

# NETWORK CONFIGURATOR AND SIMULATOR SYSTEM BASED ON CIM STANDARD AND NODE-DEPTH ENCODING

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**Abstract**— The extensive automation envisaged for smart networks brings challenges related to the difficulty of integrating a great deal of data from sensing, metering, actuating, control and protection devices. Application tools developed for smart grids rely on standardized and open data formats for data exchange. Effective communication depends on a common model of information about the power grid. The Common Information Model (CIM) of IEC 61970 provides a consistent definition and data structure using object-oriented modeling. In the topological modeling of distribution networks, the network data structure given by Node-Depth Encoding (NDE) has been widely used for its computational efficiency. This paper aims to present a Network Configurator and Simulator System (NCSS) capable of generating metadata of the electric network in CIM standard and converting them into NDE metamodels integrated to power flow and short-circuit calculation tools. The NCSS was designed for the development, testing and validation of automation systems for electric power distribution systems.

**Keywords**— IEC61970/61968, Node-Depth Encoding, Smart Grids, Electrical Distribution Networks, Standardization.

**Resumo**— O extenso uso da automação previsto para redes elétricas inteligentes traz desafios relacionados à dificuldade de integrar uma grande quantidade de dados de sensores, medidores, atuadores, controles e dispositivos de proteção. As ferramentas de aplicação desenvolvidas para redes elétricas inteligentes dependem de formatos de dados padronizados e abertos para troca de dados. A comunicação efetiva depende de um modelo comum de informações sobre a rede elétrica. O Common Information Model (CIM) do IEC 61970 fornece uma definição consistente e estrutura de dados usando modelagem orientada a objetos. Na modelagem topológica de redes de distribuição, a estrutura de dados de rede fornecida pela Representação de Nó-Profundidade (NDE) tem sido amplamente utilizada por sua eficiência computacional. Este trabalho tem como objetivo apresentar um Sistema Configurator e Simulador de Rede (NCSS) capaz de gerar metadados da rede elétrica no padrão CIM e convertê-los em metamodelos NDE integrados a ferramentas de cálculo de fluxo de potência e curto-circuito. O NCSS foi projetado para o desenvolvimento, teste e validação de sistemas de automação voltados para sistemas de distribuição de energia elétrica.

**Palavras-chave**— IEC61970/61968, Representação Nó-Profundidade, Redes Inteligentes, Redes Elétricas de Distribuição, Padronização.

## 1 Introduction

As the smart grids evolve, there is a strong need for information exchange, both internal and externally to the utilities, to achieve the requirements of reliable, safe and efficient operation of the power systems. Such information exchanges have become essential for power system planning, operation and market.

The demand for interoperability has boosted the development of standards and tools to facilitate data transformation and integration (Filet, 2011). In a global scale, the main agents in the electricity sector consent that data integration models are vital for smart grid development by acknowledging IEC 61850 and IEC61970 as the two most important

standards in this approach (Sucic, Martinic and Kekelj, 2012). An effective communication greatly depends upon a common model of information about an electrical network, independent of their manufacturer or provider.

The IEC 61970 and IEC 61968 series of standards define standards for exchange of information for energy management system and electrical distribution systems. The Common Information Model (CIM) defines a utility industry standard object-model for the development and integration of applications used for electric power systems engineering, planning, management, operation and commerce. The CIM architecture is based upon the Unified Modelling Language (UML) (Apostolov, 2010), used to diagram CIM models, while eXtensible Markup Language (XML) is used to describe the data computational structure (Mcmorran, 2007).

McMorran (2007) provides some background on the CIM with an introduction to the concept of Class Hierarchies which are useful to define the components of a power system and demonstrates how the CIM class structure is mapped and the data encapsulated in an XML format.

Network topology processor is widely used in many power systems analysis programs such as on-line load-flow, on-line short-circuit, real-time fault diagnosis, restoration program and adaptive protection (Vasileios *et al.*, 2017). However, the approach used to develop the network topology may cause computation burden for real-time applications in special. The Node-Depth Encoding algorithm proposed by (Delbem *et al.*, 2004) has showed better performance when dealing with changes in the network topology in comparison to other types of data structure.

Armendariz *et al.* (2015) present an open method and supporting tool for translating power system information from a proprietary format to a simulation tool like MATLAB-Matpower by using CIM-XML format as the middleware.

