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A Topology-Based Local Identifier Mapping Scheme for Power System Resources in Common Information Model Framework for Interoperability

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Abstract: The Common Information Model (CIM) defined in international electrotechnical commission technical committee 57 (IEC TC57) has been utilized for achieving interoperability by employing a canonical data model strategy for standardizing interfaces in the power industry. In adopting the CIM framework for data exchange, problems regarding identifiers (IDs) such as two different local IDs for the same object can occur, and local ID mapping tables are required for the object identification in advance of the data exchange. This paper proposes a new local ID mapping scheme using a topological fingerprint (TF) that represents a unique property of a power system resource. The concept of standard information, defined as common data that all systems considered for data exchange have in common, is introduced to make duplicated TFs separable. Case studies considering numerous power system resources in a distribution management system (DMS) are conducted and it can be seen from the simulation results that the proposed scheme can generate a unique TF for every resource in a system by the local ID mappings and automatically create an accurate mapping table of local IDs issued by each system differently.

Keywords: common information model; data exchange; interoperability; local ID mapping; master resource identifier; topology search



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1. Introduction

With the introduction of the smart grid concept, electrical power utilities operate a large number of systems (or applications in a system) in both transmission and distribution domains. For the efficient operation of the systems, it is expected that the need for data exchanges between the systems will be increased significantly. For example, data exchange between a transmission system operator (TSO) and a distribution system operator (DSO) has been newly required for auxiliary service procurement and balancing purposes [1,2]. Therefore, the complexity of mappings required for the interface between systems will also rise exponentially since conventional one-to-one data mapping by agreement between individual system managers should be conducted for the data exchange. Due to a lack of a standard data exchange process, a system exchanges the same data in multiple formats, and any change in the data format results in failures of data exchange. Under the smart grid environment with frequent exchange of a large amount of data, a standard semantic model is required to solve the associated interoperability problems by enabling seamless data exchange [3–7].

International electrotechnical commission (IEC) common information model (CIM) is an abstract model to express power system networks and resources, and it is defined in IEC 61970 [8] and IEC 61968 [9] for transmission and distribution system objects, respectively. CIM is maintained by unified modeling language (UML) as it represents power system resources in the form of object-oriented classes, attributes, and associations between the

classes [10]. CIM provides a powerful and flexible system integration technology with the help of agreement over the semantics of data being exchanged [11,12].

Due to the availability of a consensus standard data model, CIM has been adopted by many electrical utilities to enable the standard data exchange process, thereby accomplishing the interoperability requirements for the smart grid. The California independent system operator (CAISO) takes advantage of CIM to ensure an integrated environment of multiple systems and applications [13,14] and the European network of transmission system operators (ENTSO-E) developed a common grid model exchange specification (CGMES) based on CIM for network model exchanges to ensure interoperability between TSOs [15]. In addition, Chinese electrical power control centers (CEPCCs) have adopted CIM to exchange data between an automated voltage control system to the existing energy management system (EMS) and integrate multiple control centers through a constituted hierarchical network [16].

Some challenges regarding the problem of identifiers have been reported in applying the CIM framework as a standard integration process [16,17]. Master resource identifications (mRIDs), specified in IEC 61970-301 [8], are recommended to be used as persistent and globally unique identifiers in CIM-based data exchanges. The CIM concept of modeling authority sets (MASs) was introduced in [18] and has been applied to multiple CIM-based integration projects for the assembly and merging of power system network models [17,19,20].

Although the uniqueness of identifiers for power system resources can be achieved by the introduction of Universally Unique Identifier (UUID) and MAS concepts, the problems of boundary sets containing all boundary points necessary for a merge model remain, which requires the mapping of different mRIDs for the same power system resource to ensure that the objects with different mRIDs are confirmed to be identical. Previously, only a few mapping boundary sets were required by mutual agreement since an mRID for a power system resource is issued by a regionally divided MAS and only a few elements are in the boundary regions. It means that only a few local ID mappings are required, and it can be manually performed. Furthermore, the boundary sets that should be mapped are to be easily recognized (e.g., well-known control area tie points) due to the regional characteristics and rarely changed. However, a large number of mappings are required so that the ID mapping for each pair of the same objects becomes difficult in cases where most power system resources are included in boundary sets because two systems handle the same power system resource from different points of view. The local ID mapping problems in such cases have not been addressed in previous works.

