japan's market reform is centered on opening up a distribution market and improving the coordination of DER. Japan is on track to unbundle the transmission and distribution business from its vertically integrated model. When the transmission and distribution operator is legally separated from the rest of the traditional utility functions in 2020, Japan plans to establish a real-time market to facilitate the participation of DER to provide wholesale grid services to the transmission networks. The TSO has identified capacity services to maintain operating reserves as a near-term need and the first service to be offered to the real-time market. Future services could include frequency regulation and response services as renewable energy increases although local distribution services are not contemplated at this time.

The current architecture in Japan (left side of Figure 19) is a simple TSO model where the TSO is the balancing authority for the region with direct command and control of large and small generators. The present architecture is simple and shows a partially layered but disjointed structure. A combined TDSO (TO/DO) handles DER coordination and solar PV curtailment directly. This architecture is not sufficient to deal with the complexities associated with growing volumes of controllable end devices and distributed generators in Japan.

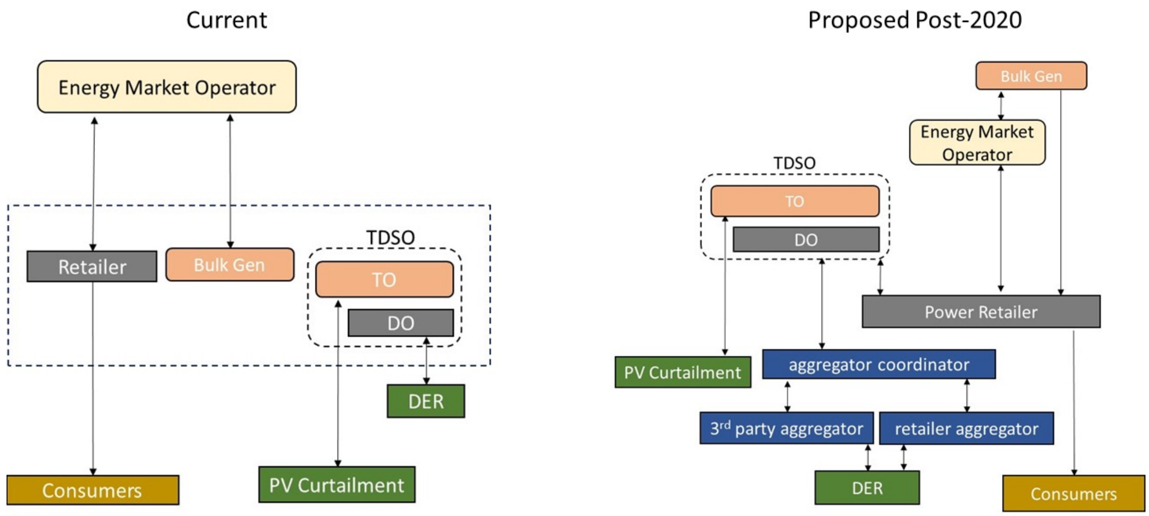


Figure 19: Japan Current and Proposed Future Architecture Direction

The future architectural direction (right side of Figure 19) in Japan is reasonably well structured from a layering standpoint because transmission and distribution operations are not separated. There is a possibility of tier bypassing for the PV curtailment function, but this could be easily mitigated by coordination within the TDSO.

This future structure adds a layer through the introduction of an aggregator coordinator intended to lessen the operational burden of the TDSO. This means multiple entities may be able to control or dispatch supply-side and demand-side resources creating possibilities for hidden coupling. There are hidden coupling possibilities because disjointed sets of DER on the same system may be instructed by separate aggregators (third party or retailer). The aggregator coordinator may be able to mitigate this issue if its responsibilities include that activity. The question here is whether separate aggregators would be able to pursue differing goals for DER aggregation or are simply acting as layered interfaces.

