A Review on TSO-DSO Data Exchange, CIM Extensions and Interoperability Aspects

Arsim Bytyqi, Siddhesh Gandhi, Eric Lambert, and Nejc Petrovič

Abstract—**The exchange of information between transmission system operators (TSOs) and distribution system operators (DSOs) is a common practice. However, the evolution of the regulatory frameworks in Europe has increased the need for enhancing TSO-DSO data exchange and interoperability. This paper provides an overview of the TSO-DSO data exchanges and demonstrates the best practices using International Electrotechnical Commission (IEC) common information model (CIM), including the implementation of IEC common grid model exchange standard (CGMES), and discussion of the corresponding advantages, disadvantages, and challenges. Furthermore, this paper evaluates and reports the activities already carried out within European projects, with particular focus on TSO-DSO interoperability. Finally, this paper concludes the need for TSOs and DSOs to rely on standard-based solutions when performing TSO-DSO data exchange, which enables the efficient operation and development of the future power systems.**

Index Terms—**Transmission system operator (TSO), distribution system operator (DSO), data exchange, interoperability, standardization, common information model (CIM), common grid model exchange standard (CGMES).**

I. Introduction

The volume and frequency of the data exchange, and the services procured by transmission system operators (TSOs) through distribution-connected resources are constantly increasing [1]. This requires better coordination between TSOs and distribution system operators (DSOs). There are several TSO-DSO coordination models adopted to meet these demands [2], [3]. However, all of them have corresponding advantages, disadvantages, and challenges. Recently, common grid model exchange standard (CGMES) [4] has been demonstrated to hold a strong potential to support the TSO-DSO data exchange related to grid model exchange. The International Electrotechnical Commission (IEC) CGMES is a standard based on the IEC common information model (CIM) [5], [6], which is developed to cover the requirements outlined in the European legislation. CGMES is used to exchange pan-European common grid models (CGMs) built with the individual grid models (IGMs) from the TSOs. The CGM is used in several pan-European or regional services for both operation planning and system development. These processes are also related to TSO-DSO interactions. CGMES is an IEC standard interface among all parties involved in a given data exchange, which enables them to perform common studies despite their reliance on different analytical applications [7], [8].

Although CGMES is developed to support transmission part of the power system in Europe, several application cases developed recently have shown promising results to support the TSO-DSO interaction. The main potentials for CGMES are summarized as follows.

1) CGMES is based on IEC CIM, which is not transmission grid specific.

2) TSO-DSO data exchanges do not need to go in the details of the unbalanced modelling of the concerned part of power system; hence, a balanced way of modelling supported by CGMES can be used.

In this paper, we describe the implementation of CIM and CGMES and the extensions made in different cases to serve the need for a better coordination between TSOs and DSOs in terms of data exchange and interoperability.

II. TSO-DSO Data Exchange Based on CIM and CGMES

To ensure more TSO-DSO coordination and better interoperability, it is required to have a common ontology to build the respective profiles for data exchange. The European Network of Transmission System Operators (ENTSO-E) proposed to use the IEC CIM as a main standard for interoperability and extensions for specific TSO-DSO demands. CIM uses classes that contain specific attributes to describe different data object types required for a data exchange between TSOs and DSOs. CIM allows extensions to cover specific demands and it is also flexible when defining data exchange profiles built as a subset of semantic canonical model comprising of CIM and custom extensions. In the context of TDX-ASSIST project, a gap analysis was performed to identify if the defined application cases and related business objects (BOs) are covered by the existing profile part of CG-

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MES or CIM extensions. The gap analysis identified 33 BOs that are not yet considered in the CGMES profiles and 18 BOs that should be changed to include all the information required in the proposed application cases. Figure 1 shows the methodology used (based on IEC standard profiling) to assess the standard support for each BO [9].