It is important to create an accurate mapping table for fast and efficient identification of data exchanged because it can cause system malfunction due to wrong data interpretation if the mapping table for data exchange is created incorrectly. Furthermore, an autonomous local ID mapping table not affected by a database schema of each system is necessary to avoid increased costs of development and maintenance due to changes in the data for each system. To deal with this problem, this paper proposes an autonomous local ID mapping scheme for power system resources by making use of a CIM-based topology searching process. The main contribution of this paper is summarized as follows:

- The proposed scheme can create a unique feature of a power system resource by using topological characteristics;
- An accurate mapping table of different local IDs issued by individual systems can be automatically generated for fast and efficient identification of the same power system resources;
- System malfunctions due to wrong data interpretation and increased maintenance costs can be avoided;
- Data reliability is secured by accurately identifying all the resources.

This paper is organized as follows: Sections 2 and 3 describe the overview of the CIM framework for interoperability and identifier-related challenges in applying the CIM framework, respectively. Section 4 presents the proposed topology-based local ID mapping

schemes. Case studies considering various conditions are presented in Section 5, and finally, the conclusion is drawn in Section 6.

2. Overview of CIM Framework

With the deregulation of the power industry, operations of power systems under the smart grid environment require more complex computer software, causing a significant increase in the operational complexity of relevant systems. CIM has become a promising solution for meeting the information layer of interoperability requirements for the smart grid, as shown in Figure 1, by employing a canonical data model strategy for standardizing interfaces in the power industry and reducing complexity with clear consistent semantic modeling across the enterprise [21]. CIM provides the basis for a common system language for exchanging information between systems that have different ways of representing data internally [6,7]. Mapping data sources to CIM offers a much more scalable and maintainable way to manage and integrate data compared to conventional one-to-one mapping.

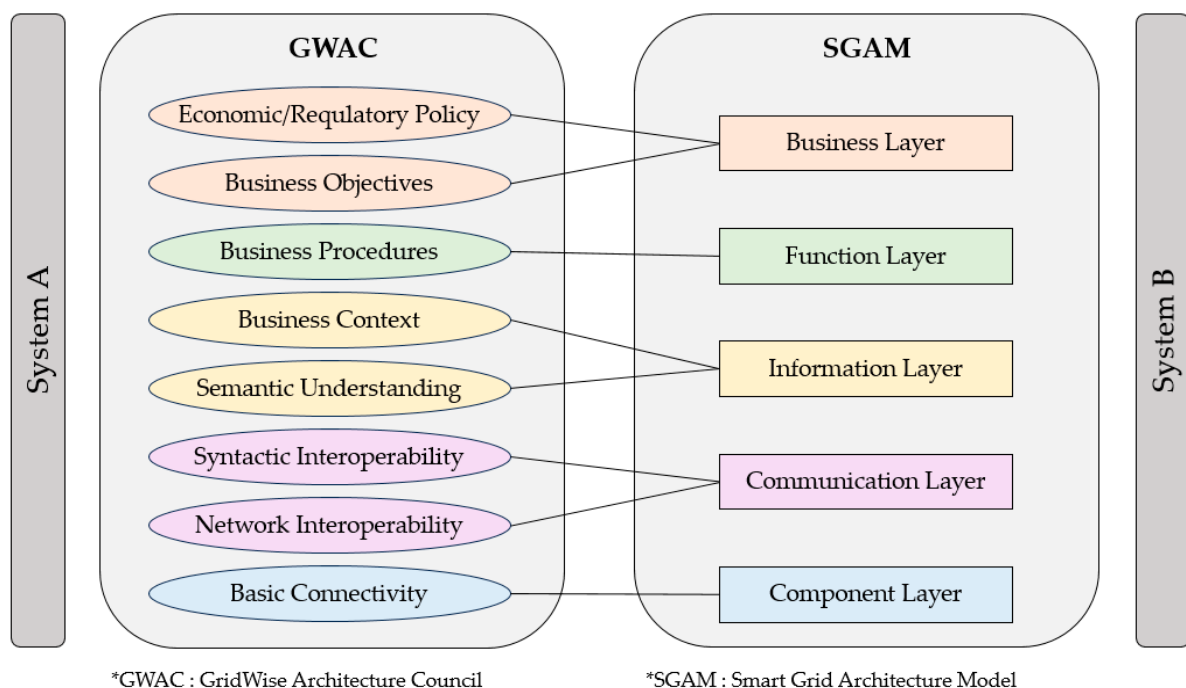


Figure 1. Interoperability categories in GridWise Architecture Council and Smart Grid Architecture Model.

The standards in IEC 61970 series define CIM as an organized framework as shown in Figure 2. The CIM framework includes a semantic model expressed in UML, and profiles are utilized for specifying a subset of the CIM classes and attributes for a specific context at a specific system interface [22]. Furthermore, it specifies the implementation syntax of instance data for understanding data structure in messages exchanged and uses extensible markup language (XML) and resource description framework (RDF) to create serialized files and messages.

