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Executive Summary

Sections 3 and 4 of this deliverable provide context to the reader in order to understand the functions of Transmission System Operators (TSO) and Distribution System Operators (DSO) and also the need of integration between grid operators. Those sections serve as a basis to reflect that Interoperability among different software components used by different utility operators (TSOs and DSOs) is of capital importance at European level, and so it is for OPENTUNITY. This involves the exchange of up-to-date and reliable topological models of the grid.

In those sections it is extracted that **CIM is the common topology format for TSOs, that is used for sharing data between them or with their Regional Security Coordinator. However, DSOs are missing a common format.** This is due to there are inherent problems linked to the CIM grid modelling that might compromise its widely adoption by DSOs. These can be summarized as follows:

- **Complexity:** CIM is extensive; implementation and understanding require expertise.

- **Granularity:** Utilities must carefully select which assets to model, because a very fine-grained modelling might take a lot of time. It could even be infeasible case as the DSO might lack the details of the assets deployed several years ago or in a rush. As an example, when modelling LV grids, the cable and wires vary in its physical characteristics depending on the type of cable, brand, whether it is aerial or subterranean, etc. These physical details in the topology affect very slightly the results of the calculations but heavily increase its complexity.

- **Legacy Systems:** Mapping CIM to or from older data schemas (proprietary, GIS, SCADA) can be labour-intensive and are prone to errors. Legacy or proprietary systems are quite usual in DSO systems, and no automated conversion to and from CIM is normally possible with such systems, so specific converters are required.

- **Performance:** Large, dense urban distribution grids can result in very large XML files, even for small areas.

- **Real-time changes:** Handling frequent updates in topology (switching, distributed resources connecting/disconnecting) is an evolving challenge.

As an answer to these problems, <u>**OPENTUNITY proposes a methodology and a set of tools to facilitate the interoperability of topological models between different software components used by different utility operators, with a focus on the DSO utilities**</u>, that lacks a version of CIM that cover its specific topological modelling requirements.

The availability of CIM/CGMES importers and exporters is very limited in the software components normally used by DSOs, so in the OPENTUNITY methodology we have opted for a more realistic approach that do not restricts to software components natively supporting CIM/CGMES but also supports other alternatives.

So, the methodology proposed is composed by the following elements:

- A **software component that allows converting among different topological data models**. This software component has been provided as an open-source component available to the broad audience. The component integrates different open-source available converters and facilitated its usage within the tool.

- **A new tabular/excel data model** that allows easily defining the topology has been defined. This is particularly well suited for small distribution networks and is an alternative to other specific and proprietary topology editors. Documentation of the data model Is provided in section "10-Annex 2. Excel topology data modelling instructions." and make available in an open-source fashion.
- **An on-line topology visualization tool** that allows representation of the grid topology in a graphical way. It does not require any previous knowledge on any specific software component, nor require any software license.

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1 INDEX

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2 INTRODUCTION

2.1 Purpose of the document

The purpose of this deliverable is to provide a clear explanation about methodology developed as part of the Task 5.1: "Methodology to ensure interoperability and integration of DSO/TSO available infrastructure into software platforms"

2.2 Scope of the document

This document focuses on describing the aforementioned methodology, providing details of the converter tool, the tabular topology format and the ETER visualizer. Potential usage of this methodology by other processes or use cases in OPENTUNITY is described in other documents.

2.3 Structure of the document

Apart from this introductory section, the current document is structured as follows:

The document initiates its content with a description of the types of utility operators and what are the responsibilities of each of them.

Then, the rationale of the integration between utility operators is described, highlighting the advantages and reasons for these integrations.

The state of the art in topological data models is presented in section 5.

After previous chapters, focused on giving context to the reader, the core of the methodology is presented in section 6, where all the points described in the previous sections are consolidated in a software component and a methodology can that fulfil the integration needs identified.

Finally, concussions are presented.

As complementary information, two annexes have been provided: The first one describes the command line interface of the topology converted software component, **and the second one describes the tabular topological data model proposed in the methodology.**

3 TSO AND DSO ROLES AND RESPONSIBILITIES

3.1 TSO main responsibilities

The Third Energy Package on Electricity and Gas Markets (TPEGM) sets the common rules responsibilities of the stakeholders related to the development of the European internal electricity market. TPEGM is legally binding *acquis* for EU Member States and via Energy Community Treaty, for all Energy Community Contracting Parties. The Directives and Regulations comprising TPEGM set the general obligations of various stakeholders that are involved in the operation of the electricity systems and electricity markets. In this context, the Directive 2009/72/EC [1] sets the responsibilities of the transmission system operators (TSOs), which include [1]:

- Ensuring the long-term ability of the system to meet reasonable demands for the transmission of electricity, operating, maintaining and developing under economic conditions secure, reliable and efficient transmission systems with due regard to the environment.

- Ensuring adequate means to meet service obligations.

- Contributing to security of supply through adequate transmission capacity and system reliability.

- Managing electricity flows on the system, considering exchanges with other interconnected systems. To that end, the TSO shall be responsible for ensuring a secure, reliable and efficient electricity system and, in that context, for ensuring the availability of all necessary ancillary services, including those provided by demand response, insofar as such availability is independent from any other transmission system with which its system is interconnected.

- Providing to the operator of any other system with which its system is interconnected sufficient information to ensure the secure and efficient operation, coordinated development and interoperability of the interconnected system.

- Ensuring non-discrimination as between system users or classes of system users, particularly in favour of its related undertakings.

- Providing system users with the information they need for efficient access to the system.

- Collecting congestion rents and payments under the inter-transmission system operator compensation mechanism, in compliance with Article 13 of Regulation (EC) No 714/2009, granting and managing third-party access and giving reasoned explanations when it denies such access, which shall be monitored by the national regulatory authorities; in carrying out their tasks under this Article TSOs shall primarily facilitate market integration."

In addition to the tasks prescribed in Article 12 of [1], Article 17(2) prescribes that the activity of electricity transmission includes a set of tasks that are related to representation of the TSO to third parties, regulatory bodies and within the European Network of Transmission System Operators for Electricity (ENTSO-E); tasks related to granting non-discriminatory third-party access to the network; collection of transmission system charges that include access charges and balancing charges; tasks related to planning, operation, development and maintenance of the transmission system in a cost-efficient manner that also ensures meeting the demand and guaranteeing security of supply. In relation to the activity of electricity transmission, the TSOs may establish joint ventures with one or more TSOs, power exchanges and other entities with the objective of facilitating the liberalization

process and develop regional markets. Regarding planning activities, the TSOs have the obligation to prepare and submit to the national regulatory authority a ten-year development plan, as prescribed in Article 22 of the Directive [1]. The plan is submitted each year, taking into account the existing and forecasted supply and demand. The TSOs also have the obligation to establish and publish non-discriminatory and efficient procedures for connection of new generation units to the transmission system. These procedures are approved by the regulatory authority.

3.2 DSO main responsibilities

3.2.1 Traditional responsibilities

As stated in Articles 2 and 25 of Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity, DSOs in the EU Internal Electricity Market are responsible for providing and operating low, medium and high voltage networks for regional distribution of electricity as well as for supply of lower-level distribution systems and directly connected customers.

European Energy Regulators' White Paper #2, "The Role of the DSO, Relevant to European Commission's Clean Energy Proposals" of 15 May 2017 observes DSOs operate local electricity networks, traditionally distributing electricity from the higher-voltage transmission network and from small generators into residential and commercial end users.

According to Article 2(6) of the aforementioned Directive 2009/72/EC, 'Distribution System Operator' is 'a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.' This definition has been maintained by the so-called 'Winter Energy Package'. More generally, regional distribution and supply are also DSOs' responsibility to ensure the security of their networks with a high level of reliability and quality. [2]

The summary of the duties assigned to the DSOs roles can be summarized as follows:

Commercial

The DSO role must provide accurate and timely charging information to all customers and stakeholders, timely collection of revenue and payment of fees, and maintenance and capital investment costs. It should be noted that a central body may own the data, but the DSO will provide access through its platform.

Investment

The DSO role must provide investment in the whole system to improve value and service to customers and provide an opportunity for all parties to successfully invest alongside it.

Connections

The DSO role is to manage all applications to connect and provide offers to customers for connection onto the distribution network based on improving whole system performance.

Planning

The DSO role is to develop the distribution network outage plan and an agreed means of implementation of the plan.

Operations

The DSO role is to operate the distribution network and enable access to assets from third parties for capital and maintenance works. This includes the direct control of the grid to guarantee a stable and high-quality electrical supply.

3.2.2 New DSO responsibilities

3.2.2.1 Market facilitator

It could be argued that the role of market facilitator is inherent to DSOs as the default interface between grid users. Nevertheless, the latest developments in the power sector lead to a changing understanding of the term 'customer'. Namely, DSO customers seeking access to the grid not only inject or draw power but can also provide various services and flexibility to the network. These are becoming more and more valuable, and so is the role of the DSO that needs to allow fair grid and market access to all users. Therefore, DSOs are taking a more central role as market facilitators.

Even within vertically integrated companies, the grid operator had immediate contact with consumers and was therefore tasked with customer interactions and various market aspects of energy supply. This responsibility then evolved and became more significant with the liberalisation of the energy sector. As a company performing exclusively regulated activities in a market environment, DSOs are obliged to offer non-discriminatory access to the grid to any potential customer, both consumer and producer, provided there is a technical solution that does not endanger network stability and security of supply. Otherwise, DSOs are tasked with performing conventional activities as outlined in section 3.2.1 – "Traditional responsibilities".

In simple terms, under the current regulatory framework and traditional activities, DSOs could be regarded as market facilitators that create a level playing field for suppliers and give customers the choice of preferred supplier [3]. To do so effectively, they should facilitate the entry of new suppliers by harmonising data exchange across distribution areas and provide perfect information to consumers.

However, as mentioned before, power networks are experiencing developments caused by technological, market and social advances, that lead to a new understanding of the role of a DSO. The European Distribution System Operators' Association for Smart Grids (EDSO) identifies seven drivers for change [4]. These are:

1) The rapidly growing shares of distributed energy resources (mainly renewable).

2) Higher engagement and market interaction of customers (a shift from consumers to prosumers).

3) The integration of new distributed energy storage technologies.

4) The digital evolution making DSOs data-centric companies through the wide-scale rollout of smart meters and automation (allowing creation of new markets).

5) The ability to perform active grid management.

6) The electrification of the transport sector and grid integration of electric vehicles.

7) The changing market structures due to new requirements such as flexibility, but also the interaction with other systems, for instance gas grids.

According to one study for the European Commission, these drivers effectively open new decentralised opportunities, services, markets and ways of customer engagement, thus changing current and creating new tasks and responsibilities for existing and emerging actors [5]. This, of course, includes DSOs that will be required to take a larger responsibility and a more important role in order to facilitate the creation and exploitation of new opportunities. The same study identifies the following emerging services:

    i.   Flexibility services

    ii.   Infrastructure provision for electric vehicles

    iii.   Energy efficiency services

    iv.   Ownership and management of metering equipment

    v.   Data handling

However, it is still unclear how the market and legal framework will develop in response to the new services because stakeholders are motivated by different drivers and will therefore lobby for different solutions [5], [6]. In any case, it is of utmost importance that DSOs remain impartial (i.e. neutral) and that the legal framework correctly and unambiguously distinguishes between the competitive and regulated aspects. Supporting this notion, the questionnaire conducted in [5] showed that a non-discriminatory market access and a level playing field are the primary concern to national regulatory authorities. Nonetheless, most of the survey participants agreed that precisely DSOs should facilitate market operation.