Additionally, the multiple layers of organization between the DER and the TDSO, especially if the aggregator coordinator exists, means that there is a cascading latency issue that would limit fast action involving the DER. Localized control would be needed to respond to short term variations in solar output. There is a disconnect involving the energy market operator and the TDSO, but this might be resolved via the connections to the power retailer. It would be better to complete the layered structure in a more regularized way. Also, this structure likely places a responsibility on the aggregators and aggregator coordinator to provide cyber security for the data flows to and from the DER, which may be an issue in terms of roles and responsibilities if these entities are not regulated. The use of aggregators and an aggregator coordinator provide some amount of communication scalability, but the centralization of DER coordination will cause computational scalability issues at transmission if DER penetration becomes high.

4 Conclusion

4.1 Conclusion

In conclusion, there are three shared central themes under discussion in the development of TDC coordination.

Theme 1: Customer DER to distribution interconnection standardization and operational integration technology maturity for the provision of services is currently inadequate.

The number of potentially applicable standards for information, controls and communications mediums and associated permutations create a significant challenge to address the situational awareness and controllability required. The relative immaturity of the related software, hardware and communications technologies involved compound the issues.[38] There is a need for a more holistic set of distribution grid codes in the US that fully address both the interconnection and operational coordination standards (e.g., physical, information, control, communication and cybersecurity) needed to ensure system reliability. Such distribution grid codes are employed in the UK[39], Europe and other countries.

Theme 2: The current DER coordination models for all locations exhibit considerable distribution operator bypassing, with the attendant issues of hidden coupling and bulk system cyber vulnerability.

All current models reflect incremental evolution based on existing legacy structure and initial focus on market access for DER and market efficiency issues. As such, none of the locations have fully addressed the critical architectural structure issues that will impact operational risk, chiefly reliability and resilience. More focused examination of alternative grid architectures in relation to operational risk is needed. The processes in Australia and the UK, with enhancements to more specifically assess structural risk, offer reference models to conduct more complete evaluations required to address multi-utilization of DER at scale. Such a systematic inquiry into grid operational risk issues and architecture alternatives will reliably enable high levels of DER utilization for the optimal benefit for all customers.

Theme 3: The present and future models involve two schools of thought regarding coordination structure: 1) a centralized approach where the TSO performs all coordination, and 2) layered approaches where a DSO has a significant role in coordination.

The choice of centralized or layered structure is a foundational architectural decision. This decision has significant implications for downstream decisions about the architecture, design and implementation of control systems, communication networks, market mechanisms, organizational roles and responsibilities, and consequently industry structure.[40] The grid architecture considerations described in this paper suggest layered structures to coordinate and optimize significant amounts of DER as the most robust approach to address reliability, resilience and market efficiency objectives.

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[38] Modern Distribution Grid Report, Volume II, 2017 Available at: https://gridarchitecture.pnnl.gov/media/Modern-Distribution-Grid_Volume-II_v1_1.pdf

[39] The Distribution Code of Licensed Distribution Network Operators of Great Britain, Issue 36, December 2018 Available at: http://www.dcode.org.uk/assets/uploads/D_Code_36_clean_181206.pdf

[40] See Kristov, De Martini and Taft (2016) *Two Visions*.

DER coordination will require high levels of visibility into the operating conditions of the distribution network, including physical switching coordination and distribution level nodal state estimation. TSO dominant models will also need to address these requirements as failing to do so may lead to distribution tier bypassing, scalability challenges, hidden coupling, and bulk energy system cyber vulnerability. The layered DSO model is architecturally simpler and more robust, but tougher to transition to in practice given the highly centralized industry structure starting point for most power systems. The existing centralized architecture appeals to DER developers due to more direct access to wholesale markets, particularly while distribution-level grid-services markets do not yet exist.

Nevertheless, several Hybrid DSO future approaches are under discussion internationally and would seem to be attempts to have it both ways. Although appealing as a potential compromise between the divergent TSO and DSO perspectives, Hybrid DSO models are not without their issues because they introduce complexity in the structure of roles and responsibilities, specifically with regard to information flows, control mechanisms, and authorities. These complexities may be manageable at lower levels of DER participation in market and network services, but they will introduce operational risks from the structures impacting reliability and resilience and require that scalability issues be addressed as DER participation grows.