The benefits of using a common format that covers all the areas of data exchange in the power electrical domain are counted in the network configurator that encompasses the NCSS developed. Different open tools as PYPISA [<https://pypsa.org/>] and PYPOWER [<https://pypi.org/project/PYPOWER/>] can be integrated to the network configurator, making it possible by CIM. These toolboxes were designed for automation of analysis and optimization of modern power systems.

The objective of this paper is to present the development of a Network Configurator and Simulator System (NCSS) in which the data model for distribution network components is based on the CIM standard and the network topology output which the load flow and the short circuit can be executed based on the Node-Depth Encoding (NDE).

At following, three additional sections are presented. Section 2 describes the architectural model of the modern power systems. Section 3 presents the data format based on CIM model and the network data structure given by Node-Depth Encoding, which encompass the developed Network Configurator and Simulator System. Section 4 gives the paper final conclusions.

## 2 Smart Grid Architectural Model

Smart grids refer to the entire power grid from generation, through transmission and distribution infrastructure all the way down to a wide range of electricity consumers (Leonardi *et al.*, 2014). A Smart Grid Architectural Model (SGAM) framework,

proposed in (Cen-Cenelec-Etsi, 2012) and illustrated in Figure 1, aims to assist the design of smart grid use cases with an architectural approach that considers a representation of interoperability viewpoints in a manner that is technology neutral, both for current implementation of the electrical grid and future implementations of the smart grid (Leonardi *et al.*, 2014).

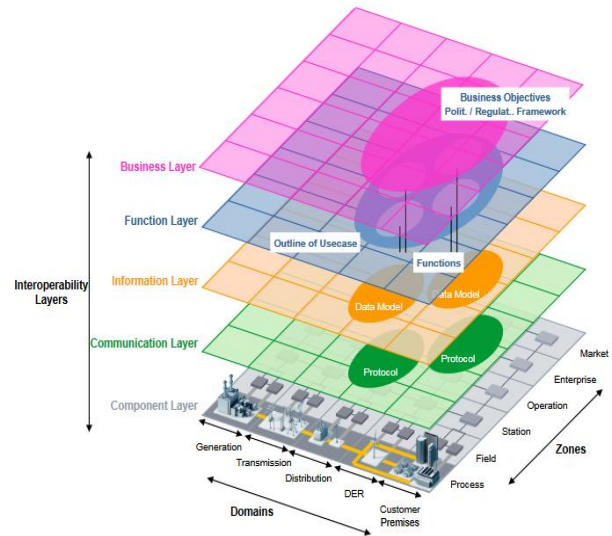


Figure 1. Three-dimensional architecture for smart grids (CEN-CENELEC-ETSI, 2012)

SGAM is a three-dimensional model that introduces interoperability aspects considered from three distinct viewpoints: the application domains, the hierarchical levels of smart grids management referred to as zones and the interoperability layers. The domains cover the entire electrical energy conversion chain that includes bulk generation, transmission, distribution, distributed energy resources, and customers premises. The zones are partitioned in process, field, station, operation, enterprise, and market. The interoperability layers highlight the interconnections that must be supported among business, functions, information (data model), communication (protocols), and components, and identify relations and dependency among them (Leonardi *et al.*, 2014).

The interoperability of information systems has been pursued for a long time by researchers and practitioners. It refers to the exchange and use of information among different systems for correct cooperation and requires agreement on formats and application domain concepts (Filet, 2011).

According to the SGAM architectural concept, a Network Configurator and Simulator System (NCSS), designed for the development, testing and validation of automation systems for electric power distribution systems, has the following axes:

- Domain: Distribution which represents the infrastructure and organization responsible for supply in electric energy to customers (Cen-Cenelec-Etsi, 2012);

- Zone: Operation of smart distribution grids that involves distributed energy resources and customers (Cen-Cenelec-Etsi, 2012);
- Interoperability layer: Information layer that describes the information that is being used and exchanged between functions, services and components. It contains information objects and the underlying canonical data models. These information objects and canonical data models represent the common semantics for functions and services to allow an interoperable information exchange via communication means (Cen-Cenelec-Etsi, 2012).

### 3.1 IEC 61970/61968 – CIM

The IEC 61970 series of standards deals with the application program interfaces for energy management systems. It enables the integration of software applications developed by different providers to promote more efficient real-time data exchange between control centers and generation, transmission and distribution systems. The Part 3 in IEC 61970 specifies a Common Information Model (CIM).