According to ACER and CEER, to take on this important role, DSOs need to have reached a sufficient level of unbundling and enhanced TSO-DSO coordination [7]. Another foreseeable challenge is data handling, since DSOs have an immense responsibility to impartially provide smart metering and other data to different parties, while adhering to the principles of personal data protection and privacy. These are defined in EU legislation, specifically the Directive on Security of Network and Information Systems [8] and the General Data Protection Regulation.

In fact, this evolution in the role of DSOs as a result of the decentralisation and digitalisation of power systems is recognised in the Clean Energy for All Europeans Package. Accordingly, in addition to the traditional tasks like managing and operating the grid, DSOs will clearly be allocated the role of market facilitators. This is strongly supported by EDSO, claiming that the Package acknowledges and enhances the roles of DSOs as a 'cornerstone' in the fight against climate change [9]. EDSO envisages the role of DSOs as neutral market facilitators, albeit with a primary task of maintaining security of supply and quality of service which must not be compromised by the users [7]. Lastly, it is important to highlight the need for cooperation with market participants, customers and TSOs in order to unlock the potential of the services identified above and enable a more efficient distribution and transmission network planning and operation.

3.2.2.2   Flexibility services enabler

Flexibility is evolving as a key topic in European energy markets, which is not surprising, given the significant change that has taken place in European energy systems and the continued change that is expected in the future [10]. Flexibility can be defined as the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system. The parameters used to characterise flexibility include

the amount of power modulation, the duration, the rate of change, the response time, the location etc. [11].

3.2.2.3   Functionalities of phasor-aided state estimation

Secure operation of power systems requires a comprehensive understanding of the system operating status, which helps in identifying potential critical operating conditions and determining the necessary preventative measures. Power system load flow analysis and state estimation (SE) play an important role in secure operation of power systems [1]. It provides an optimal estimate/forecasting of the system states based on continuous monitored measurements, pseudo-measurements, load estimation and forecasted load demands etc, helping the operators identify current network states or potential network states. With the increasing penetration of distributed renewable energy resources, the connection of medium-sized distributed generation (DG) and more and more electronic interfaced devices (e.g., different types of load storage and electric vehicles) connected in the networks, it is required to have an improved networks observability in order to ensure secure operation. The increasing deployment of PMU in the transmission system, which is used to measure the magnitude and phase angle of voltage or current in the grids, has led to the intensive research and application of employing both SCADA and PMU data for transmission system state estimation. OPENTUNITY enhanced state estimation tools developed within work package 5 are an example of such tools.

4 INTEGRATION BETWEEN GRID OPERATORS

4.1 TSO-DSO integration.

The integration between TSO and DSO has been a field of research, especially considering the new responsibilities the DSOs are acquiring in recent years (see 3.2.2 - New DSO responsibilities), principally, the increased penetration of decentralized and renewable generation sources.

These distributed generation (DG) management introduces new challenges to ensuring the reliability and quality of power supply [12]. Most of these new generators are being connected to distribution networks nowadays. This development has radical implications for DSOs. Until recently, DSOs designed and operated distribution networks through a top-down approach. Predictable flows in the electricity network did not require extensive management and monitoring tools on the distribution grids, but this paradigm is changing. Higher shares of distributed energy sources lead to unpredictable network flows, greater variations in voltage at the distribution grid and different reactive power characteristics. Local grid constraints are breached more frequently, adversely affecting the quality of supply. Nevertheless, DSOs are expected to continue to operate their networks in a secure way and to provide high-quality service to their customers.

In theory, due to its proximity to the loads, distributed generation should contribute to the security of supply, power quality, reduction of transmission and distribution peak load and congestion, avoidance of network over capacity through deferral of network investments, reduced need for long distance power transfer and reduction in distribution grid losses (via supplying active power to the load and managing voltage and reactive power in the grid) [13].

In reality, integrating distributed generation into DSO grids represents a capacity challenge due to DG production profiles, location and volatility. DG is not always located close to load and DG production is in many cases non-dispatchable (cannot control its output). Therefore, production does not always coincide with demand and power injections to higher voltage levels need to be considered where the local capacity exceeds local load. Distributed generation such as intermittent RES, poses a challenge not only for system balancing, but also for local network operation. The security and hosting capacity of the distribution system is determined by voltage (statutory limits for the maximum and minimum voltage ensure that voltage is kept within the proper margins and is never close to the technical limits of the grid) and the physical current limits of the network (thermal line rating, transformers' capacity that determine the maximum power flow). The aforementioned poses important challenges for both distribution network operation and development.

Coordination among DSOs and TSOs and information exchange (topological and power flow models) will play a beneficial role as the amount of DER increases and as DSOs are forced to become more active and assumed some of the responsibilities of transmission system operators [14]. On the transmission level, generators send schedules to the TSO for system balancing purposes. On the distribution level, DSOs have no systems installed for acquiring data from DG (especially of those that are of smaller size). DSOs rarely receive information from DG in real-time and usually there is no short-term operational data exchange between TSOs and DSOs.

However, in future systems with even higher DER penetration, a well-structured and organized information exchange between relevant actors is necessary: the DSO will need information about DG forecast, schedules and active dispatch to improve their visibility and to assist with close to real-time management of the distribution network respecting local network constraints. On the one hand, the

participation of flexibility resources in balancing markets run by the TSO could lead to constraints in the distribution grid if there is lack of prequalification from the DSO. On the other hand, DSO congestion management to solve constraints could have repercussive effects on transmission grids and TSO operation.

Given the complexity of the tasks and the large number of agents involved, a hierarchical decomposition of the supervision and control actions is mandatory. A clear hierarchy of functions between TSO and DSOs has to be established, which is the main subject of debate on this topic. Namely, there are various options to organize the hierarchical structure of network optimization, and hence market structure. Perhaps the most traditional approach is whole-network optimization in which case the TSO would by default be the responsible entity considering the current state of play (TSO tasks, functions and responsibilities). On the opposite end of the spectrum is the option where priority is given to the DSO to optimize its grid in accordance with operational limits outlined in the previous subsection. Then, notify the TSO of resulting power flows and offer balancing services, if available. However, arguably the most effective option that weighs the importance of balancing the system and upholding local security of supply is a 'back-to-back' structure, where the TSO engages with DSOs, while DSOs engage with DERs.

The argument for the third option is the following. The TSO is the party that is responsible for system balancing. DSOs, after having undertaken their DER-related activities should submit their protocols to the TSO. Such protocols are especially important for those DER that can provide services to both TSO and DSO. In this sense, all DER have to be monitored with respect to what product they are offering and at which time. Subsequently, the data on dispatch should be given to DSOs as soon as possible, so that the DSO can react accordingly in emergency situations and control the most appropriate DER. Furthermore, any action on distribution network users requested by the TSO should be agreed with the respective DSO. A TSO should not act on any individual DER connected to distribution grid, but an order from a TSO towards DER embedded in distribution systems should be examined and executed by the DSO. However, with the current legislative framework, this option is difficult to establish. In line with the integration of the internal energy market in Europe, the EU network codes have to take account of the new tasks and need for coordination for system operators. These network codes have to account for the possibilities for cost recovery of European DSOs and TSOs, as otherwise the respective system operators do not have sufficient incentives to engage in their tasks.

Lastly, it is important to highlight the fact that with the substantial increase of concerned agents and information exchange, cyber security and data privacy became a major concern and an additional obstacle. Therefore, any solution needs to adhere to the latest trends and guidelines on data protection, including relevant legislation.

Summarizing, the aforementioned paragraphs clearly state that the transition to the smart grid era entails the involvement of the DSOs in the active operation of the distribution grid, which prerequisites the suitable coordination between TSOs and DSOs. The current status in the distribution grids which consists of minor visibility and control, will gradually be changed, transforming them to smart grids with augmented supervision and control over the power sources connected to its premises in order to fulfil the new tendency and the respective requirements, contributing to enhanced governance of the power grid.

4.2 TSO-TSO integration.

Transmission System Operators (TSOs) in Europe are responsible for the reliable operation of the high-voltage electricity grid across national borders. With the increasing interconnection and utilization of European power networks, the risk of cross-border incidents and cascading failures has grown—making coordinated security analysis essential. TSOs integrate their grid topologies to collectively evaluate and anticipate operational security risks, especially under contingencies such as unexpected line or generator outages. Integrated security analysis allows TSOs to identify vulnerabilities that could propagate across neighbouring systems, thereby preventing widespread disturbances and ensuring system stability.

The drive for such coordination is shaped by both technical requirements and regulatory frameworks. The European Network of Transmission System Operators for Electricity (ENTSO-E) and mandates like the EU Network Codes—specifically the Common Grid Model Exchange Specification (CGMES) and the System Operation Guideline (SO GL)—require TSOs to regularly exchange data and conduct Coordinated Security Analysis (CSA). Through these mechanisms, TSOs share detailed network models, including real-time topology, planned switching operations, and forecasted injections from generation and loads. These data exchanges are managed via dedicated platforms and procedures, such as the Regional Security Coordinators (RSCs), which process and merge national grid models into a Pan-European Common Grid Model (CGM) for joint analysis.

The integration process involves several stages. Each TSO first prepares a detailed model of its own transmission network, including current operational status and planned outages. This local model is then shared with neighbouring TSOs and the designated RSC. The RSC consolidates the national models, resolving inconsistencies and ensuring that tie-lines and interconnectors are correctly represented. This harmonized model serves as the basis for simulations—like load flow and contingency analyses—that examine the effect of disturbances across the entire interconnected system. The results support TSOs in making informed decisions about remedial actions, such as re-dispatching power plants, switching network elements, or coordinating cross-border countermeasures.

By integrating their topologies and performing coordinated security analysis, European TSOs not only comply with legislative obligations but also increase the resilience and security of a deeply interconnected electric grid. This proactive approach reduces the risk of widespread disturbances, supports the integration of renewable energy, and ultimately helps TSOs fulfil their responsibility of ensuring a secure, stable, and efficient electricity supply for all consumers across Europe.

4.3 DSO-DSO integration.

While large-scale, formal integration of DSO topologies across borders, comparable to what TSOs perform, does not currently exist in Europe, there is a growing interest and need for enhanced DSO-to-DSO data exchange and coordinated analysis. This need is driven by several emerging challenges: increasing cross-border electrification, proliferation of microgrids, and the rise of local energy communities which may span multiple DSO areas. Moreover, DSOs often need to coordinate at their boundaries to manage power flows, resolve congestion, and maintain voltage stability—especially in cases where one DSO's actions can impact another's network.

To facilitate this, DSOs are starting to cooperate more closely by sharing key operational data at their points of interconnection. Some progressive regions have established digital platforms or data hubs where neighbouring DSOs can exchange real-time or near real-time information about network status, switching operations, and planned outages. In certain pilot projects across Europe, groups of DSOs are working together to develop harmonized grid models and coordinate management of distributed flexibility (such as demand response, storage, and DER curtailment), which can provide mutual benefits in congestion management and balancing.

The European Union has also recognized the importance of DSO cooperation and standardization. Initiatives such as the European Distribution System Operators' Association (E.DSO) and the EU DSO Entity—as mandated under the Clean Energy for All Europeans package—facilitate collaboration, knowledge-sharing, and the development of common methodologies, including the exchange of data relevant to network operation and market processes.

Although DSO-to-DSO integration is not yet as advanced or formalized as TSO coordination, it is becoming increasingly important. As distribution grids grow more dynamic and interconnected, and as customer prosumers and local energy systems proliferate, effective cooperation among DSOs will be vital in supporting security of supply, efficient grid operation, and successful energy sector decarbonization. In the future, enhanced DSO-to-DSO integration is expected to underpin coordinated security analysis at the distribution level, enable local flexibility markets, and support system-wide resilience across Europe's evolving electricity system.