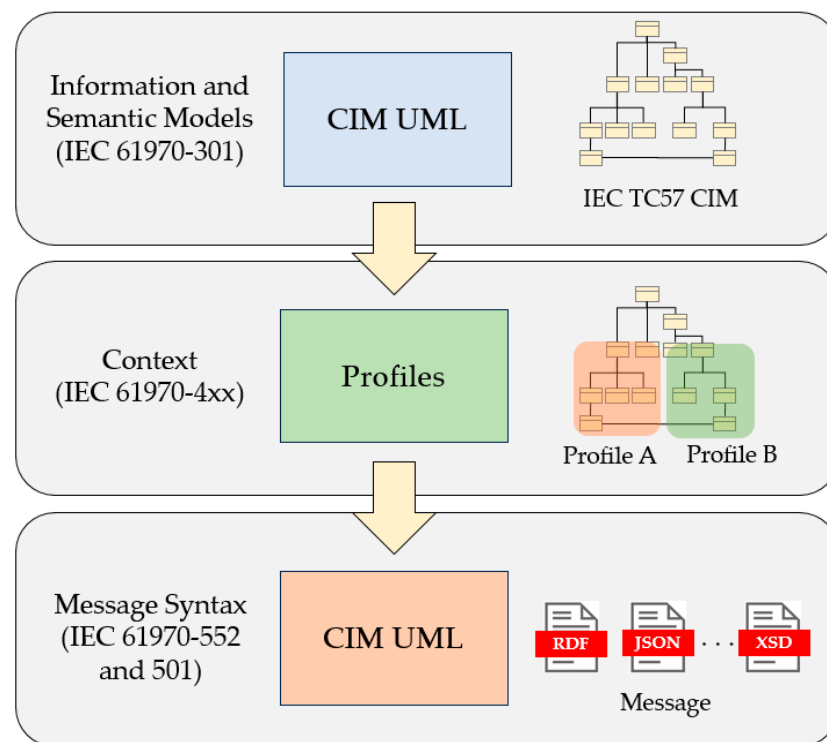


Figure 2. CIM three-layered architecture.

3. Identifier-Related Challenges

Resource description framework identifier (rdfID) is specified in IEC 61970-552 to ensure that every object in the CIM XML message file has a unique identifier so that all the objects realize their relationships to other objects, such as association and aggregation in the message file [17,23]. The concept of mRID is recommended to be used for identifying a unique name for a resource, and the mRID is mapped to rdfID for CIM XML data files in RDF syntax. In this section, two main problems regarding identifiers are described in detail.

3.1. Global Uniqueness of Identifier

The problem of duplicated IDs, representing the same IDs for different objects, can occur in merging two or more CIM XML message files, although rdfIDs in a single XML message are distinguishable. The concept of MAS can be applied to avoid the duplication of IDs [16,20]. As indicated in Figure 3, two types of regionally divided MASs are defined; (1) regional sets containing no objects that reference objects in another regional set, and (2) boundary sets containing all objects that have relationships with objects in different regional sets. Each MAS can issue mRIDs for power system resources in its territory, meaning that most power system resources except for boundary ones have the dedicated authority for managing their mRIDs. The utilization of a universally unique identifier (UUID) algorithm is strongly recommended for the creation of the mRID of an object since it can ensure the global uniqueness of the identifier [8,19]. With the help of MAS, mRIDs will never be duplicated by another MAS as long as the mRIDs for all power system resources are globally registered and managed by one and only one authority. That is, a single institution or system assigns or manages object IDs of all power systems using the UUID algorithm and MAS.

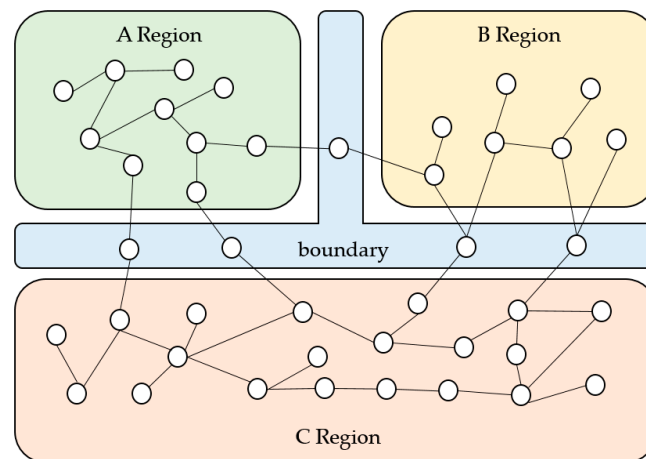


Figure 3. Three regional sets separated by three boundary sets.