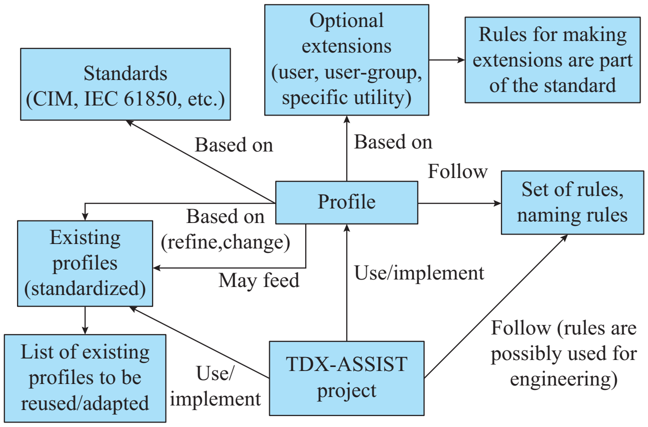

Fig. 1. Methodology used to assess standard support for each BO.

A. TSO-DSO Observability Area Based on CIM Extensions

One fundamental aspect for the efficient TSO-DSO data exchange is the necessity to define the region for which a TSO and a DSO needs to exchange their data. The responsibility area together with this part of surrounding grids that can affect the responsibility area is called the "observability area". The observability area should be built upon certain principles such as transparency, privacy and security, non-discriminatory access, and cost effectiveness. Figure 2 illustrates the proposed concept of common observability area [10] between TSO and DSO, where the responsibility and physical border are highlighted.

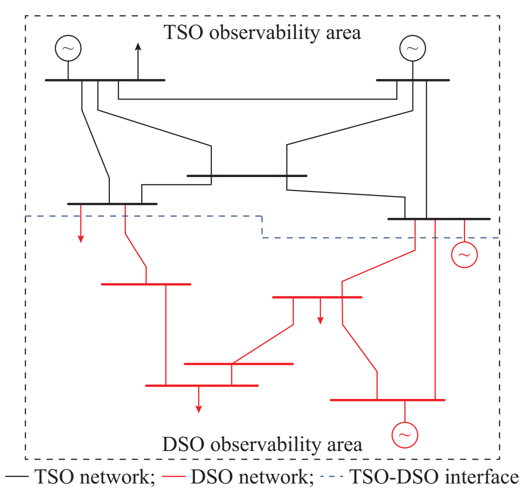

Fig. 2. Common observability area between TSO and DSO.

Based on the gap analysis performed in deliverable 1.3 as part of the TDX-ASSIST project, it was concluded that the observability area should have the following attributes supported by CIM and exchanged either within CGMES or in an additional profile to enhance the information on the grid model.

1) Time: timestamp of real-time information collected by DSO.

2) ID: set (e.g., list or vector) of unique IDs of data signals of the DSO within the TSO observability area.

3) Type: set (e.g., list or vector) of data types (e.g., measurements P, Q, U, I, states I/O, or tap position) of the corresponding IDs of data signals of the DSO within the TSO observability area.

4) Unit: set (e.g., list or vector) of data units (e.g., MW or Mvar) of the corresponding IDs of data signals of the DSO within the TSO observability area.

5) Value: set (e.g., list or vector) of numeric data values of the corresponding IDs of data signals of the DSO within the TSO observability area.

Based on the analysis performed in the CGMES profiles and the results obtained in the deliverable 1.8 as part of the TDX-ASSIST project (Core Equipment), there are two classes (GeographicalRegion and SubGeographicalRegion) as part of CGMES that are considered to be useful for supporting the TSO-DSO data exchange. However, the gap analysis done as part of the same project has shown that additional classes and attributes should be added as CIM extensions to fulfil all the TSO-DSO requirements. Figure 3 shows a unified modeling language (UML) diagram of the observability area as the CIM extensions to support the TSO-DSO data exchange [11]. The following CIM extensions are added to the Core Equipment profile of the CGMES: ObservabilityArea, ExternalObservabilityArea, InternalObservabilityArea, and ObservabilityAreaContainer. The UML diagram of the observability area shown in Fig. 3 is as part of the Core Equipment profile of CGMES.

The internal and external ObservabilityArea classes have the same association, attributes, and terminals, where connectivity nodes and all kinds of Equipment can be associated to them. Both classes (InternalObservabilityArea and ExternalObservabilityArea) can be associated to one ObservabilityArea class which contains an attribute "gridOperatorName/ID" of the grid operator, to whom this observability area belongs. ObservabilityArea class is associated to one or more SubGeorgraphicalRegion classes. Every element in a measurement data set in CGMES-based exchanges can now be related to one or more TSO or DSO observability areas, each defined for a particular grid operator. This is realized by using the extended classes: InternalObservabilityArea and ExternalObservabilityArea.