5 STATE OF THE ART IN GRID TOPOLOGY DATA MODELS.

In the context of power system modelling, **software topology** refers to the representation of how grid components are interconnected within calculation, simulation, or operation software. This *topology* is the abstraction that enables the software to build a mathematical model of the grid to perform analysis (e.g. power flow, state estimation, fault studies).

The pieces of data that compose a software topology normally include:

- **Network Elements (Nodes/Buses):** Logical points where electrical quantities are calculated or measured; can represent substations, junctions, or load/generation connection points
- **Branches (Edges/Lines):** The connections between nodes, such as transmission/distribution lines or cables.
- **Switching Devices**: Elements that can open/close electrical paths (breakers, isolators, switches, fuses).
- **Transformers**: Devices connecting different voltage levels and possibly separate (topological) islands.
- **Loads and Generators**: Points of power injection or withdrawal.
  - Loads: Energy consumer models.
  - Generators: Synchronous machines, DERs, PVs, batteries.
- **Additional Data (Depending on Purpose)**
  - **Voltage setpoints, slack/reference bus identification, protection device settings, control areas, operational constraints.**
  - **Geographical information** (coordinates) in some tools for visualization or GIS integration.
  - **Phase connectivity** (for multi-phase modelling in distribution).
  - **Equipment Definitions**: Metadata for each type of asset.

The core of each possible topology data model is the adjacency matrix. It can be defined as follows: Being the network elements (nodes and buses) the leaves of a topology graph, the adjacency graph defines the connections between them). These connections can be physically realized by a conductor, a switching device or a transformer:
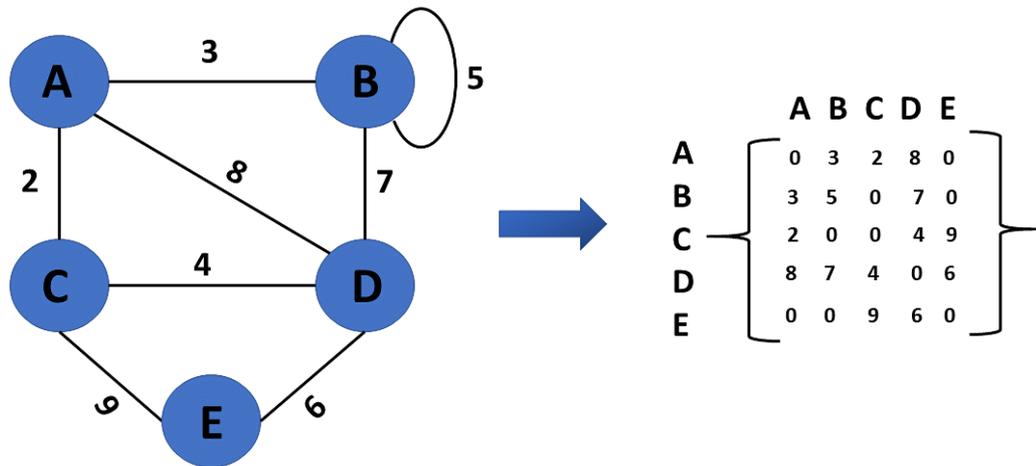
Figure 1: Adjacency matrix in power systems

There are different software components (both commercial and open source) available for grid operators to perform power flow and other types of grid calculations. Each one features a specific (and normally not compatible with other) topological data model. A summary of these can be:

- **PowerFactory:** "*.pfd" project files, DIgSILENT XML/ASCII.

- **PSS®E:** RAW (RAW Data Format), SEQ (sequence data), SAV (binary snapshot), and *.dyr (dynamic data).

- **ETAP:** Binary/SQL database; supports import/export XML.

- **CYME:** CYMDIST files, XML intermediates.

- **OpenDSS:** Text-based circuit files (*.dss), OpenDSS XML.

- **MATPOWER (MATLAB-based)**: Uses MATLAB .m or .mat files (arrays for bus, branch, gen data).

- **Pandapower (Python-based)**: Pandas DataFrame or HDF5/JSON for saving and sharing.

- **GridLAB-D**: Structured text (".glm" files).

- **OpenDSS**: ASCII text scripts or XML.

- **InterPSS**: XML-based ".ipss" files for sharing models.

- **GridTools**: JSON models.

It is important to differentiate between these data models used for internal handling of the topological data by the software components, and the data models used for data exchange with other components. Often, these software components feature exporters and importers to and from other topological data models, thus allowing technical integration. The specific integration is often offered with a cost.

Normally, the most relevant and widely used software component depends on the highest probability of other software components to support its topological data model. Nevertheless, there are other factors that influence the interoperability like ease of access to the broad audience (whether it is open source or not), specific target of the software component (educational, simulation, real time

operation, etc.), similarity of the solution (programming language), industry trends, etc. This creates a situation that restrict the options for the grid operators to select specific software components, as the interoperability cannot be possible among some of them when it is needed.

There is a specific case where the integration topology modelling data format is regulated by law: The use of **CIM/CGMES** is mandatory for all TSO and RSC to periodically exchange grid models at European level. This was decided at ENTSO-E level and is part of the network codes for the TSOs in Europe.

CGMES (**Common Grid Model Exchange**) is a specific CIM (**Common Information Model**) profile oriented to TSO grid data modelling. CIM is used for network modelling (61970 series) but also supports market-related use cases (62325 series) and utility integration related use cases (61968 series). CIM supports several IEC network codes and guidelines. In general, CIM profiles strengthens the coordination between different TSOs, but it will increasingly be used between TSOs, DSOs and other market participants [15], in fact it is becoming a *lingua franca* for interoperability among grid operators.

6 METHODOLOGY DESCRIPTION.

From the previous sections, it becomes clear that interoperability among different software components used by different utility operators (TSOs and DSOs) is of capital importance at European level, and so it is for OPENTUNITY. This involves the exchange of up-to-date and reliable topological models of the grid.

The previous section presents an analysis of existing topological modelling alternatives, identifying the CGMES/CIM as the option to use for the exchange of such models.
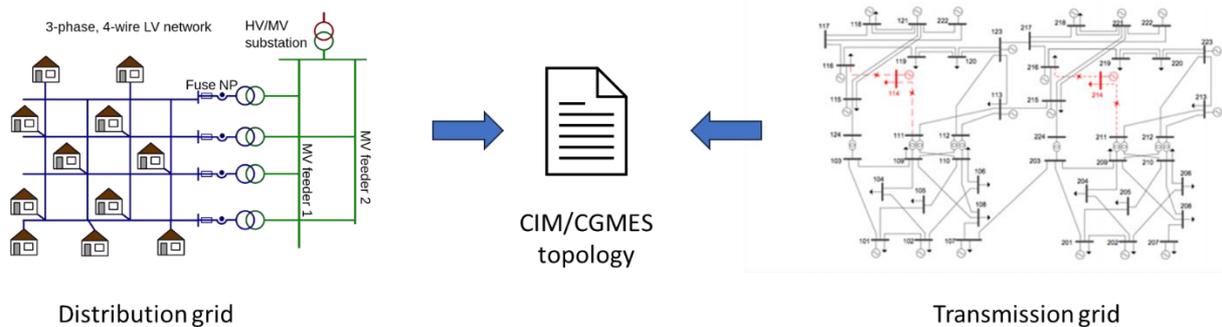

Figure 2: CIM/CGMES adoption by TSOs and DSOs

Nevertheless, there are inherent problems linked to the CIM grid modelling that might compromise its widely adoption by DSOs. These can be summarized as follows:

- **Complexity:** CIM is extensive; implementation and understanding require expertise.

- **Granularity:** Utilities must carefully select which assets to model, because a very fine-grained modelling might take a lot of time. It could even be infeasible case as the DSO might lack the details of the assets deployed several years ago or in a rush. As an example, when modelling LV grids, the cable and wires vary in its physical characteristics depending on the type of cable, brand, whether it is aerial or subterranean, etc. These physical details in the topology affect very slightly the results of the calculations but heavily increase its complexity.

- **Legacy Systems:** Mapping CIM to or from older data schemas (proprietary, GIS, SCADA) can be labour-intensive and are prone to errors. Legacy or proprietary systems are quite usual in DSO systems, and no automated conversion to and from CIM is normally possible with such systems, so specific converters are required.

- **Performance:** Large, dense urban distribution grids can result in very large XML files, even for small areas.

- **Real-time changes:** Handling frequent updates in topology (switching, distributed resources connecting/disconnecting) is an evolving challenge.

As an answer to these problems, OPENTUNITY proposes a **methodology** and a **set of tools** to facilitate the interoperability of topological models between different software components used by different utility operators, with a focus on the DSO utilities, that lacks a version of CIM that cover its specific topological modelling requirements.

The availability of CIM/CGMES importers and exporters is very limited in the software components normally used by DSOs, so in the OPENTUNITY methodology we have opted for a more realistic

approach that do not restricts to software components natively supporting CIM/CGMES but also supports other alternatives.

So, the methodology proposed is composed by the following elements:

- A **software component that allows converting among different topological data models**. This software component has been provided as an open-source component available to the broad audience. The component integrates different open-source available converters and facilitated its usage within the tool.
- **A new tabular/excel data model** that allows easily defining the topology has been created. This is particularly well suited for small distribution networks and is an alternative to other specific and proprietary topology editors. Documentation of the data model Is provided in section "10-Annex 2. Excel topology data modelling instructions." and make available in an open-source fashion.
- **An on-line topology visualization tool** that allows representation of the grid topology in a graphical way. It does not require any previous knowledge on any specific software component, nor require any software license.

The first element, the open-source topology converter, has the following architecture:
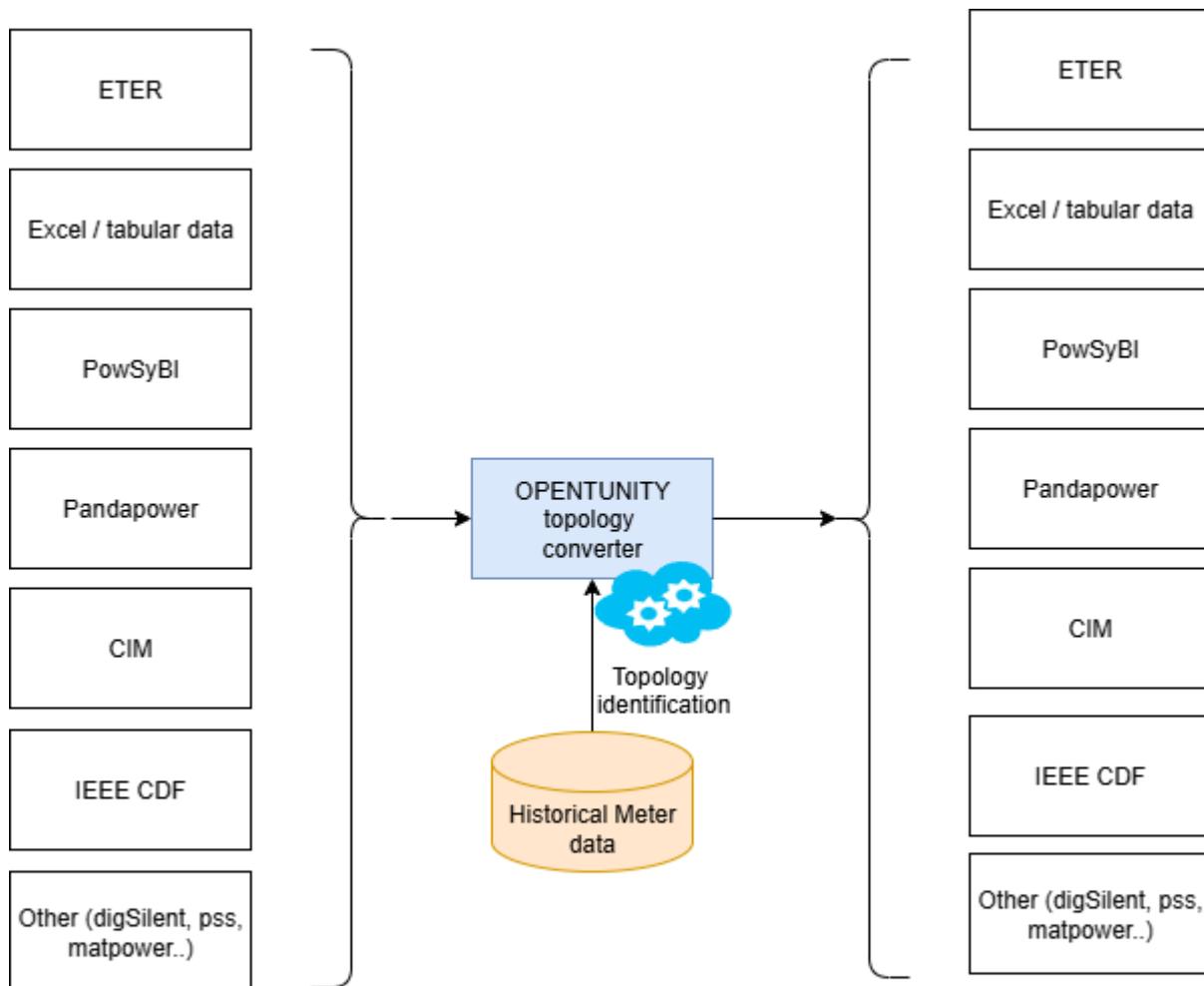