It is also important to note that the Open Networks efforts in both Australia and the UK have benefited from the U.S. DOE funded research on Grid Architecture and TDC coordination conducted by Pacific Northwest National Laboratory and Lawrence Berkeley National Laboratory. The Australian efforts over the past few years, for example, include extensive citation to the related research papers and consultation with the research teams.

4.2 Considerations for Moving Forward

A. Subsequent investigation of TDC coordination should further examine the key issues highlighted by the CIGRE and AEIC reports to gain a more complete understanding of the changes needed to integrate and utilize DER for bulk power and distribution services. The United States would benefit from the development of a general distribution grid code that can be adapted to individual state needs. Such a code would not only incorporate the recent IEEE 1547-2018 standard and related advanced inverter functions, but also address the additional planning and operational information, control, communication and cybersecurity requirements as well as roles and responsibilities. Additionally, a maturity assessment of the relevant standards, software, hardware (e.g., inverters), communications and cybersecurity should be conducted. This assessment would inform regulatory and industry decision makers on development roadmaps for greater operational integration and utilization of DER while ensuring system reliability.

B. An evaluation process based on comparative analysis of grid architectures and operational risk that can be used by individual states and regions to address evolving needs for greater TDC coordination is needed. The current short-term oriented approaches are not systematically addressing the architectural principles nor fully addressing the operational risk issues to meet reliability and resilience criteria for both bulk power and distribution systems while achieving market efficiency objectives over the next decade. Specifically, greater knowledge sharing across the various markets/states and a set of guidelines or reference implementations is needed to help decision makers develop needed holistic strategies for transmission and distribution coordination across planning, grid operations, and market operations. Much has been learned in the past two years since the Grid Architecture reports and De Martini and Kristov paper[41] were written. There is a need to develop decision maker guidance by providing a process framework that can inform the development of holistic strategies for reliable and resilient TDC coordination. Such a set of guidelines would ideally enable stakeholders in each jurisdiction to evaluate the path forward to addressing the unique market and power system structural issues within each ISO/RTO and state.

To begin such an effort, it would be beneficial to create a series of educational briefings that focus on key coordination architecture principles (e.g., laminar decomposition, tier bypassing, observability, and scalability), which form the basis for comparing and guiding TDC coordination models.

[41] De Martini and Kristov (2015)

5 Glossary

Roles and Responsibilities

Across the world, different terminology is used to refer to similar roles and responsibilities in the coordination and control of power systems. A comparative matrix of the acronyms used for each jurisdiction is identified in Table 2. In this report, the local acronym is described and a generic reference introduced in this glossary is employed to facilitate comparisons.

Table 2: International Roles & Responsibilities Translation Matrix

Function	Australia	UK	EU	US	Japan
Own, maintain & operate physical transmission assets	TNSP	TO	TO	TO / TDO	TDSO
Transmission service and real-time balancing (i.e., balancing authority)	TSO (AEMO)	TSO	TSO	ISO/RTO/TSO	TSO (OCCTO)
Operate energy markets	TSO (AEMO)	Power exchange	Power exchange	ISO/RTO	Power exchange
Own, maintain and operate physical distribution assets	DNSP	DNO	DSO	UDC/DO/TDO	TDSO
(Future) Provide distribution service and coordination for DER	DSO	DSO	DSO, third parties	DSO, DSP (NY)	TDSO
Provide retail electric energy to end users	FRMP	Retailers	Retailers	LSEs, Retailers	Retailers
Aggregate DER resources to participate in wholesale markets and offer grid services	Aggregators	Aggregators	Aggregators, VPP	DERP (CA) DCEA (NY)	Aggregator Coordinator

BALANCING AUTHORITY (BA) is the responsible entity that integrates resource plans ahead of time, maintains load-interchange-generation balance within an electrically-defined Balancing Authority Area (BAA), and supports interconnection frequency in real time. A transmission owner (TO) or ISO/RTO may be an area balancing authority also known as a transmission system operator (TSO).