An information exchange platform may keep a record of all ObservabilityArea master resource identifiers (mRIDs) of every grid operator. Under the assumption that in the platform, every element of the grid has a global ID, the platform can use the list of ObservabilityAreas to identify which grid elements lie in two or more observability areas. When the grid operator requests real-time measurements from an information exchange platform, the operator only needs to provide one mRID of the respective ObservabilityArea and the platform can provide the correct measurements in return.

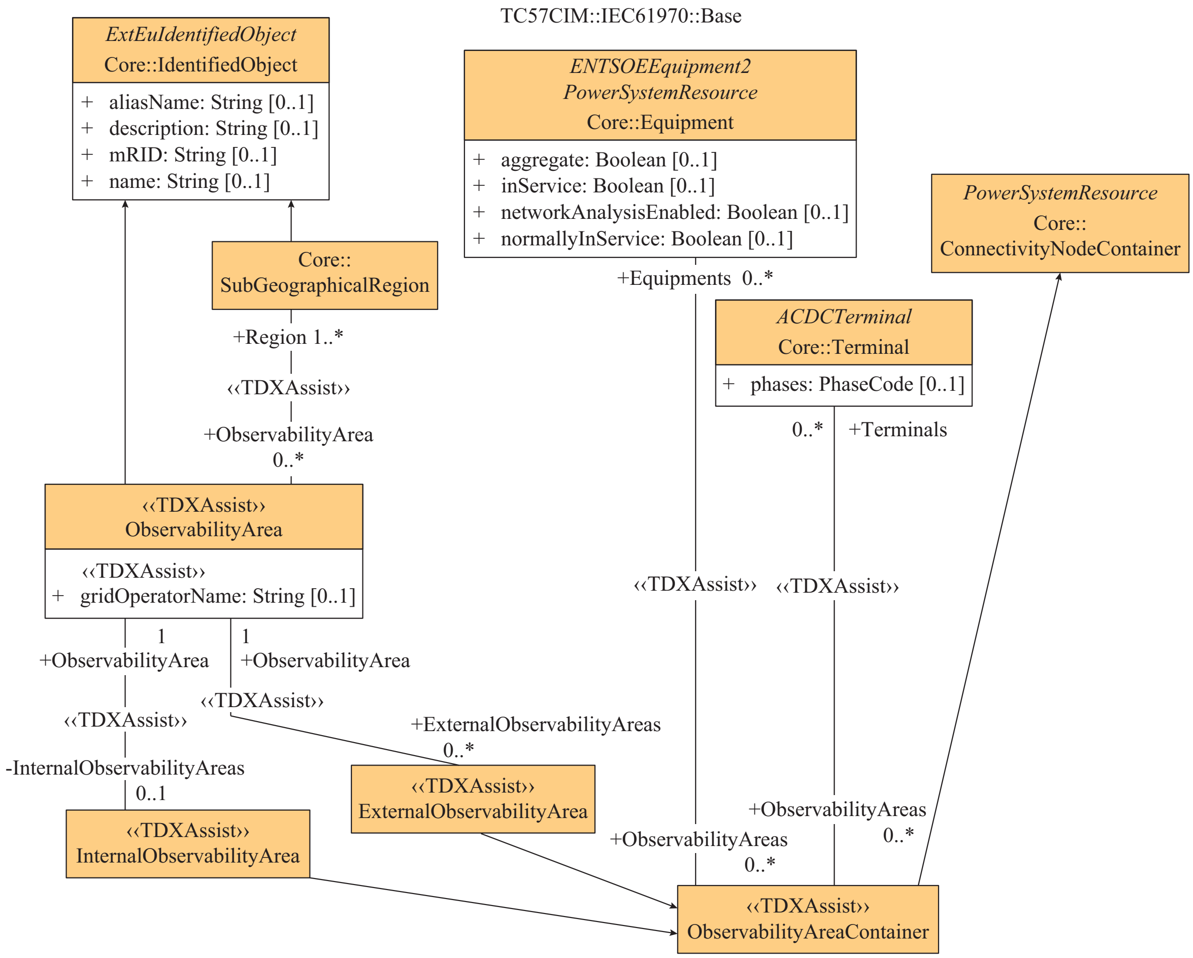

Fig. 3. UML diagram of observability area as CGMES extensions to support TSO-DSO data exchange.