3.2. Identification of an Object with Different Local IDs

One of the challenges in adopting the CIM framework for seamless data exchanges is the identification of an object with different local IDs (or mRIDs). When an object is instantiated in two different systems, two different local IDs are issued by each system. Suppose that a system wants to obtain data on the same object from another system. To ensure that the objects with different local IDs are confirmed to be identical, the local IDs should be mapped in advance to the data exchange.

Figure 4 shows an example of data exchange between two different systems. Systems A and B in the figure represent the distribution management system (DMS) and customer information system (CIS), respectively. It is assumed that data on switches need to be exchanged between systems A and B since both systems have the data on switches for the internal applications of each system. As shown in Figure 4, the local IDs represented by ‘switch_id’ for switches are different; therefore, local ID mapping is required to identify the origin of data acquired by another system. Data both systems have in common such as ‘pole_no’ in Figure 4 can be used for the local ID mapping. For instance, 100 of ‘switch_id’ in the DMS database can be mapped to 200 of ‘switch_id’ in the CIS database since both local IDs have the same pole number which is 123A123. Similarly, the switches with local IDs 101 and 102 in the DMS can be matched to ones with local IDs 201 and 202 in the CIS, respectively. However, the mapping scheme that uses common data cannot be applied if there is a human error in the common data such as typos and missing or duplicated data. Furthermore, it is hard to guarantee that the common data can be always available in all cases with the necessity of local ID mapping.

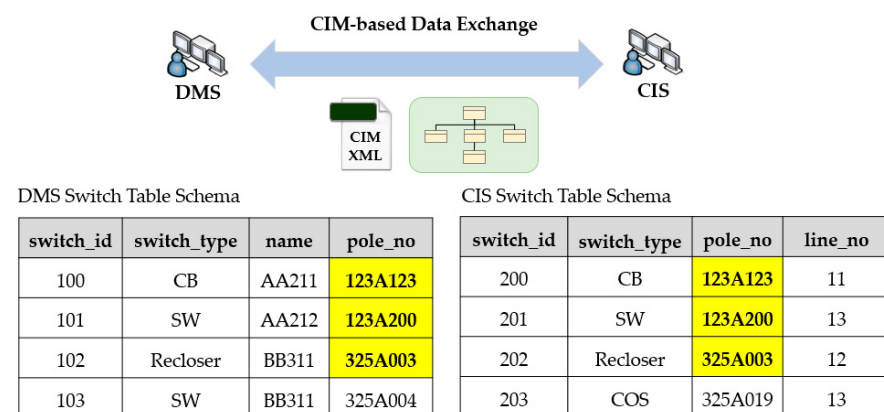


Figure 4. An example of data exchange between DMS and CIS.

The concept of regional MAS cannot be utilized for the mapping of local IDs where several authorities can be involved in the same region, as in the example depicted in Figure 4. In addition, one and only one authority issuing mRIDs is not applicable to legacy systems that have numerous local IDs already issued. In cases where data exchange between legacy systems is required, it could be time-consuming to perform the local ID mapping for numerous objects. Table 1 summarizes the identifier-related challenges described in Section 3.

Table 1. Summary of identifier-related challenges.

Challenges	Global Uniqueness of IDs	Mapping of Different Local IDs
Description	Duplicated IDs for different power system resources	Different local IDs for the same power system resource
Solution	Introduction of UUID managed by a single authority	Introduction of a fast and efficient local ID mapping scheme

4. Proposed Local ID Mapping Scheme

To tackle the problem of local ID mapping, this paper presents a topology-based local ID mapping scheme for power system resources in the CIM framework. Topology searches for graph structures are conducted, and the concept of standard information is introduced to overcome topological limitations.

4.1. Topology-Based Local ID Mapping Algorithm

The proposed local ID mapping scheme creates a topological fingerprint (TF) for an object that can represent its uniqueness. If TFs for objects with different local IDs are identical, then it can be concluded that the objects are the same.

Figure 5 presents the flowchart for creating TFs for power system resources in a system and the resulting local ID–TF mapping table. Firstly, the algorithm loads all power system resources from the database of a system and creates objects for the resources using CIM. With the help of the CIM concept, all the objects can be considered from a standard point of view in terms of semantics so that the objects with different data semantics are unified. Then, a graph structure with node(i) as the root and edges is created. A node can be any type of conducting equipment (CEQ) such as a switch and line segment, whereas an edge is composed of terminals (Ts) and a connectivity node (CN) since the CIM-based topology can be represented by the node-breaker connectivity representation such as CEQ-T-CN-T-CEQ as illustrated in Figure 6. For the graph created, sorting is conducted and it is noted that a single common sorting rule should be applied to every graph because sorted graphs using different rules for the same topology cannot result in the same TF. In this paper, the following instructions are utilized for the common sorting rule.