Figure 3: Architecture

Basically, the process is provided as a command line script that take as input a grid topology of a given type and the type of conversion required. The output will be the topology translated to the output format. The converted topology can directly be used in the appropriate software component. The detail of the command line syntax is presented section "9 - Annex 1: COMMAND LINE USER MANUAL "

The list of topological models supported by the tool is evolving, as new topology formats are needed. The initial list includes: CIM/CGMES, some relevant open alternatives (pandapower, powsybl, IEEE CDF) and some relevant proprietary solutions (PSS).

It must be noted that the chain of transformations might increase the possibilities of data conversion: E.g. A given software component using a specific data model A might not be supported by the topology converter tool, but it may feature export capability to data model B; that might be compatible with topology converter tool, thus allowing the conversion to other data models. This type of task could be challenging to the utility operator due to the heterogeneity of the data models, so the aim of the tool is to facilitate for such things.

The "topology identification" feature and the input of "historical data" into the topology converter is linked to the topology identification feature described in deliverable D5.2 [16].

In the topology converter tool diagram, there are two specific types of inputs and outputs that do not correspond to any existing data model, but are specific to OPENTUNITY:

Excel/tabular. In most cases, DSO use proprietary systems that are not widely used or are even tailor made for them. In these cases, the topology model must be rebuilt from scratch (or using external specific converters) to some other data model compatible with the tool. This requires a considerable effort in the translation, and most of the times there is no editor available to assist in the process or the format is not open, or the process requires deep knowledge of the other data model.

To cover for such cases, within the methodology, a data model has been defined based on Excel/tabular files for the definition of the elements. Excel is the *de-facto* standard for representing and editing tabular data. The methodology provides an Excel template, with pre-defined column structures within its tabs, and guidelines for introducing the topological data in the excel template. Details of the excel template are provided in "Annex 2. Excel topology data modelling instructions.".

The other OPENTUNITY specific topology model format presented is the **ETER topology model**. This is the native data model used within the OPENTUNITY ETER tool, described in deliverable D5.2 [16] , and is provided here as a way of simplifying the integration of the topologies of the pilot sites into the ETER tool.

This ETER topology model support has other main purpose linked to the third element provided by the methodology. The **on-line topology visualization tool** is basically a simplified version of the ETER tool deployed on the cloud and made available for on-line visualization of topologies. This visualization tool can be configured by making use of the ETER topology model files obtained with the topology converter. The next picture depicts the whole process:
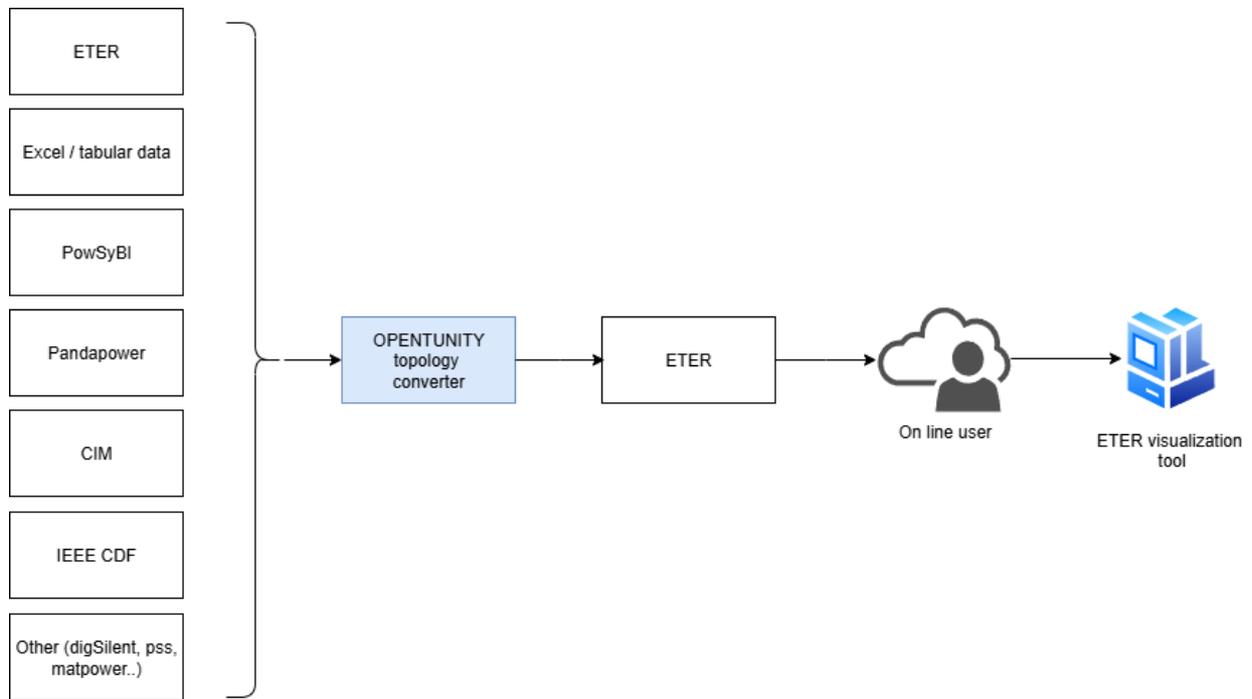
Figure 4: Process

The process starts with the conversion from a given format to the ETER format, Then the user can take the resulting topology model file and upload it to the ETER visualization tool. The tool will present the topology and let user assess the correctness of the transformation.

The usage of this web platform is not open to everybody but requires an invitation. The idea is to let any person or organisation with a legitimate interest to access the platform and make use of it freely.

This is the section where the topology can be uploaded to the ETER tool:
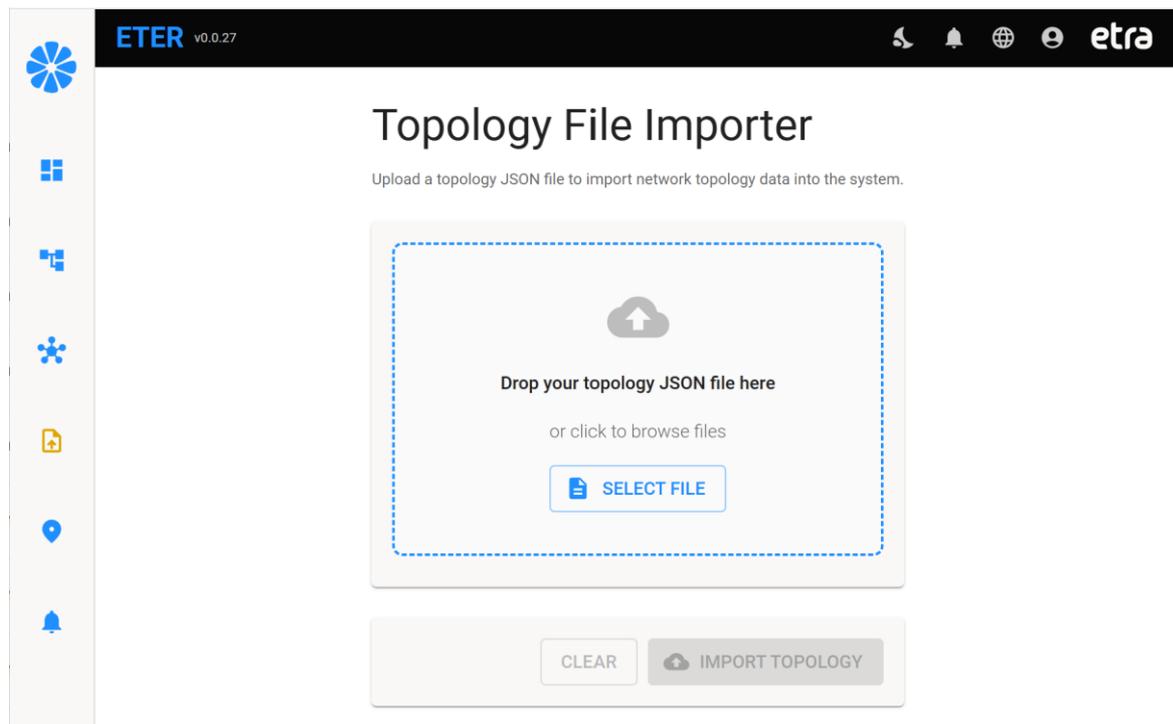
Figure 5: Topology file importer screenshot (1)