The distribution static database from the DSO is provided to the TSO using the core elements (classes) in the CIM. The existing CIM classes such as ACLineSegment provide the option to model both the characteristics of conducting network elements (e. g., impedances), while other more abstract classes such as the Terminal and ConnectivityNode provide topological connectivity for the distribution grid. In essence, the distribution grid is the same as the transmission grid. However, the modelling style and details are different between transmission and distribution. TSOs are normally using balanced ways of modelling the grid while DSOs may have more detailed three-phase representation of their part of the grid. Therefore, a model that supports adequate level of model reduction is needed. This goes together with the task to have data transformation abilities of such platform to enable communications based on different versions of CIM. The overall objective is that the community applies model-driven implementations, and tooling is upgraded in a more flexible and efficient way. The solution presented here in this paper is also considered to be part of the coordinated security analysis (CSA) [12] profile with slight modifications, and the updated version is expected soon to be published from ENTSO-E.

B. Activation Status Information

Another important application case analyzed in deliverable 1.3 as part of the TDX-ASSIST project was the modelling of BOs that contain data of activation status of the generation unit, active power and voltage violation in the distribution network. Results have demonstrated that in CGMES, this information is represented by using the CGMES measurement related information included in the Operation profile. However, the modelling of "Violation Status" related to the activated generation unit and how this activation impacts the distribution network to which the unit is connected require an extension of CIM. In particular, two types of violations caused by unit activation in the distribution network are considered: congestion and voltage violation. This is the information that a DSO periodically sends to a TSO during procured balancing product delivery (after activation). For this purpose, TDX-ASSIST project proposed a CGMES extension with new class "ViolationStatus" that contains three attributes: violation, violationType, and timeStamp.

Figure 4 shows a UML diagram of the ViolationStatus class as a CIM extension to support the TSO-DSO data exchange.

In a similar way, the TDX-ASSIST project has modelled several other application cases such as consumption and production forecast for operation planning purposes, peak demand forecast (external) information, short-circuit power forecast, pre-qualification report, etc.

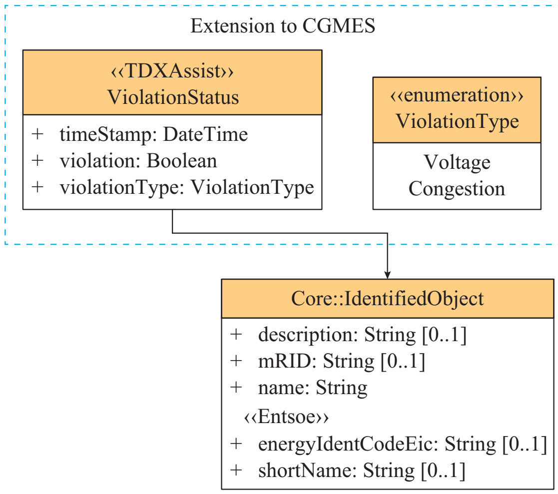

Fig. 4. UML diagram of "ViolationStatus" class.

III. Extended Instance File Header and Metadata to Support TSO-DSO Data Exchange

At present stage, the file header of CGMES related exchanges contains the information about the metadata of the model, which is serialized in an instance file. The data exchange between TSOs uses the header and metadata models developed by IEC TC57 WG13, which is standardized in the IEC 61970-552:2016. However, since the business needs to implement the CGM building process and the CSA process, ENTSO-E concludes that the existing header and metadata described in IEC 61970-552:2016 are not sufficient to meet all the requirements of the data exchange between TSOs. ENTSO-E has developed a new header and metadata model that contains new attributes and descriptions that will serve the demands of TSOs. This new header and metadata model will serve as a basis to be extended for the demands of TSO-DSO data exchange. ENTSO-E is working actively in Horizon 2020 OneNet consortium together with OneNet partners including European DSOs (EUDSOs), to gather requirements and identify gaps for building a more representative header and metadata model. Figure 5 shows a UML diagram of the header/metadata model with attributes added to serve different TSO data exchange requirements [13].