- A node with more child nodes is sorted to the left;
- A node with greater depth is sorted to the left.

Once a graph structure is generated and sorted by the common rule, a TF(i) for a node(i), defined by a serialized string containing topological information for a node(i), is created. The TF is determined by the depth-first graph search (DFS) and the number of child nodes. It is worth mentioning that a common search rule, DFS used in this paper, should be applied to every graph as in the sorting rule. The number of child nodes for a node is used as a part of the TF and the whole TF is serialized as a combination of integer values according to the search order. The derived TF represents a distinguishable graph structure (fingerprint) for an arbitrary node (object or equipment). Figure 7 shows an example of the TF generation for a sample graph structure. Once a graph for node(i) is sorted by the common rule, it calculates the number of child nodes of node(i) as '1' since node(i) is root one and stores the value at the TF. Then, it goes to the next node (A) following the DFS algorithm, and '3' is calculated and stored because node A has three child nodes.

Similarly, other integer values are calculated and stored at TF for every search until the search is ended.

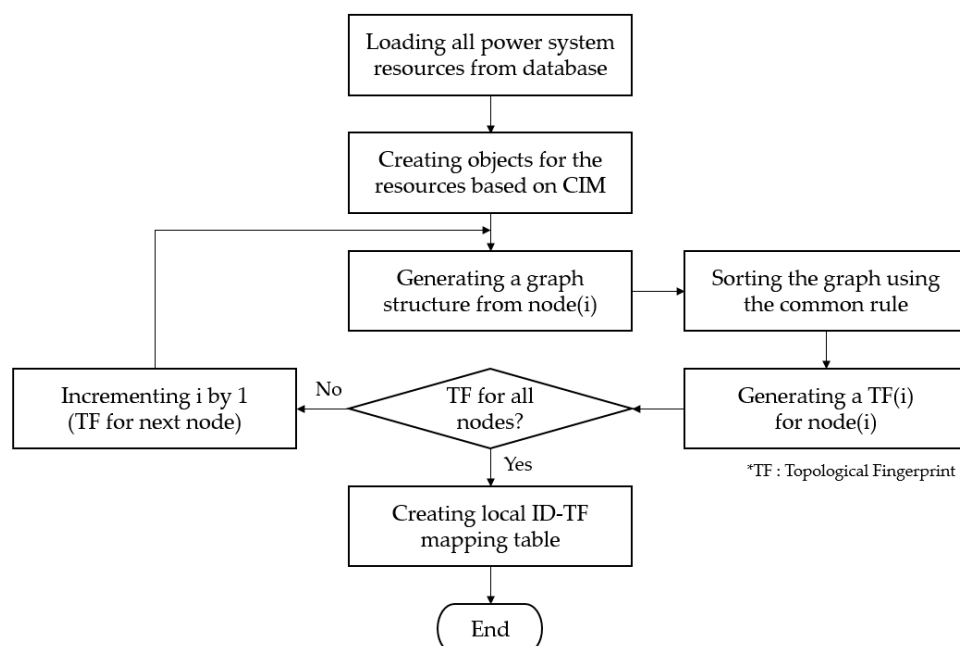


Figure 5. Flowchart for creating local ID-TF mapping table.

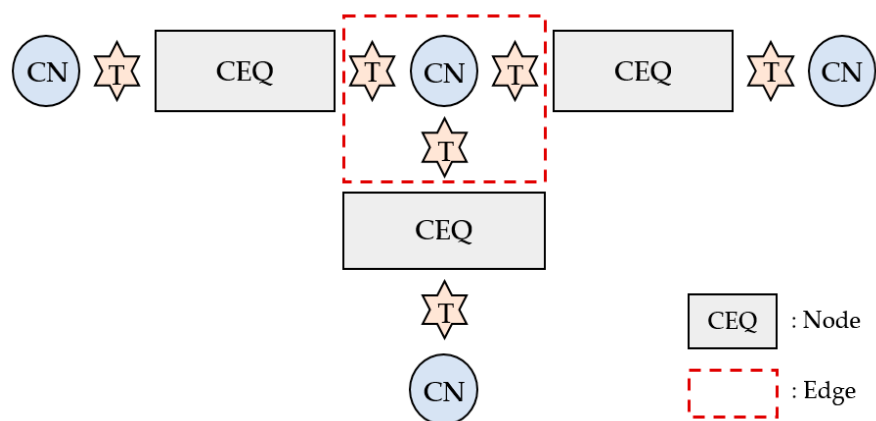


Figure 6. Connectivity model in CIM and a graph structure representation.