The tool lets the user drag and drop a ETER topology file format (with .json extension).
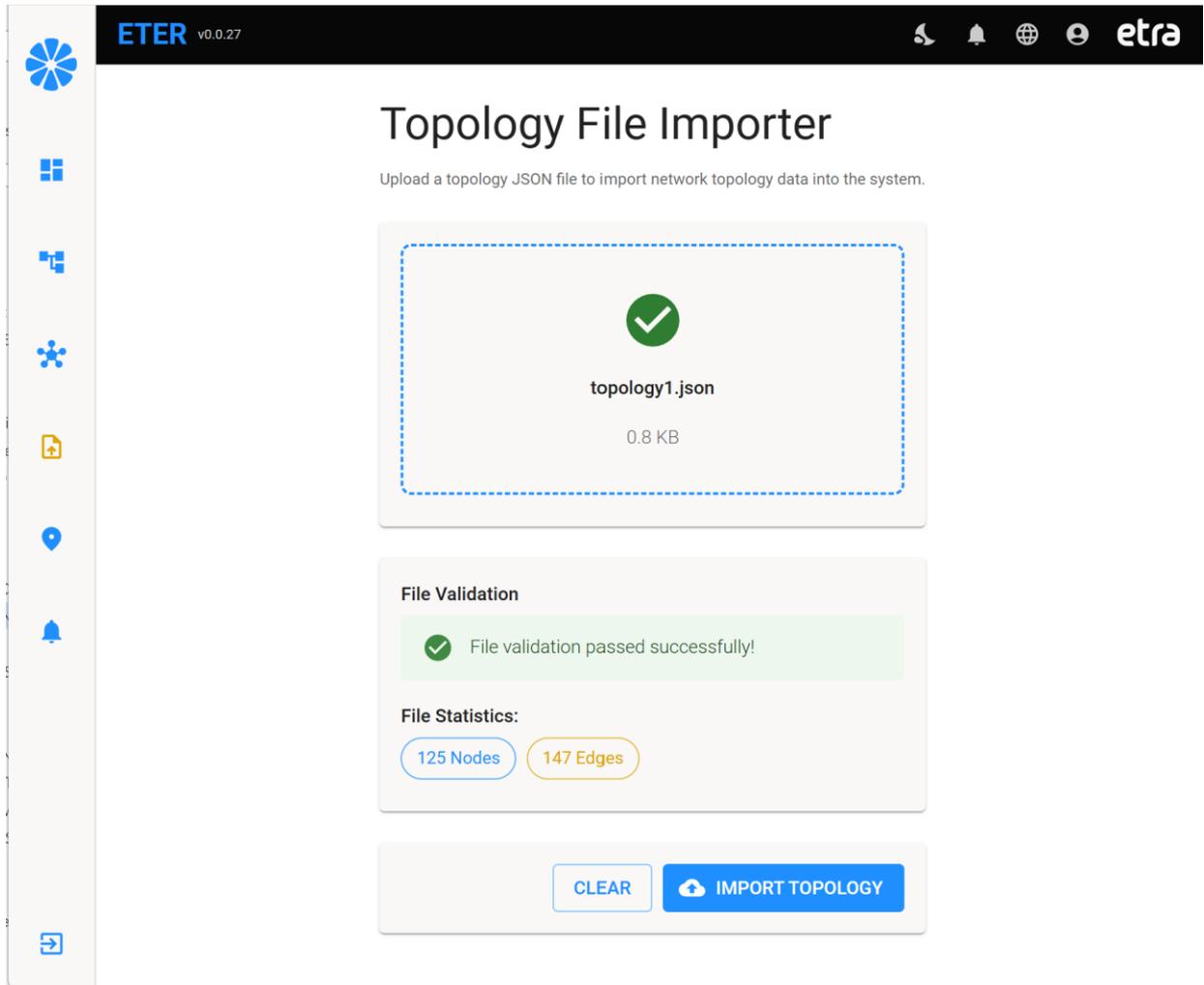
Figure 6: Topology file importer screenshot (2)

When uploaded, the format of the file is checked and the summary presented. The user can then proceed with the import of the file, that will add this topology to the list of topologies that the user can access. This is an example of the topology imported visualization:
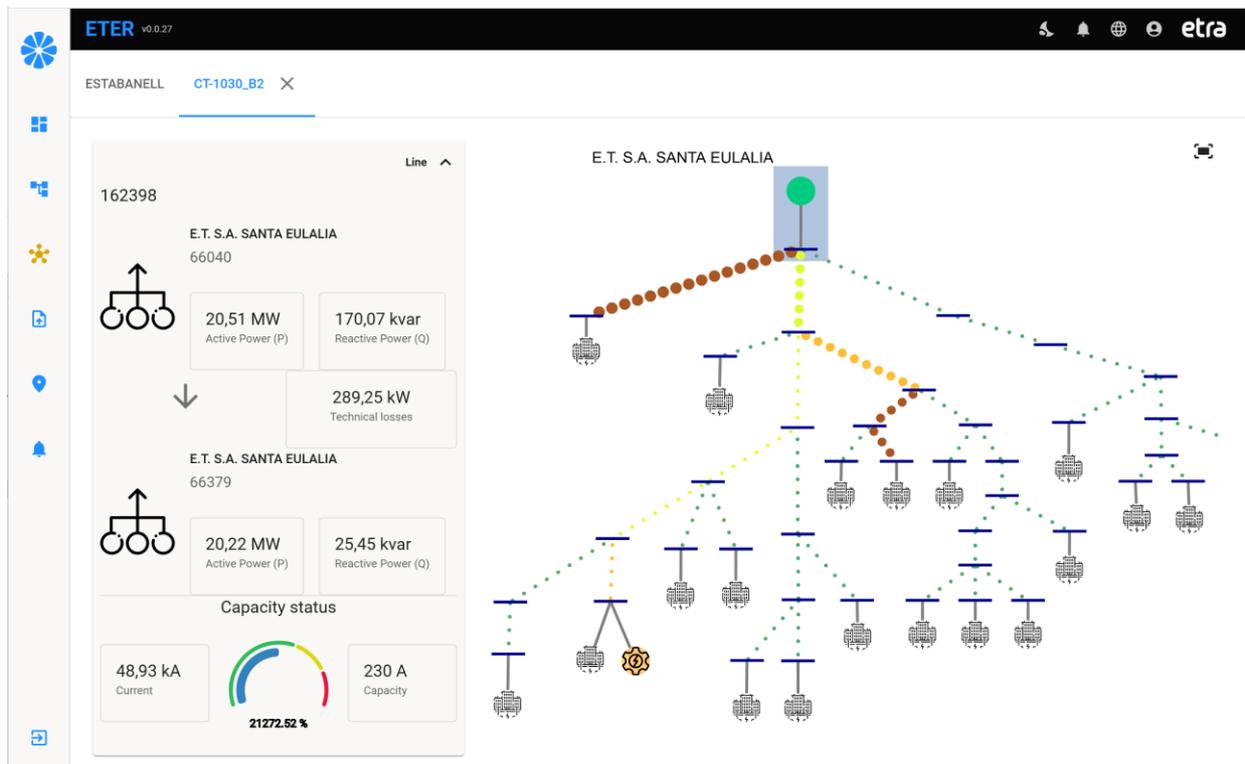
Figure 7: Visualization

The visualization tool presents the topology in a way similar to the ETER tool described in D5.2, including the power flow visualization, and details of measurements, but the features linked to access historical or forecasted data are disabled, as the tool just presents data currently included in the topological data model.

7 CONCLUSIONS

The methodology described, with its related software components and data models, have been successfully used within the project to model and integrate the network topologies of the pilots. Feedback can be obtained from them, and the methodology has been adjusted to meet its requirements (that are not specific from them but general to any utility operator).

The resulting software components are offered as open source in the common open-source code sharing platform (Github), for any interested person to access it freely. It is expected to share it also with the Linux Foundation and, potentially host it there.

The specific topology data model defined has also been described in depth in a document that will allow any scientific or utility operator to define a grid and use it in any of the supported software components or even visualize in the ETER visualization tool, also provided for free to let use visualize the topologies defined.

8 REFERENCES AND ACRONYMS

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8.2 Acronyms

Table 1. Acronyms

Acronym	Explanation
CGMES	Common Grid Model Exchange Specification
CIM	Common Information Model
DSO	Distribution System Operator
HV	High voltage
LV	Low voltage
MV	Medium voltage
NC	Network code

9 Annex 1: COMMAND LINE USER MANUAL

The OPENTUNITY converter tool is provided as an application that can be used from the command line of any computer, no matter the operating system.

This output is obtained by executing 'topologyConverter -h' command

```
Starting Topology Alchemy...
['src/main.py', '-h']
usage: main.py [-h] --iFormat {powsybl,cim,tabular,pandahub,pandapower,ETER,cdf,matpower,topologyIdentification} --input INPUT --oFormat
               {powsybl,cim,tabular,pandahub,pandapower,ETER} --output OUTPUT [--activateTransliterate] [--processLV] [--deletePrevious] [--system SYSTEM]
               [--context CONTEXT] [--verbose] [--log LOG] [--defaultLayoutMV DEFAULTLAYOUTMV] [--defaultLayoutLV DEFAULTLAYOUTLV]

This program allows transforming topologies between different formats. It has been developed under the EU research project OPENTUNITY

options:
  -h, --help            show this help message and exit
  --iFormat {powsybl,cim,tabular,pandahub,pandapower,ETER,cdf,matpower,topologyIdentification}
                        Input format
  --input INPUT         Input file
  --oFormat {powsybl,cim,tabular,pandahub,pandapower,ETER}
                        Output format
  --output OUTPUT       Output file
  --activateTransliterate
                        Transliterate Greek characters
  --processLV           Import LV network
  --deletePrevious      Generate delete commands for previous data
  --system SYSTEM       System id
  --context CONTEXT     Context
  --verbose             Increase output verbosity
  --log LOG             Log level
  --defaultLayoutMV DEFAULTLAYOUTMV
                        Default cytoscape layout for MV network
  --defaultLayoutLV DEFAULTLAYOUTLV
                        Default cytoscape layout for LV network
```

The syntax of the application is as follows:

- **iFormat**, Topology format of the input file. It must be one of these: powsybl, cim, tabular, pandahub, pandapower, ETER, cdf, matpower, topologyIdentification.
- **Input**. Input file name
- **oFormat**. Topology format of the outpout file. It must be one of these: powsybl, cim, tabular, pandahub, pandapower, ETER
- **output**. output file name
- **activateTransliterate**. This option enable the Greek characters transliteration, to let Cyrillic characters in node names be mapped to the correct ASCII characters
- **processLV**. Wheter or not the topology includes LV networks
- **deletePrevious**. Whether or not this topology is accumulative to an existing topology or replaces it completely
- **system**. Name of the system the topology belongs to. In OPENTUNITY this corresponds to pilot names
- **context**. Internal code of the topology to avoid collision of identifiers among different nodes in different topologies. This is required, as the application is multitenant and thus allows different users to interact with the platform without accessing data of other users.
- **Verbose**. Where of not to provide extra information in the conversion process
- **Log**. Log level of the traces. Can be ERROR, WARNING, INFO and DEBUG
- **defaultLayoutMV**. The default layout strategy that will be used to position the nodes in the MV grids for the first time. Can be one of these: Force-directed, Circular, Hierarchical, Grid, Attribute-based, Cluster and Geographic
- **defaultLayoutLV**. The default layout strategy that will be used to position the nodes in the LV grids for the first time. Can be one of these: Force-directed, Circular, Hierarchical, Grid, Attribute-based, Cluster and Geographic

10 Annex 2. Excel topology data modelling instructions.

In the next section the instructions for using the excel template for topology modelling are presented. These instructions are meant to be distributed to the broad audience and have been presented here with its specific document format

Topology Creator User Manual

- INTRODUCTION

The present document describes in detail the Excel spreadsheet that is used to collect the required data in order to build the topology model of the grid to be integrated.

This data model have been developed under the umbrella of the European project OPENTUNITY (https://opentunityproject.eu/ , https://cordis.europa.eu/project/id/101096333/es)

- STRUCTURE OF THE EXCEL SPREADSHEET

The Excel spreadsheet contains different tabs, each one requiring details on different elements. The following sections follow a practical example of a simple grid as a guideline to completing the spreadsheet.

NOTE: The fields with an asterisk are optional

o Networks

A list of MV networks—which should be the main element(s) represented in this spreadsheet—and HV networks they connect with.

Property	Type	Description	Reference
ID	String	Unique identifier of the network	
NAME	String	Human-readable name of the network	
TYPE	String	"MV" or "HV"	
EXTERNAL	Number	0: No (i.e. its elements will be described in further sheets of this book) 1: Yes (i.e. only the connection point will be represented)	
BUS*	String	ID of the bus the external network connects to. It should be included in the Buses section. Keep it blank for non-external networks.	Buses.ID

o Substations

Under this tab, a list of the substations present in the grid needs to be provided. Substations in the model serve as other component containers.