Although all attributes present in this header can be considered important to support the TSO-DSO data exchange, the list below highlights some of the attributes that are defined in W3C vocabularies such as PROV [14] and DCAT [15] and that can enhance more effective TSO-DSO data exchange and interoperability. They are also consistent with the findings and gap analysis listed in many European research projects (OneNet, Interface, TDX-ASSIST).

1) atLocation: this can be an identifiable geographic place (ISO 19112) [16], but it can also be a non-geographic place such as a directory, row, or column. As such, there are numerous ways in which location can be expressed, such as by a coordinate, address, landmark, and so forth.

2) generatedAtTime: generation is the completion of production of a new entity by an activity. This entity does not exist before generation and becomes available for usage after this generation.

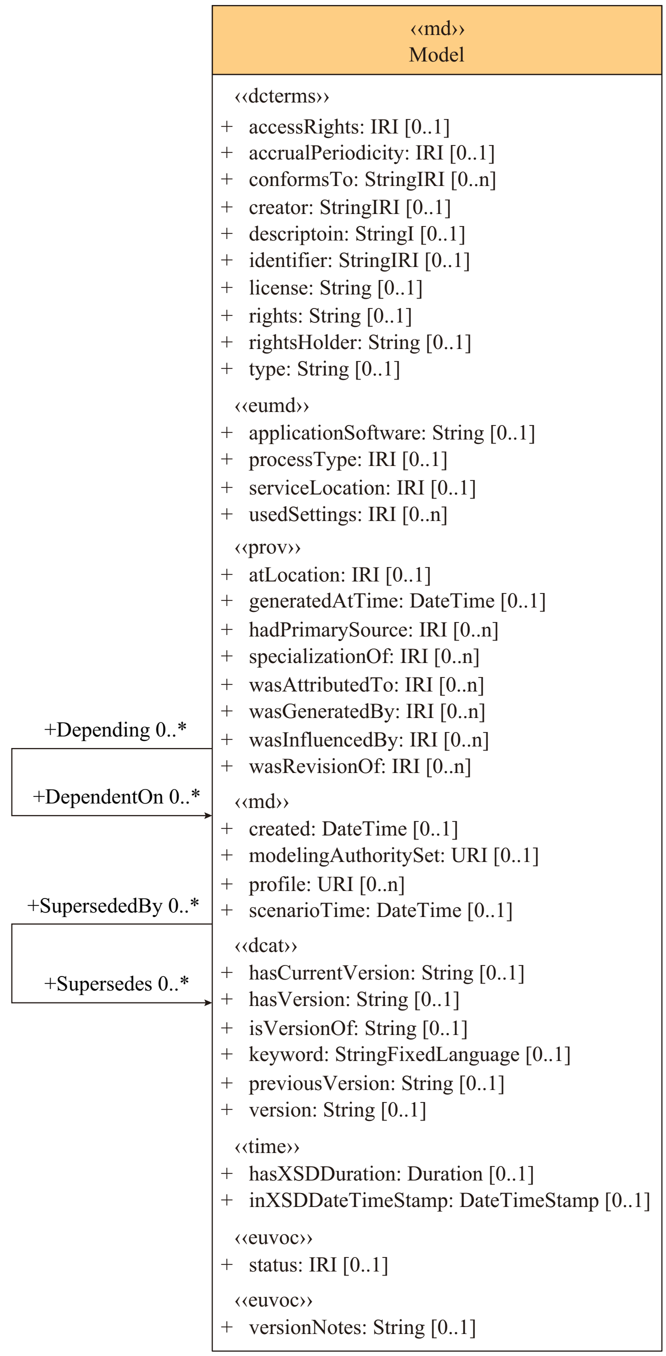

Fig. 5. UML diagram of header/metadata model with attributes added to serve different TSO data exchange requirements.