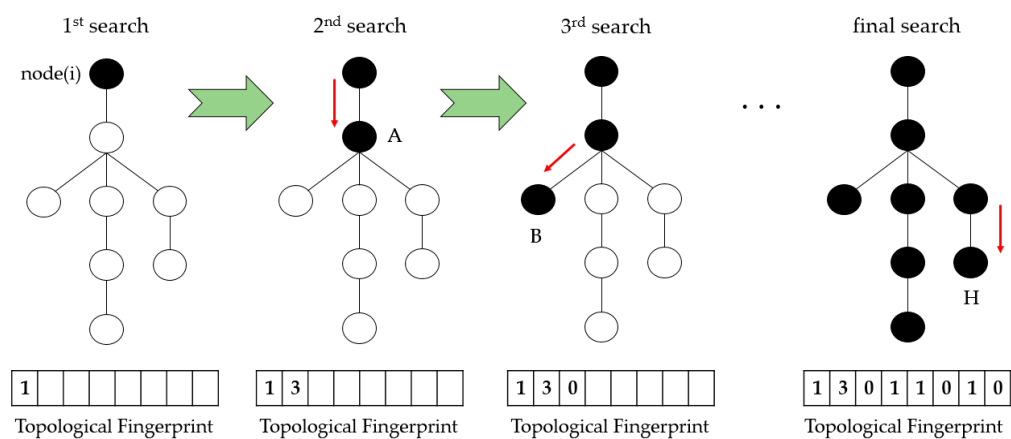


Figure 7. An example of the TF generation for a sample graph structure.

The algorithm in Figure 5 iterates until TFs are derived for all nodes in a graph. Then, a mapping table with local ID-TF pairs for all the objects is created. The algorithm can be applied to another system, resulting in a new mapping table. Different local IDs for the same object can be mapped by selecting IDs with the same TF. Figure 8 indicates a case with different sorting rules applied to the same graph structure. Although the graph has the same topology, different TFs are derived. Therefore, it should be ensured that the common rule is applied to a graph when the graph is sorted.

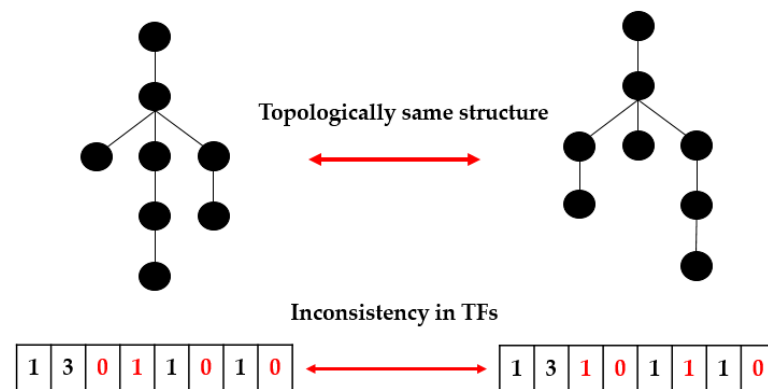


Figure 8. A case with different TFs for the same topological structure.

4.2. Utilization of Standard Information

The topology-based local ID mapping scheme has a limitation in some cases where two different power system resources have the same topological characteristic. Figure 9 illustrates a case with the same TF for different objects. When graphs are created and sorted by the common rule, TFs for nodes 1 and 2 are identical since the graphs for nodes 1 and 2 are topologically symmetrical. It causes duplicated mappings to local IDs issued by another system, which leads to failed accurate object identification in data exchange. To deal with these cases, the utilization of standard information is introduced in the proposed scheme.

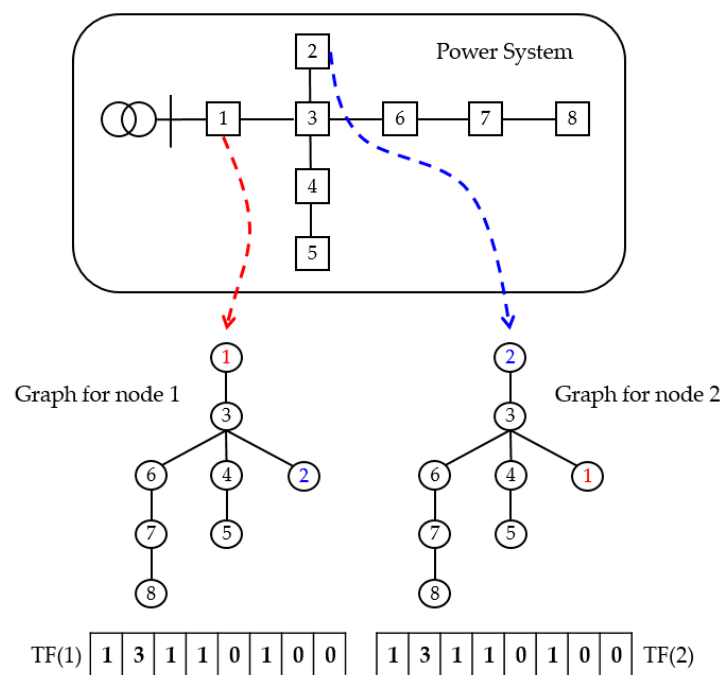


Figure 9. A case with the same TFs for different objects.