Property	Type	Description	Reference
ID	String	Unique identifier of the substation	
NAME	String	Human-readable name of the substation	
NETWORK	String	ID of the MV network it belongs to	Networks.ID
LATITUDE*	Float	Latitude of the geographic coordinates of the element	
LONGITUDE*	Float	Longitude of the geographic coordinates of the element	

o Buses

Buses are non-impedant elements used to connect equipment inside substations.

Property	Type	Description	Reference
ID	String	Unique identifier of the bus	

NAME	String	Original name of the bus	
SUBSTATION	String	Substation where the bus is located	Substations.ID
U	Float	Nominal voltage of the bus (kV)	
LATITUDE*	Float	Latitude of the geographic coordinates of the element	
LONGITUDE*	Float	Longitude of the geographic coordinates of the element	

o **Lines**

Lines are used to connect buses located on different substations. They are modelled using a standard π model with distributed parameters.
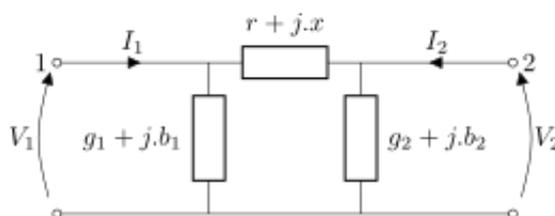
Property	Type	Description	Reference
ID	String	Unique identifier of the line	
NAME	String	Original identifier of the line	
BUS1	String	Source bus	Buses.ID
BUS2*	String	Sink bus	Buses.ID
R*	Number	The series resistance (Ω)	
X*	Number	The series reactance (Ω)	
G1*	Number	The first side shunt conductance (S)	
B1*	Number	The first side shunt susceptance (S)	
G2*	Number	The second side shunt conductance (S)	
B2*	Number	The second side shunt susceptance (S)	
CURRENTLIMIT*	Number	The line maximum acceptable current (A)	
LENGTH	Number	The length of the line in meters	
WIREINFO*	String	Optional. Reference to the wire info ID in the last sheet. Properties of the line will be taken from there.	Wireinfo.NAME
COORDS**	Number	The cells in the row starting from this column should contain the sequence of coordinates in the following order: lat_point1, lon_point1, lat_point2, lon_point2 …	

▪ *Hints online modelling for distribution grids*

• **Ideal lines**

As a first step towards constructing and performing an early validation of the model, it may be interesting to proceed by modelling all lines as ideal lines (R=X=G1=B1=G2=B2=0). Electrical details can be updated in the model on a second stage.

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- **Series resistance and reactance**

Resistance depends on the temperature of the conductor. The following table contains reference values that can be used to estimate this parameter. As default value the column 20⁰C may be used.

Conductor temperature			
	20⁰C	**Thermoplastics 70⁰C**	**Thermoset 90⁰C**
Cu	58.00	48.47	45.49
Al	35.71	29.67	27.80

Values provided in [m / (Ω·mm²)]

In general, reactance (x) can be considered constant, equal to 0.08 Ω/km regardless of the line type (three-phase or single-phase), conductor material (copper, aluminium) or section size. This value is accepted by IEC 60364-5-52.

- **Shunt conductance/susceptance**

For distribution lines (length < 80km), those values are negligible (G1 = B1 = G2 = B2 = 0)

- **Feeders**

LV Feeder lines must be defined specifying the source bus but leaving the sink bus empty.

o **Transformers**

Two-winding transformers are used to connect buses under the same substation with different nominal voltages. They are modelled using the equivalent Π model.

Property	Type	Description	Reference
ID	String	Unique identifier of the transformer	
NAME	String	Original name of the transformer	
BUS1	String	Source bus	Buses.ID
BUS2	String	Sink bus	Buses.ID
R	Number	The nominal series resistance at the side 2 of the transformer (Ω)	
X	Number	The nominal series reactance at the side 2 of the transformer (Ω)	
G	Number	The nominal magnetizing conductance at the side 2 of the transformer (S)	
B	Number	The nominal magnetizing susceptance at the side 2 of the transformer (S)	

D5.5 OPENTUNITY Grid integration methodology (20250711-etra-OPENTUNITY- d5_5- OPENTUNITY grid integration methodology- pu_v1.0)

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Property	Type	Description	Reference
~~RATEDU1~~	~~Number~~	~~The rated voltage at side 1 (kV)~~	Removed, to be taken from BUS1.U
~~RATEDU2~~	~~Number~~	~~The rated voltage at side 2 (kV)~~	Removed, to be taken from BUS2.U
NOMINALPOWER	Number	Nominal power of the transformer (kVA)	
LATITUDE*	Float	Latitude of the geographic coordinates of the element	
LONGITUDE*	Float	Longitude of the geographic coordinates of the element	

o **Three-winding transformers**

A three windings power transformer is connected to three voltage levels (side 1, side 2 and side 3) that belong to the same substation. We usually have:
- Side 1 as the primary side (side with highest rated voltage)
- Side 2 as the secondary side (side with the medium rated voltage)
- Side 3 as the tertiary side (side with the lowest rated voltage)

A three windings transformer is modeled with three legs, where every leg model is electrically equivalent to a two windings transformer. For each leg, the network bus is at side 1 and the star bus is at side 2
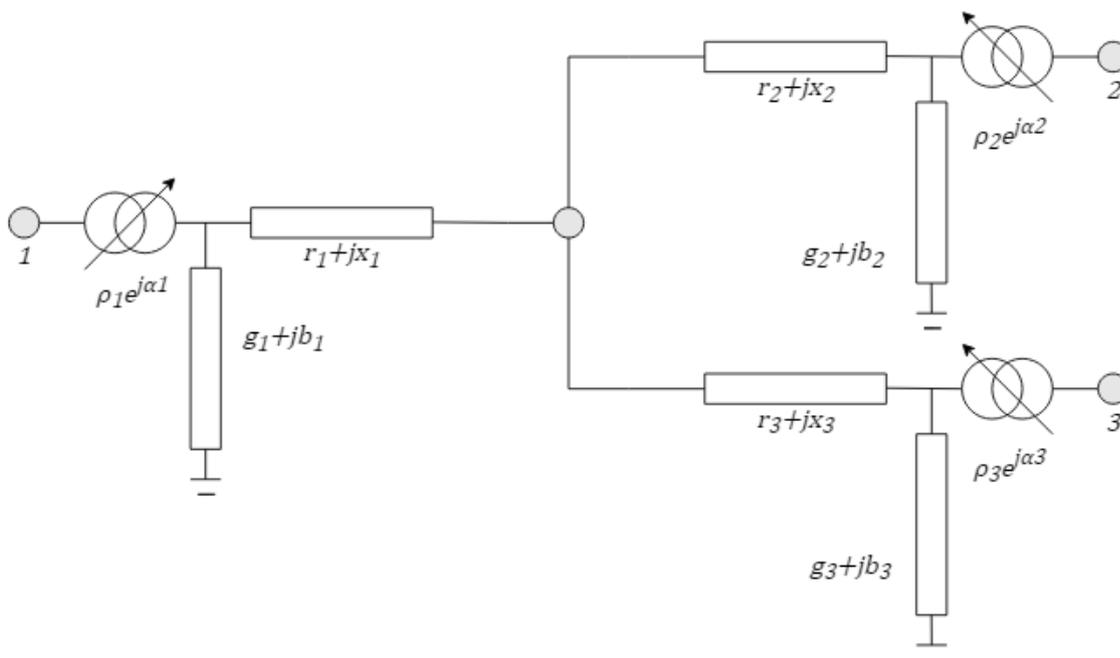
Property	Type	Description	Reference
ID	String	Unique identifier of the transformer	
NAME	String	Original name of the transformer	
BUS1	String	Leg1 bus	Buses.ID

D5.5 OPENTUNITY Grid integration methodology (20250711-etra-OPENTUNITY- d5_5- OPENTUNITY grid integration methodology- pu_v1.0)

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BUS2	String	Leg2 bus	Buses.ID
BUS3	String	Leg3 bus	Buses.ID
RATEDUSTAR	Number	The rated voltage at the star bus (kV)	
R1	Number	The nominal series resistance at the side of the leg 1 of the transformer (Ω)	
X1	Number	The nominal series reactance at the side of the leg 1 of the transformer (Ω)	
G1	Number	The nominal magnetizing conductance at the side of the leg 1 of the transformer (S)	
B1	Number	The nominal magnetizing susceptance at the side of the leg 1 of the transformer (S)	
R2	Number	The nominal series resistance at the side of the leg 2 of the transformer (Ω)	
X2	Number	The nominal series reactance at the side of the leg 2 of the transformer (Ω)	
G2	Number	The nominal magnetizing conductance at the side of the leg 2 of the transformer (S)	
B2	Number	The nominal magnetizing susceptance at the side of the leg 2 of the transformer (S)	
R3	Number	The nominal series resistance at the side of the leg 3 of the transformer (Ω)	
X3	Number	The nominal series reactance at the side of the leg 3 of the transformer (Ω)	
G3	Number	The nominal magnetizing conductance at the side of the leg 3 of the transformer (S)	
B3	Number	The nominal magnetizing susceptance at the side of the leg 3 of the transformer (S)	
~~**RATEDU1**~~	~~Number~~	~~The rated voltage at the leg 1 bus (kV)~~	Removed, to be taken from BUS1.U
~~**RATEDU2**~~	~~Number~~	~~The rated voltage at the leg 2 bus (kV)~~	Removed, to be taken from BUS2.U
~~**RATEDU3**~~	~~Number~~	~~The rated voltage at the leg 3 bus (kV)~~	Removed, to be taken from BUS3.U
RATEDS1	Number	Leg 1 bus nominal power (kVA)	
RATEDS2	Number	Leg 2 bus nominal power (kVA)	
RATEDS3	Number	Leg 3 bus nominal power (kVA)	
LATITUDE*	Float	Latitude of the geographic coordinates of the element	
LONGITUDE*	Float	Longitude of the geographic coordinates of the element	

o **Loads**

Loads represent relevant active power demand nodes in the topology model. Normally refer to MV loads or LV circuits (feeders) that are simplified in the form of a load from the MV perspective

Property	Type	Description	Reference
ID	String	Unique identifier of the load	
NAME	String	Original name of the load	
BUS	String	Bus the load is connected to	Buses.ID
P	Number	Reference active power demand for this node (kW)	
Q	Number	Reference reactive power demand for this node (kvar)	
LATITUDE*	Float	Latitude of the geographic coordinates of the element	
LONGITUDE*	Float	Longitude of the geographic coordinates of the element	

Please note that P and Q values will be updated with metered values accordingly to the corresponding analysis performed (e.g. current or forecasted power flows) during system operation. Values provided at this point will be used at system commissioning to validate the topology model.

o **Generators**

Generators represent relevant active power injection nodes in the MV topology model (usually RES or flexibility assets).

Property	Type	Description	Reference
ID	String	Unique identifier of the generator	
NAME	String	Original name of the generator	
BUS	String	Bus the generator is connected to	Buses.ID
MINP	Number	**Minimum** generator active power output (kW). Usually negative to consider that a generator may actually consume power (e.g. TSO connections)	
MAXP	Number	Maximum generator active power output (kW)	
TARGETP	Number	The active power setpoint (kW)	
TARGETV	Number	The voltage setpoint (kV). Usually the nominal voltage of the bus the generator is connected to	
TARGETQ	Number	The reactive power setpoint (kvar)	
MINQ	Number	Minimum generator reactive power output (kvar)	
MAXQ	Number	Maximum generator reactive power output (kvar)	
CONTROLLABLE	Number	0: not controllable (its value is constant for power flow calculation) 1: controllable (its value can be adjusted when calculating power flow)	
LATITUDE*	Float	Latitude of the geographic coordinates of the element	
LONGITUDE*	Float	Longitude of the geographic coordinates of the element	

Please note that targetP and targetQ values will be updated with metered values accordingly to the corresponding analysis performed (e.g. current or forecasted power flows) during system operation. Values provided at this point will be used at system commissioning to validate the topology model.

o **Shunt compensators**

A shunt compensator represents a shunt capacitor or reactor or a set of switchable banks of shunt capacitors or reactors in the network. A section of a shunt compensator is an individual capacitor or reactor: if its reactive power (Q) is negative, it is a capacitor; if it is positive, it is a reactor.