3) CIM context: the date and time when the model is serialized in the document where the header is located. The format is an extended format according to the ISO 8601-2005. European exchanges shall refer to UTC.

4) conformsTo: an established standard to which the described resource conforms.

5) CIM context: an international resource identifier (IRI) [17] describing the profile that governs this model. It uniquely identifies the profile and its version. Multiple instances of the property describe all standards or specifications that the model and the document representing this model conform to.

6) A document that would normally conform to profile

definitions, and the constraints that relate to the profile and/or the set of business specific constrains. A reference to a machine-readable constraints or specification indicates that the document is tested against these constraints and it conforms to them.

7) specializationOf: an entity that is a specialization of another shares all aspects of the latter, and additionally presents more specific aspects of the same thing as the latter. In particular, the lifetime of the specialized entity contains that of any specialization. Examples of aspects include a time period, an abstraction, and a context associated with the entity.

8) CIM context: reference to modelling authority set version that sources the model. The agent that makes a revision of a model indicates the primary source using prov: hadPrimarySource and refers to its own version of modelling authority set using this property.

The attribute atLocation can be used to identify the observability area that is proposed as extension of the CGMES profile to support TSO-DSO data exchange. In similar way, the attribute specializationOf in line with the DSO needs to identify the version of the modelling authority set which covers the observability area. It is evident from the research done so far in OneNet, Interface, and TDX-ASSIST that in order to cover other demands of DSO, the header and metadata needs some additional extensions and attributes. This is an ongoing activity where ENTSO-E is collaborating with DSOs and other European partners to bring a more inclusive models that can cover these needs.

TSOs and DSOs aim to follow some key principles and agreed messages when starting the data exchange with corresponding metadata. In most cases, the TSO-DSO agreement for data exchange is based on regulation requirements stated in Grid codes and elaborated by ACER and ENTSO-E or other entities like EUDSO. From practical point of view, the agreement includes identifying together, at an early stage, new technologies, data models, communication protocols, data formats, set up of structured meeting platform on TSO and DSO (e.g., joint working groups, agreement on common objectives, etc.), and using harmonized role models [18] and existing network codes.

IV. TSO-DSO Gap Analysis in Terms of Data Exchange and Interfaces

In this section, the gap analysis present in different European research projects (TDX-ASSIST, EU-SysFlex, INTERRFACE, OneNet [19]-[21]) are overviewed.

Although the gap analysis can be studied according to the five layers (business, function, information, communication, and component) defined in the smart grid architecture model, this paper focuses on the information (i.e., interface, data models) layer of the architecture and standardization (missing standard or the usage of specific standard for interface).

Nowadays, there is large amounts of intermittent generation embedded in the distribution network. This poses challenges on the methods to perform balancing and frequency control. In addition, restoration issues are more complex to handle. Therefore, a detailed gap analysis would need to cover a range of topics and would require significant resources. In this effort, we focus on the TSO-DSO data exchange, where the following services are needed to be performed.

1) Congestion management: the demand for congestion management arises when the power flows predicted or observed by the system operators violate the operation limits of at least one network elements (e.g., by exceeding the power capacity of an asset). Congestion management is necessary for both distribution and transmission networks to exchange the data related to availability of flexibility, effects on neighbouring grid areas, and cooperation, which requires structural, market-related data in real time on their observability area when it comes to congestions.

2) Voltage control: next to congestion management, voltage control services are arising due to the large-scale integration of renewable energy sources together with meshed topologies, which requires a more coordinated voltage control.

All the projects have commonly used CIM as information model. Therefore, the assessment is performed to analyze the extent to which the system use cases (SUCs) are covered by CIM standard. In Table I, we give an example of gap analysis related to data exchanges and interfaces performed in the projects (TDX-ASSIST, EU-SysFlex, INTERRFACE, OneNet).

It is important to mention that the gap analysis provided here are based on an ongoing work, and the complete list of the gaps, challenges, and recommendations will be published when the work is finalized. However, this is an indication that in the future, some other complementary profiles could be added to CGMES: asset and catalog related profiles, like in IEC 61968-13 published as Edition 2 in 2021. Some extensions could also concern European style market profiles (ESMPs) associated to IEC CIM 62325 series and take into account some H2020 European R&D projects. For instance, EU-SysFlex project introduces the concept of "Cimification". The process consists in the following aspects.