IEC 61968 series extends CIM standard for distribution management related to its operation, asset management, meter reading and control, power outage management, geographic information systems, etc.

CIM is an open standard developed for the electrical sector for enterprise integration, which defines the data model that allows the application software to exchange information about the electrical network.

Figure 2 shows the use of CIM as a system integrator. Each control center (S1-S4) represents its data differently; the data of each system are converted into a standard data model to exchange them (AYERS, 2011).

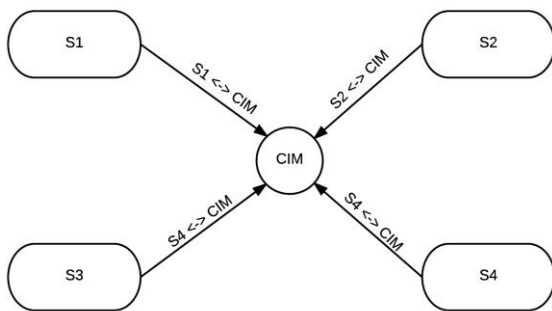


Figure 2. Use of CIM standard to integrate SCADA systems

CIM is a common language that enables interoperability and data exchange in a smart grid domain (Neto *et al.*, 2014). In addition to providing

the data model, the standard specifies guidelines for the writing of data in XML standard format. The use of XML format is emphasized by its simplicity, hierarchical structure, and usability across Internet (Fawcett, Quin and Ayers, 2012). It employs tags to structure data, but XML tags are defined for each application and can be used to identify the meaning of the data (Filet, 2011).

Figure 3 illustrates an electrical network in its CIM representation. Each equipment (Breaker, EnergyConsumer, SynchronousMachine, and PowerTransformer) has their respective terminal, while the Connectivity Nodes (CN) represent the connection between two or more terminals (Neto *et al.*, 2014).

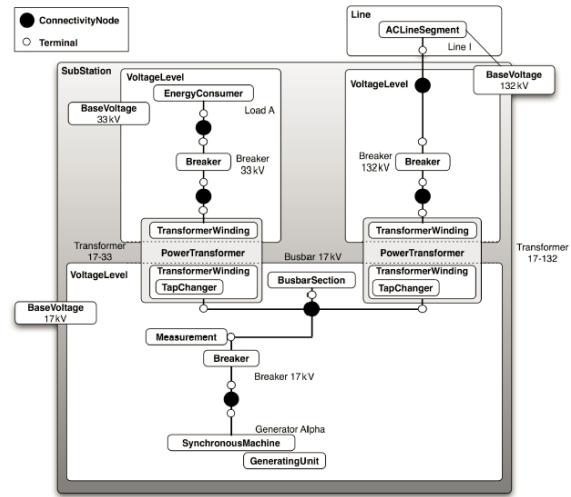


Figure 3. Simple network connectivity modeled in CIM standard [1]

### 3.2 Node-Depth Encoding (NDE) Algorithm

NDE approach is an algorithm based on graph theory applied to represent a power network topology (Delbem *et al.*, 2004). From the NDE point of view, trees represent feeders, forests are set of feeders, switches are edges, nodes are sectors delimited by switches and substations are root nodes. Figure 4 shows an example of a graph representing an electrical distribution network, which comprises sectors (node S1, A, B, C, D, E, S2), edges (switches 1,2,3,4,5,6,7) and root nodes (substations S1, S2). The arrays that represent the trees (feeders) are given by

$$T_1 = \begin{bmatrix} S1 & A & B & C \\ 0 & 1 & 2 & 2 \end{bmatrix} \quad (1)$$

$$T_2 = \begin{bmatrix} S2 & D & E \\ 0 & 1 & 2 \end{bmatrix} \quad (2)$$

where numbers represent the relative depth of each sector with respect to the assigned root nodes (S1 and S2). The NDE can represent a sector (energy consumer) in more detail as a tree root and calculate the depth of other consumers within a sector.