Property	Type	Description	Reference
ID	String	Unique identifier of the shunt compensator	
NAME	String	Original name of the shunt compensator	
BUS	String	Bus the shunt compensator is connected to	Buses.ID
MAXSECCOUNT	Number	The maximum number of sections that may be switched on	
BPERSECTION	Number	The Positive sequence shunt (charging) susceptance per section	
GPERSECTION	Number	The Positive sequence shunt (charging) conductance per section	
REFERENCEPOWER	Number	Reference power (kVA)	
LATITUDE*	Float	Latitude of the geographic coordinates of the element	
LONGITUDE*	Float	Longitude of the geographic coordinates of the element	

o **Breakers/Switches**

Switches represent the ability to open/close connections between buses under the same substation.

Property	Type	Description	Reference
ID	String	Unique identifier of the switch	
NAME	String	Original name of the switch	
BUS1	String	Source bus	Buses.ID
BUS2	String	Sink bus	Buses.ID
OPEN	Number	Default state of the breaker/switch 0 = open 1 = closed	
LATITUDE*	Float	Latitude of the geographic coordinates of the element	
LONGITUDE*	Float	Longitude of the geographic coordinates of the element	

Please note that "open" value provided at this point will be used at system commissioning to validate the topology model.

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o **Protecting devices**

A generic device designed to close, open or both; one or more electric circuits. All switches are two terminal devices including grounding switches. They can operate automatically and/or manually.

Property	Type	Description	Reference
ID	String	Unique identifier of the protection device	
NAME	String	Original name of the protection device	
FEEDER	String	Identifier of the feeder in MV this protection device belongs to (identifier of the LV bus)	Buses.ID
FEEDER_NUM	Index of the feeder in the bus	Identifier of feeder (1,2…)	
BUS1	String	Source bus	Buses.ID
BUS2	String	Sink bus	Buses.ID
TYPE	String	"fu" = fuse "se" = sectionalizer "re" = recloser "di" = disconnector "gd" = ground disconnector	
OPERATINGCURRENT	Number	The current that will blow fuse or trip protection (A)	
NORMALLYOPEN	Number	Default state of the protection 0 = normally open 1 = normally closed	
LATITUDE*	Float	Latitude of the geographic coordinates of the element	
LONGITUDE*	Float	Longitude of the geographic coordinates of the element	

o **Line segments (feeder details)**

The columns in the LINESEGMENTS tab contain the following information:

Property	Type	Description	Reference
ID	String	Unique identifier of the segment	
NAME	String	Original name of the segment	
FEEDER	String	Identifier of the feeder in MV this line segment belongs to (identifier of the LV bus)	Buses.ID
FEEDER_NUM	Index of the feeder in the bus	Identifier of feeder (1,2…)	

LENGTH	Number	Length of the cable in metres	
WIREINFO*	String	Name of the type of wire of this line section. As identified in section WIREINFO. OPTIONAL	WireInfo.NAME
NODE1	Identifier of the starting node of the line segment	Could be: - The identifier of the MV bus, if it is the first line segment - A node already defined and used to connect with other line segments - Usage point location ID - Empty, in this case, a fictitious node will be created based on the geographical coordinates. In this case the coordinates field is mandatory and the line segments will be connected based on the coincidence of the coordinates	BUSES
NODE2	Identifier of the ending node of the line segment	Could be: - A node already defined and used to connect with other line segments - Usage point location ID - Empty, in this case, a fictitious node will be created based on the geographical coordinates. In this case the coordinates field is mandatory and the line segments will be connected based on the coincidence	
R*	Number	The series resistance (Ω)	R*
X*	Number	The series reactance (Ω)	

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G1*	Number	The first side shunt conductance (S)	
B1*	Number	The first side shunt susceptance (S)	
G2*	Number	The second side shunt conductance (S)	
B2*	Number	The second side shunt susceptance (S)	
CURRENTLIMIT*	Number	The line maximum acceptable current (A)	
COORDS**	Number	The cells in the row starting from this column should contain the sequence of coordinates in the following order: lat_point1, lon_point1, lat_point2, lon_point2 …	

o   **Usage Point Locations**

Location of an electric connection, typically associated to a building or facility. One or more supply points and meters could be linked to a location.

Property	Type	Description	Reference
ID	String	Unique identifier of usage point location. It must match one of the ends of a line segment.	LineSegments.NODE1 or LineSegments.NODE2
NAME	String	Original name of usage point location	
FEEDER	String	Identifier of the feeder in MV this location belongs to (identifier of the LV bus)	Buses.ID
FEEDER_NUM	Index of the feeder in the bus	Identifier of feeder (1,2…)	
LATITUDE*	Float	Latitude of the geographic coordinates	

Property	Type	Description	Reference
LONGITUDE*	Float	Longitude of the geographic coordinates	

o   Usage Points

Supply point for electricity. In most cases, only one meter is associated to a usage point at a specific moment in time.

Property	Type	Description	Reference
ID	String	Unique identifier of usage point location	
NAME	String	Original name of usage point location	
FEEDER	String	Identifier of the feeder in MV this usage point belongs to (identifier of the LV bus)	Buses.ID
FEEDER_NUM	Index of the feeder in the bus	Identifier of feeder (1,2…)	
USAGEPOINTLOCATION	String	ID of the location associated to this usage point. It must match one of the ends of a line segment.	UsagePointLocations.ID and (LineSegments.NODE1 or LineSegments.NODE2)
LATITUDE*	Float	Latitude of the geographic coordinates	
LONGITUDE*	Float	Longitude of the geographic coordinates	

o   DERs

Distributed Energy Resources represent relevant active power injection nodes in the LV topology model (usually RES or flexibility assets).

Property	Type	Description	Reference
ID	String	Unique identifier of the generator	
NAME	String	Original name of the generator	
FEEDER	String	Identifier of the feeder in MV this generator belongs to (identifier of the LV bus)	Buses.ID

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FEEDER_NUM	Index of the feeder in the bus	Identifier of feeder (1,2…)	
USAGEPOINTLOCATION	String	ID of the location associated to this generator. It must match one of the ends of a line segment.	UsagePointLocations.ID and (LineSegments.NODE1 or LineSegments.NODE2)
MINP	Number	**Minimum** generator active power output (kW). Usually negative to consider that a generator may actually consume power (e.g. TSO connections)	
MAXP	Number	Maximum generator active power output (i.e. installed power) (kW)	
TARGETP	Number	The active power setpoint (kW)	
TARGETV	Number	The voltage setpoint (kV). Usually the nominal voltage of the bus the generator is connected to	
TARGETQ	Number	The reactive power setpoint (kvar)	
MINQ	Number	Minimum generator reactive power output (kvar)	
MAXQ	Number	Maximum generator reactive power output (kvar)	
~~CONTRACTEDPOWER~~	~~Float~~	~~Installed power of the DER (kW)~~	
CONTROLLABLE	Number	0: not controllable (its value is constant for power flow calculation) 1: controllable (its value can be adjusted when calculating power flow)	
LATITUDE*	Float	Latitude of the geographic coordinates of the element	
LONGITUDE*	Float	Longitude of the geographic coordinates of the element	

Please note that targetP and targetQ values will be updated with metered values accordingly to the corresponding analysis performed (e.g. current or forecasted power flows) during system operation. Values provided at this point will be used at system commissioning to validate the topology model.

o **Meters**

Meters connected to usage points, providing measurements.

Property	Type	Description	Reference
ID	String	Unique identifier of the meter	

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USAGE POINT	String	Identifier of the usag epoint	UsagePoints.ID
FEEDER	String	Identifier of the feeder in MV this meter belongs to (identifier of the LV bus)	Buses.ID
FEEDER_NUM	Index of the feeder in the bus	Identifier of feeder (1,2…)	

o **Wire info**

Here the characteristics of the different cables are defined. Every cable type is defined once and can be used multiple times in the line segments definitions

Property	Type	Description	Reference
NAME	String	Unique identifier of the wire type	
DESCRIPTION*	String	Textual description of the wire type	
MATERIALKIND*	String	Wire material. One of: • "co" = Copper wire. • "st" = Steel wire. • "al" = Aluminum wire. • "as" = Aluminum-steel wire. • "acsr" = Aluminum conductor steel reinforced. • "aa" = Aluminum-alloy wire. • "aas" = Aluminum-alloy-steel wire. • "aaac" = Aluminum-alloy conductor steel reinforced. • "other" = Other wire material.	
INSULATIONMATERIAL KIND*	String	Insulation type. One of: • "asbestosAndVarnishedCambric" = Asbestos and varnished cambric wire insulation. • "butyl"= Butyl wire insulation. • "ethylenePropyleneRubber" = Ethylene propylene rubber wire insulation. • "highMolecularWeightPolyethylene" = High nolecular weight polyethylene wire insulation. • "treeResistantHighMolecularWeightPolyethylene" = Tree resistant high molecular weight polyethylene wire insulation. • "lowCapacitanceRubber" = Low capacitance rubber wire insulation. • "oilpaper" = Oil paper wire insulation. • "ozoneResistantRubber" = Ozone resistant rubber wire insulation. • "beltedPilc" = Belted pilc wire insulation. • "unbeltedPilc" = Unbelted pilc wire insulation. • "rubber" = Rubber wire insulation. • "siliconRubber" = Silicon rubber wire insulation. • "varnishedCambricCloth" = Varnished cambric cloth wire insulation. • "varnishedDacronGlass" = Varnished dacron glass wire insulation.	