Standard information is defined as common data that all systems considered for data exchange have in common. Since standard information can provide additional distinguishable data, two objects with the same TF can be also separated. For instance, the data of ‘switch_type’ shown in Figure 4 can be used as standard information for local ID mapping between objects in DMS and CIS. If a local ID for an object has its own TF and available standard data, it enables more accurate mapping to another local ID for the same object. Therefore, standard information such as the type of switch should be included in the local ID-TF mapping table. Figure 10 shows an example of a local ID mapping table derived by using the proposed scheme.

Local ID-TF mapping table for system A			Local ID-TF mapping table for system B		
local_id	switch_type	topological_fingerprint	local_id	switch_type	topological_fingerprint
111	CB	13110100	AAA	CB	13110100
222	SW	41101000	BBB	SW	41101000
...	...	...	...	...	...
999	SW	11311000	FFF	SW	11311000

Local ID mapping table between system A and B		
local_id_A	topological_fingerprint	local_id_B
111	13110100	AAA
222	41101000	BBB
...	...	...
999	11311000	FFF

Figure 10. An example of a local ID mapping table.

5. Case Studies

5.1. Case Description

To verify the performance of the proposed local ID mapping scheme, all objects in the modified database of DMS managing Korean distribution networks are considered. Since numerous power system resources exist in a distribution system, the DMS can be considered a good system to verify the performance of the proposed scheme. Figure 11 shows the layout of the distribution system considered for case studies, and it consists of 40 substations, 11,457 switches, and 231 distributed generations (DGs). The distribution system used for the case study is the one operating the actual Korean distribution system, and it is chosen to take advantage of the DMS for verifying the performance of the proposed scheme. Table 2 indicates a mapping table of power system resources and classes defined in IEC TC57 CIM to create objects for the resources based on CIM. Power system resources in the DMS database such as lines, subtypes of switches, and DGs are transformed into objects based on CIM according to the mapping table shown in Table 2.

A new DMS database is created by duplicating the original DMS database to generate two different IDs for the same objects and the corresponding local ID mapping table. The local IDs for power system resources in the duplicated database are randomly issued, which makes the local IDs in the duplicated database completely different from the local IDs in the original database.

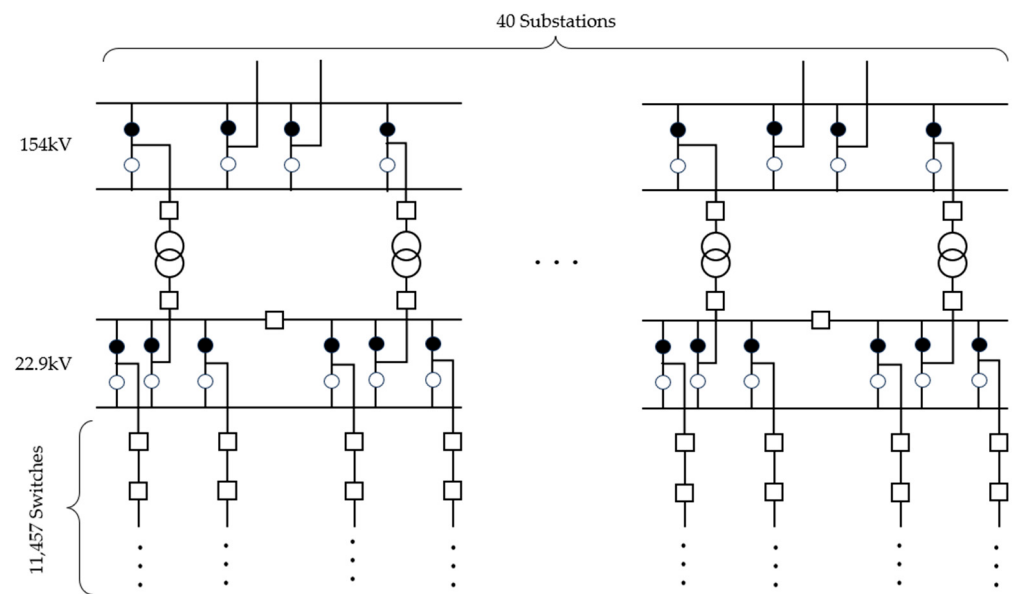


Figure 11. Layout of the distribution system considered for case studies.