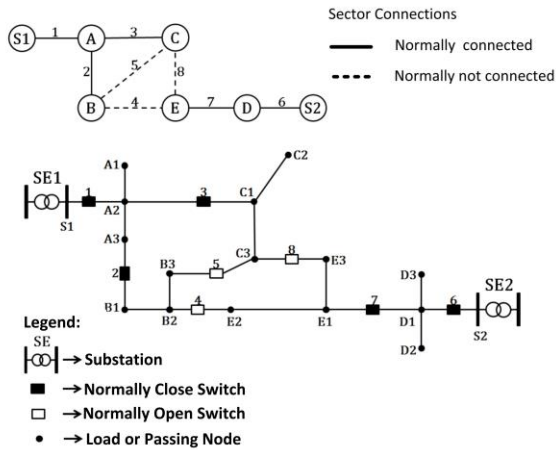


Figure 4. Graph representation of a simplified electrical distribution network

Using electric network representation by NDE graph-based, it is possible to perform manipulations in the graphs trees using pruning and insertion operators, making it easy representation of changes in the configuration of an electrical power distribution system (Delbem *et al.*, 2004). The NDE therefore brings about great efficiency for analysis of radial distribution systems.

The NCSS encompasses two modules, the network configurator and the network simulator as described at the following.

### 3.3 NCSS Configurator Module Data Structure

To enable the representation of the power system data in CIM standard, the network configurator is designed with two categories of objects: network elements and sections or conductors. The network elements belong to a class called Node that encompasses substations, transformers, buses, reclosers and load nodes. This class has a parameter to designate the element type, which in turn will define the element parameters. The sections or conductors are elements of the Edge class. This class, in addition to storing parameters of the conductor, such as impedance and length, has two connective terminals, w1 and w2, which refer to the two nodes connecting the section.

### 3.4 Data Generation in CIM Standard

The input data of the network elements as given by the user when drawing the network diagram undergo to a conversion to the CIM standard. The network connection data is generated automatically by the NCSS when the diagram elements are connected. They are converted to the CIM standard as well as undergo a structural change with the creation of a new element for node connectivity. As shown in Figure 5, the network elements (buses and switch) are connected through the ConnectivityNode object.

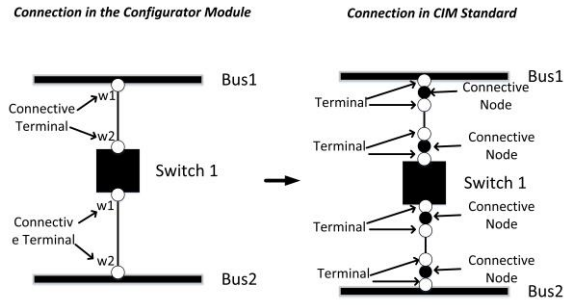


Figure 5. Connection of electrical elements

### 3.5 NCSS Simulator Module

The configurator module of the NCSS was developed for diagramming the network and exchanging of data in standard format, while the NDE-based simulator module, named MyGrid [<https://github.com/greifuc/MyGrid>], is aimed to perform at the studies in radial distribution electrical networks.

MyGrid was conceived for integrating algorithms development under the concept of interoperability for smart grids.

### 3.6 The Converter Module

Figure 6 presents the simulation environment developed to draw distribution systems whose elements (buses, reclosers, substations, load) are CIM-based.

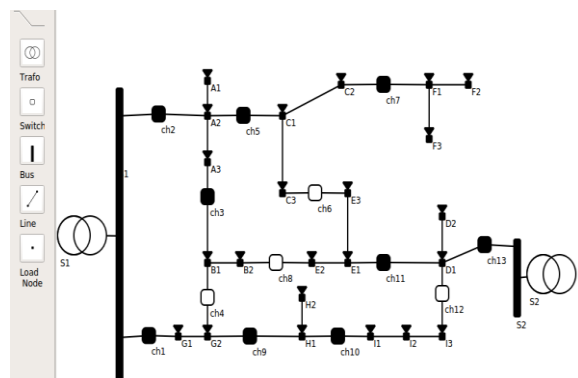


Figure 6. Test System with network in 13.8 kV

Figures 7 and 8 shows, respectively, the representation of a power network elements in CIM model and in NDE model as given by MyGrid. As it can be observed, there is a need of integration of data given by the CIM standard with that of the NDE for computer simulation of the power distribution. Therefore, a power distribution network based on CIM model is straight converted to the MyGrid representation, making it possible that any Application Programming Interface (API) development (self-healing, adaptive protection, etc.) utilize the power system information.