DISTRIBUTED ENERGY RESOURCES (DER) as used in this report encompasses the full range of energy resources, end-use devices and communication/control systems operating on the electric system below the level of the high-voltage transmission or bulk power system. DERs may be connected to the distribution utility’s system directly or may be “behind-the-meter” on the premises of end-use customers. DERs may also be aggregated to operate as sub-resources of a virtual resource that provides services to the distribution utility or participates in the wholesale market. The key defining feature of DER is their point of interconnection below the bulk system.

DER COORDINATION means, at a minimum, coordinating the operation of DER to ensure reliable operation of the distribution system and the TDC interfaces. Under some architectural models it can also entail optimizing DER operation to meet various needs of the power system at both bulk and distribution levels and may include DER participation in wholesale and distribution-level markets.

DER Orchestration in this document describes aggregator-coordinated DER behavior, enabling large numbers of distributed resources to perform as if they are one virtual resource.

Distribution Network Operator (DNO) is a term used in several countries to describe the entity that is responsible for the distribution of electricity and that operates the local distribution network. The EU countries refer to this entity as the DSO.

Distribution System Operator (DSO) refers to the anticipated future entity in a high-DER system that is responsible for planning and operational functions associated with coordinating DER services for distribution networks and/or DER participation in wholesale markets in coordination with the TSO, aggregators, and other relevant parties. The future DSO may be the same entity as the existing DO/DNO with expanded roles and functions, or may be formed as an independent DSO (IDSO) separate from the DO. The EU countries refer to the existing DNOs as DSOs.

Distribution Owner (DO) is the entity that owns, maintains, and operates the distribution system physical assets that deliver electricity from the transmission-distribution interface to end-use customers. In general, the DO and the DNO are the same entity. The distribution owner may also be a transmission owner (TO) and in that case is a TDO (defined below).

Independent System Operator (ISO) or **Regional Transmission Organization (RTO)** is an independent, federally regulated (in the U.S.) entity that is a Transmission System Operator (see below), a wholesale market operator, a Balancing Authority, and is responsible for transmission planning.

Load-Serving Entity (LSE) serves the retail electricity demand and energy requirements of its end-use customers. LSEs may be competitive retailers, regulated investor-owned utilities, or municipal governmental or cooperative electric service providers.

Provider of Last Resort (POLR) is an entity that has the regulatory or statutory obligation to offer default retail electric commodity service to those consumers who do not choose a competitive supplier or whom the competitive market does not serve.

Regulator is a general term to describe the governing entity responsible for oversight of the essential functions of the electric utility, including funding authorizations for power procurements, investments, and operational expenses. This oversight extends to rate design, planning, scope of services, and competitive market interaction.

Retailer is a competitive electricity provider who sells electricity to retail customers.

Transmission Distribution Owner-Operator (TDO) is a regulated entity that owns and operates transmission and distribution network assets and may or may not be a TSO. In the case of the U.S. ISOs and RTOs, the ISO or RTO is the TSO or BA and is institutionally independent of the TDOs that are its members. In the EU, in contrast, the TDO and TSO are the typically same entity.

Transmission and Distribution System Operator (TDSO) is used in Japan to refer to the transmission and distribution network owner and operator that also is the TSO for their respective regional balancing areas.

Transmission System Operator (TSO) is responsible for real-time balancing services to the network and coordinating generation suppliers and load serving entities (LSEs) to ensure electric system reliability and security. Also referred to as the BA.

Utility Distribution Company (UDC) or **Electric Distribution Company (EDC)** is the US equivalent term for the **DNO**.

Vertically Integrated Utility is a utility that owns its own generating plants (or procures power to serve all customers), transmission system, and distribution lines, providing all aspects of electric service to retail customers.

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