1) Establishing standardized data models of BOs. This task was realized with the Sparx Enterprise Architect UML tool and the Électricité de France (EDF) Modsarus plugin [22] to help the elaboration of the data models. The data models were built on data model standards (such as ESMP) and were structured by means of dedicated CIM profiles. Modsarus was also used to generate standardized extensible markup language (XML) schema definitions (XSDs).

2) Mapping actual and standardised XSDs with each other, so that correspondences could be drawn between XML documents compliant with them. This task was realized with the Altova MapForce XML tool. This tool generated the extensible stylesheet language transformation (XSLT) codes mentioned above.

V. Conclusion

This paper concludes the demand for proficient standard TSO-DSO interactions to enable the efficient operation of the future power systems. Moreover, TSOs and DSOs should have mutual agreements on the data format, data models, and communications protocols, utilizing more well-known European standards.

TABLE I
EXAMPLE OF GAP ANALYSIS RELATED TO DATA EXCHANGES AND INTERFACES PERFORMED IN PROJECTS

Project	Application case	Description	Gaps identified vis-à-vis CIM
EU-SysFlex	Managing flexibility bidsActivation of flexibility asset Verification and settlement	Managing flexibility bids: exchange of information related to SO need and flexibility offers on platform). Activation of flexibility asset: mechanism that ensures the activation (dispatch) of a flexible resource/pool in the context of a congestion management Verification of delivery and settlement: energy transactions validated, and flexibility provider's accounts settled	Current CIM coverage for flexibility services and products not sufficient for congestion management Structural data (mainly location) of aggregated DS-connected assets required for ensuring the operational security of the distribution system
EU-SysFlex	Calculation of baseline	A baseline methodology needed to quantify the performance of flexibility service providers (FSPs) towards the customers of the flexibility (TSO or DSOs) and provide a basis for the transfer of energy	All of the data flows which are required for baseline calculation not covered by CIM
EU-SysFlex	Transferring energy data (portability) Anonymizing energy data Aggregating energy data	Energy data portability: the ability to move data among different application, programs, computing environments or cloud services Anonymizing energy data: the process of protecting private or sensitive information by erasing or encrypting identifiers Aggregating energy data.: compiling of information from databases with intent to be used for benchmarking, imbalance reporting, etc.	Comprehensive CIM coverage required
TDX-ASSIST	Consumption and production of historical profiles for long-term planning Consumption and production forecast for operation planning purposes	Consumption and production historical profiles for long-term planning Consumption and production forecast for operational planning purposes	Insufficient classes and attributes for BOs for TSO-DSO data exchange in CIM/CGMES
OneNet	Managing active power flexibility to support congestion management and voltage control	Explanation on how active power flexibilities from distribution networks can be used to solve congestions in transmission networks, while respecting distribution network constraints on the one hand and solving congestions in distribution grids on the other hand Timing of this application case lasting from day-ahead to intraday Active power flexibilities activated on the basis of schedule	Current CIM CGMES header and metadata models not sufficient enough to cover all TSO/DSO needs CGMES header required to include information about metering data operator and reference data Exchange of difference model required to be described

CIM CGMES examples provided in this paper show the promising potential for implementing a robust TSO-DSO coordination. However, it became apparent that business requirements should be well formulated and the gap identification should be prioritized as a prerequisite to have a good model.

Activities carried out within European projects with particular focus on TSO-DSO data exchange and interoperability also showed that many projects are providing a broad notion of engagement without specifics regarding their targets. The initial step on data exchange and gap analysis performed within OneNet, INTERRFACE, EU-SysFlex and TDX-ASSIST support the conclusion that projects should provide detailed information on data exchange and interfaces, to base the future CIM CGMES models. On the other hand, CIM UML model must be available for free to allow projects to contribute to extensions. The results presented in this paper are also in line with other TSO-DSO interoperability initiatives like the Smart Grids Task Force (SGTF) set up by the European Commission (EC) to draft the implementing acts on data access and data interoperability, BRIDGE Data Management working group [23], SmartGrid forum, and IEC TC57 WG13 activities.

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