The NCSS save function generates a XML file containing network data written in CIM standard that

represent the distribution network. The network elements associations are given in the Unified Modeling Language (UML) diagram as shown in Figure 7. UML is a standard visual modeling language to document business processes and software architecture using several types of diagrams - use case diagrams, class, package, component, composite structure diagrams, deployments, activities, interactions and profiles.

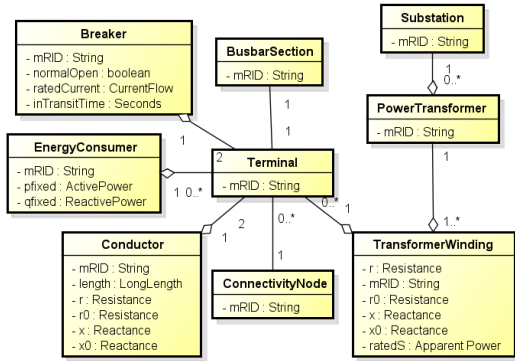


Figure 7. Network elements and their association in CIM standard

The generated CIM-XML file is the input of a converter module whose purpose is to generate the distribution network topology based on the NDE approach using MyGrid. The new network elements associations that represent the power network are given in the UML diagram as shown in Figure 8.

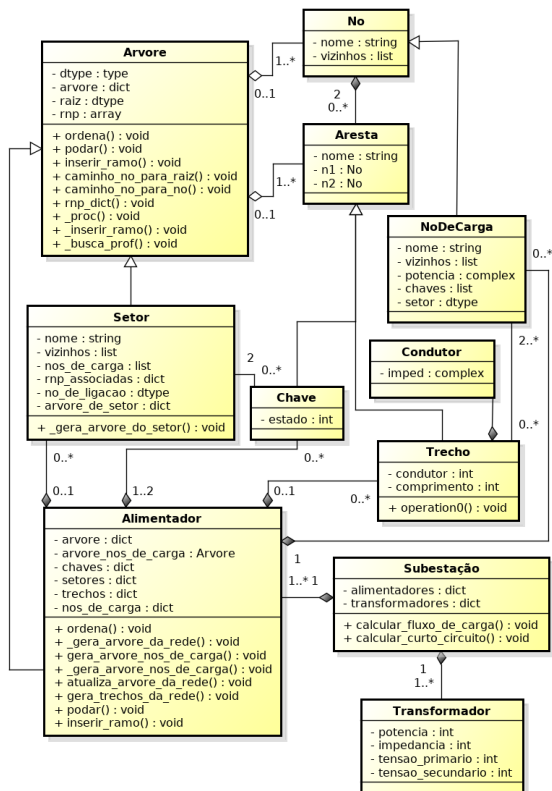


Figure 8. Network elements and their association in MyGrid

As shown in Figure 8, the user enters the data of the electrical network through the graphical interface

given by the NCSS. Then, on 'save diagram' function, the configurator generates two XML files: the first one has a description of the graphical elements that represent the electrical network drawn in the interface screen; the second XML file gives a description of the characteristics of all the elements in the CIM standard.

For the execution of the network analysis algorithms (load flow and short-circuit), the module that converts the file to the CIM standard for in memory objects associated to MyGrid API is triggered and a conversion is performed so that MyGrid objects can be used in the calculations.

The distribution test system shown in Figure 6 has its topology based on NDE algorithm. Finally, Figure 9 depicts how the converter module obtains the NDE topology of the test system from the network diagram.

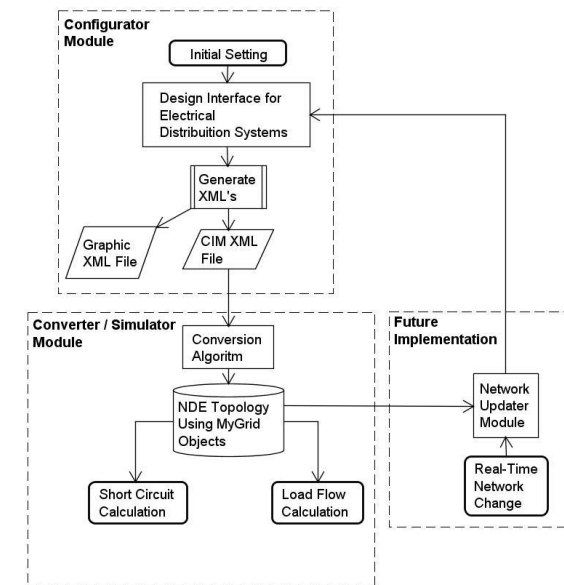


Figure 9. General software execution flowchart

From the flowchart shown in Figure 9, the configurator module and the simulator module can be decoupled / coupled from each other. This enables various simulation and information exchange modules to be incorporated. This modularity is driven mainly by the representation of the electrical networks through the CIM standard that facilitates the connection of the configurator module with systems that use the CIM as a database in its computational processes.