		• "crosslinkedPolyethylene" = Crosslinked polyethylene wire insulation. • "treeRetardantCrosslinkedPolyethylene" = Tree retardant crosslinked polyethylene wire insulation. • "highPressureFluidFilled" = High pressure fluid filled wire insulation. • "other" = Other kind of wire insulation.	
INSULATIONLEVEL*	String	Examples: • "N/A" • "6/10kV" • "12/20kV" • "15/25kV" • "18/30kV" • "26/45kV" • "36/66kV" • …	
FAMILY*	String	Extra information about wire family/category	
RATEDCURRENT*	Number	Max Current in A	
X*	Number	The series reactance (Ω)	
R*	Number	The series resistance (Ω)	
G1*	Number	The first side shunt conductance (S)	
B1*	Number	The first side shunt susceptance (S)	
G2*	Number	The second side shunt conductance (S)	
B2*	Number	The second side shunt susceptance (S)	
SECTION	String	Section in mm^2	
RADIUS	Number	Radius of the wire section	
MV_OR_LV	String	"MV" or "LV"	

- EXAMPLE #1

This section contains the complete description of the small grid shown in the figure. The grid is composed of 5 substation with the following relevant particularities:

- TSO connection is located at SUBSTATION1. This is modelled as a dangling line that feeds power at 20kV (HV/MV transformer is not present in order to simplify the model)
- SUBSTATION3 contains a 20kV/12.5kV transformer. SUBSTATION4 and SUBSTATION5 are supplied with 12.5kV
- Loads are present at SUBSTATION2, SUBSTATION3 and SUBSTATION4
- A PV generation unit is present at SUBSTATION5
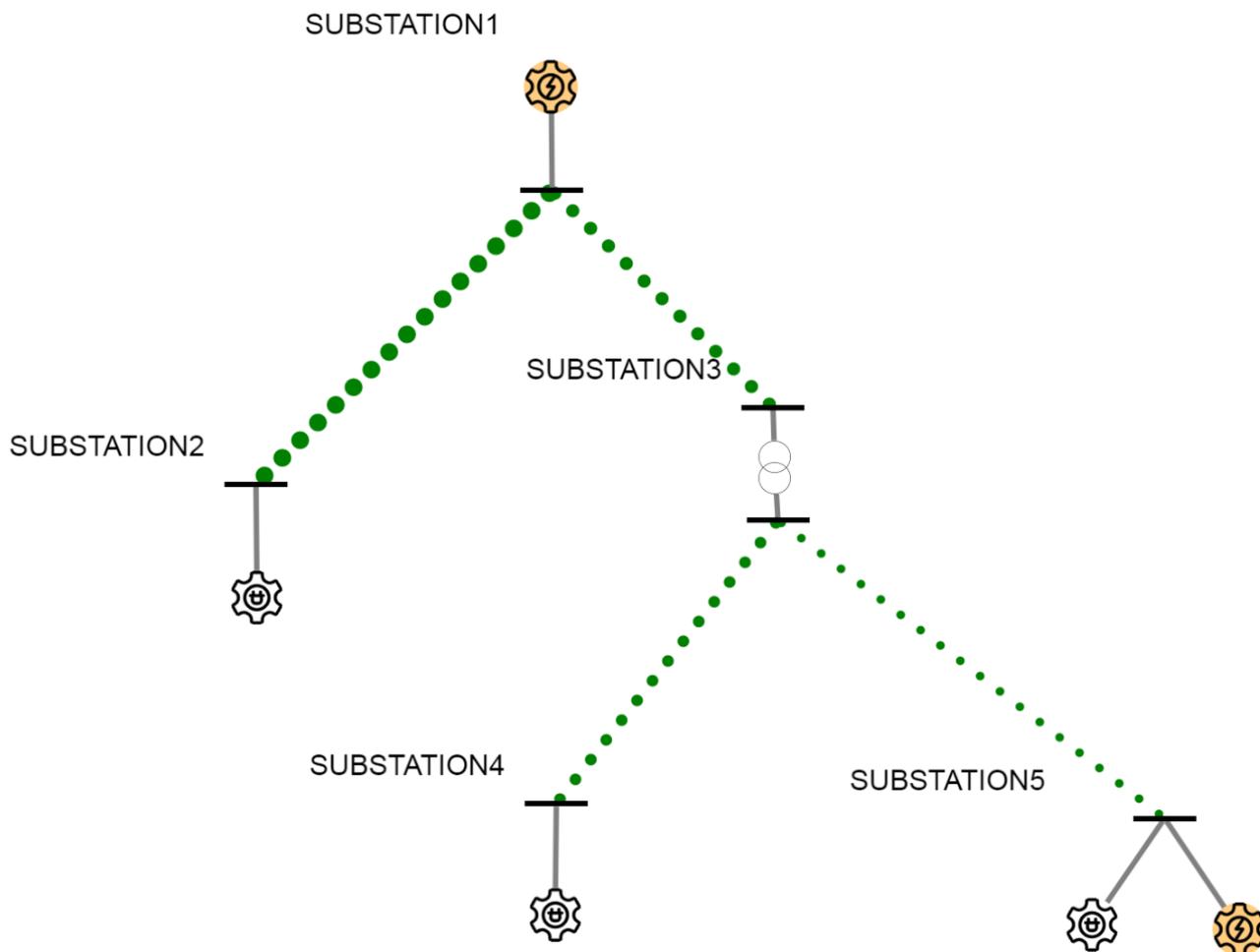
o **Substations**

ID
SUBSTATION1
SUBSTATION2
SUBSTATION3
SUBSTATION4
SUBSTATION5

o **Buses**

NAME	SUBSTATION	U
S1B1	SUBSTATION1	20.00
S2B1	SUBSTATION2	20.00
S3B1	SUBSTATION3	20.00
S3B2	SUBSTATION3	12.50
S4B1	SUBSTATION4	12.50
S5B1	SUBSTATION5	12.50

SUBSTATION3 contains 2 different buses (S3B1 and S3B2) at different voltage levels.

o **Lines**

NAME	BUS1	BUS2	R	X	G1	B1	G2	B2	CURRENTLIMIT
L1_2	S1B1	S2B1	0.93	0.80	0.00	0.00	0.00	0.00	40.00
L1_3	S1B1	S3B1	0.93	0.80	0.00	0.00	0.00	0.00	40.00
L3_4	S3B2	S4B1	0.93	0.80	0.00	0.00	0.00	0.00	40.00
L3_5	S3B2	S5B1	0.93	0.80	0.00	0.00	0.00	0.00	40.00

Assuming all lines have the following properties:
- Aluminium
- Section of 300mm^2
- Length of 10km

Calculation of R

From the reference table, Aluminium conductor at 20ºC has 35.71 m / (Ω·mm^2). Resistance is therefore calculated as:

$$R = LENGTH / (SECTION \cdot 35.71) = 10000 / (300 \cdot 35.71) = 0.93\ \Omega$$

Calculation of X

Value for reactance is considered equal to 0.08 Ω/km. Reactance is therefore calculated as:

$$X = LENGTH \cdot 0.08 = 10 \cdot 0.08 = 0.8$$

Calculation of G1, B1, G2, B2

Since length is lower than 80 km, it can be assumed that G1=B1=G2=B2=0

o **Transformers**

NAME	BUS1	BUS2	R	X	G	B	RATEDU1	RATEDU2
TRAFO3	S3B1	S3B2	0.00	0.00	0.00	0.00	20.00	12.50

In this case, transformers details are assumed to be unknown, and the transformer has been modelled as an ideal transformer (R=X=G=B=0)

o **Loads**

NAME	BUS	P	Q
LOAD2	S2B1	7.00	0.05

LOAD4	S4B1	3.00	0.05
LOAD5	S5B1	2.00	0.05

o **Generators**

NAME	BUS	MINP	MAXP	TARGETP	TARGETV	TARGETQ	MINQ	MAXQ
PV5	S5B1	0.00	2.00	1	12.5	0.3	-100.00	100.00

o **Dangling lines**

NAME	BUS	P	Q
TSO	S1B1	11	20

- ## EXAMPLE #2

This is the SLD of the LV network described in the previous sections:
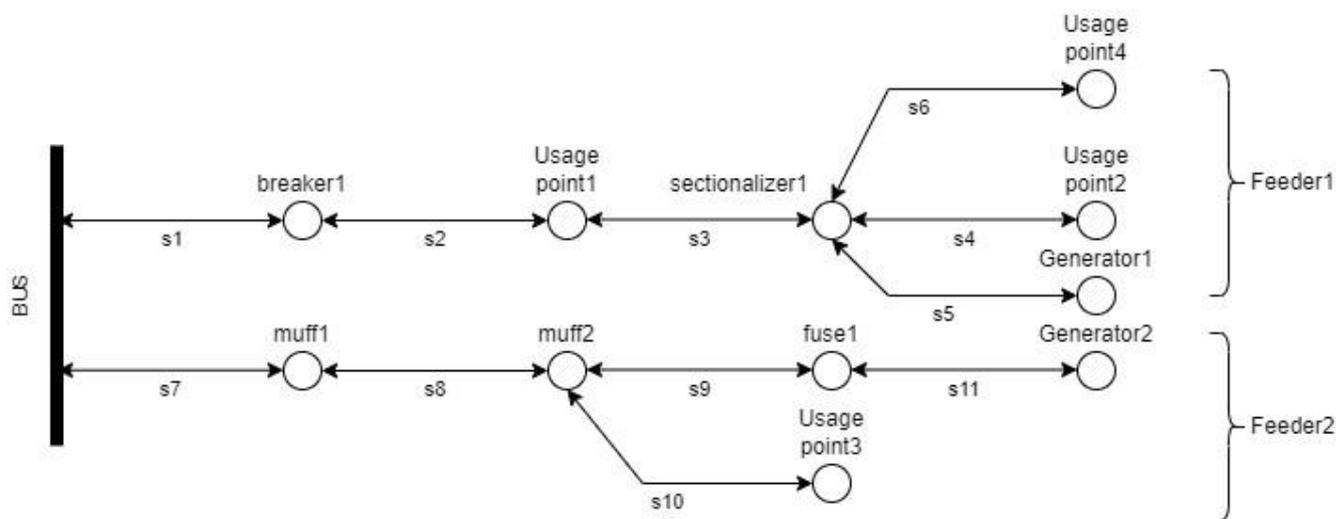
This structure could be translated in the following way:

o **Substations**

ID
SUBSTATION1

o **Buses**

NAME	SUBSTATION	U

S1B1	SUBSTATION1	20.00

o **Lines**

NAME	BUS1	BUS2	R	X	G1	B1	G2	B2	CURRENTLIMIT
Feeder1	S1B1		0.93	0.80	0.00	0.00	0.00	0.00	40.00
Feeder2	S1B1		0.93	0.80	0.00	0.00	0.00	0.00	40.00

o **Generators**

NAME	BUS	MINP	MAXP	TARGETP	TARGETV	TARGETQ	MINQ	MAXQ
Generator1		0.00	2.00	1	12.5	0.3	-100.00	100.00
Generator2		0.00	2.00	1	12.5	0.3	-100.00	100.00

o **Protections**

NAME	type	operatingCurrent	Normally opened
Breaker1		20	False
Sectionalizer1		20	False
Fuse1		30	False

o **Usage Point Locations**

NAME	Postal code	city	Address
Usage point 1			
Usage point 2			
Usage point 3			
Usage point 4			

o **Wire info**

NAME	description	materialKind	InsulationMaterialKind	family	ratedCurrent	R	X	G1	B1	G2	B2	radius
1x12000-D	Aeri Despullat	Al	rubber	embarrat	1300	0.93	0.80	0.00	0.00	0.00	0.00	40.00
1X12000-S	Subterrani	Al	butyl	HERSATENE	1300	0.93	0.80	0.00	0.00	0.00	0.00	40.00
3X150	Aeri Trenat	Al	butyl	FAMILIA	260	0.93	0.80	0.00	0.00	0.00	0.00	40.00
DHV-150	Subterrani	Al	other	DHV	260	0.93	0.80	0.00	0.00	0.00	0.00	40.00

o **Line segments**

id	line	from	fromType	To	toType	length	wireInfo

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s1	Feeder1	S1B1	b	Breaker1	P	43	1x1200-D
s2	Feeder1	Breaker1	p	usagePoint1	U	44	1x1200-D
s3	Feeder1	usagePoint1	u	Sectionalizer1	P	23	1x1200-D
S4	Feeder1	Sectionalizer1	p	usagePoint2	U	76	1X1200-S
S5	Feeder1	Sectionalizer1	p	Generator1	G	66	1X1200-S
S6	Feeder1	Sectionalizer1	p	usagePoint4	U	79	1x1200-D
S7	Feeder2	S1B1	b	Muff1	M	12	DHV-150
S8	Feeder2	Muff1	m	Muff2	M	22	DHV-150
S9	Feeder2	Muff2	M	Fuse1	P	789	1X1200-S
S10	Feeder2	Muff2	M	usagePoint3	U	53	1X1200-S
S11	Feeder2	Fuse1	P	Generator2	g	32	DHV-150

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