### 3.7 Application Example

To demonstrate the operation of the electrical network configurator and its integration with the MyGrid API, the network shown in Figure 6 was loaded in the configurator and generated an XML file in CIM standard, which contains the description of

the network elements, as shown in Figure 10. The test system has sectors of 2 km length, with same conductor configurations and structure for all sectors, which results in impedances in pu, as shown in Table 1.

```

<EnergyConsumer>
<mRID>
a1
</mRID>
<pFixed>
300000
</pFixed>
<qFixed>
100000
</qFixed>
<terminal>
<mRID>
139857422846664
</mRID>
</terminal>
<terminal>
<mRID>
</mRID>
</EnergyConsumer>
<Breaker>
<mRID>
ch1
</mRID>
<ratedCurrent>
0
</ratedCurrent>
<inTransitTime>
0
</inTransitTime>
<breakingCapacity>
0
</breakingCapacity>
<recloseSequences>
0
</recloseSequences>
</Breaker>
<Conductor>
<mRID>
ch2a2
ch2a2
</mRID>
<length>
2000
</length>
<r>
0.2391
</r>
<r0>
0.41693
</r0>
<x>
0.37895
</x>
</Conductor>

```

Figure 10. Data output in CIM standard

Table 1. Line Sequence Impedances

Positive Sequence Resistance (Ω)/ (km)	Positive Sequence Reactivity (Ω)/ (km)	Zero Sequence Resistance (Ω)/ (km)	Zero Sequence Reactivity (Ω)/ (km)
0.2391	0.37895	0.41693	1.55591

The file XML-CIM shown in Figure 10 is used as the input data to the simulator' converter to give the NDE topology of network using MyGrid objects. After that, the simulator can perform power flow and short-circuit studies. In Figure 11 the output window shows the voltage at each of the network nodes as a result of the load flow, as well as tabs with the short-circuit currents in each node of the system.

Short Circuit S2		Short Circuit S1		Voltage Levels		Section
Node		Voltage (V)		(kW)		(kvar)
1	D2	13712.03973...	300.0	100.0		
2	D1	13728.03557...	200.0	50.0		
3	I3	13467.23416...	200.0	30.0		
4	I2	13476.02802...	300.0	20.0		
5	I1	13496.62182...	200.0	20.0		
6	H2	13545.73668...	200.0	30.0		
7	H1	13554.47952...	300.0	20.0		

Short Circuit S2		Short Circuit S1		Voltage Levels	
Node		Short Circuit (pu)		Short Circuit (A)	
1	three-phase	SS pu		SS A	
2	ch13	4250.17 ∠ -57.75°		1778144.214...	
3	D1	21.15 ∠ -57.75°		8846.488629...	
4	ch11	10.6 ∠ -57.75°		4434.274849...	
5	E1	7.07 ∠ -57.75°		2958.642619...	
6	E2	5.31 ∠ -57.75°		2219.905386...	
7	D2	10.6 ∠ -57.75°		4434.274849...	

Figure 11. Output results of power flow and short-circuit

## 4 Conclusions

This paper presented an environment for power system design and simulation where the network data format complies with the CIM standard. The node-depth algorithm has been chosen for topology representation of radial power distribution systems due to their useful features and computational efficiency when dealing with power system reconfiguration. A converter module has been developed that interprets the network elements represented in CIM into a network whose topology is based on the node-depth encoding algorithm.

UML provides a visual representation for the network elements and their associations, while XML gives network data a proper structure so that computer algorithms can easily read them.

CIM standard has proven suitable for modelling data such that a developed converter module was able to build a network based on node-depth algorithm from the CIM-XML file. This suggests that CIM standard can represent an electric distribution network, providing integration and interoperability between systems in an efficient way, despite the fact it needs a converter algorithm.

The use of the proposed converter module resulted in a network model that has data written within a standard model and an efficient topology encoding. A real application comprises simulation, tests and validation of data in radial distribution systems with conventional and renewable sources and microgrids.

## Acknowledgement

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