Table 2. Mapping table of power system resources and classes in CIM.

Type of Power System Resources	Name of Class in CIM
Line Section	ACLineSegment
Internal Switch in PAD Switchgear	Switch
Automatic Switch	Switch
Manual Switch	Switch
Recloser	Recloser
Cut-Out-Switch	Fuse
Circuit Breaker	Breaker
...	...
Distributed Generation	PowerElectronicsConnection
Junction	Junction
Load	EnergyConsumer

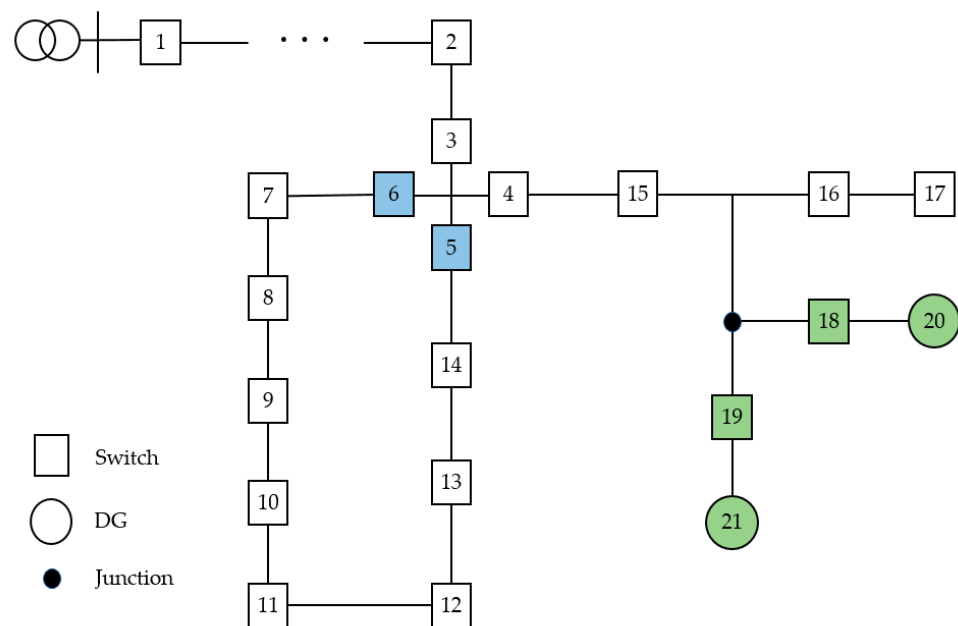
5.2. Results and Discussions

Table 3 shows the result of generating TFs for all the switches considered for case studies by using the proposed scheme, and the last 12 integers of an entire TF string are shown in the figure. It can be seen from the result that TFs, represented as serialization of integers, are created for each switch in both the DMS and the duplicated DMS according to the algorithm provided in Figure 5. As we can see in all strings in Table 3, the last integer is calculated as '0' since there is no more child node. It is noted that some switches have a 'count' value of 2 or more, which means that there are other switches with the same TF in the same system. The duplication of TF for different objects occurs due to topological symmetry. The pairs of DG20-DG21 and SW18-SW19 in Figure 12 have the same TFs since each pair is connected symmetrically from the junction. Similarly, the connectivity of switches between SW5 and SW6 causes the same TFs for SW5 and SW6. For switches with the same TF, standard information described in Section 4.2 should be applied to make the switches distinguishable from each other.

Table 4 shows the standard information used for solving the TF duplication problem that occurs in the case study and descriptions of each standard information. Data that both systems have in common such as the circuit number of a PAD internal switch (e.g., 1 for local ID of 3) and the pole number of a switch (e.g., 2173G791 for local ID of 18) are selected as the standard information. Table 5 indicates new TFs generated by applying the standard information.

Table 3. Result of TFs generated in the DMS and duplicated DMS.

DMS			Duplicated DMS		
Local ID	TF	Count	Local ID	TF	Count
1	111333210010	2	1	111333210010	2
2	111312342100	1	2	111333221000	1
3	412333321000	1	3	111333211100	2
4	113110101100	4	4	113112342100	1
5	413110101100	3	5	112112332100	1
6	413110101100	3	6	111333211100	2
7	111333211100	2	7	113113342100	1
8	311111131100	1	8	111333211200	1
...	...	...	...	...	...
5000	413010101100	1	5000	111333111000	1
5001	111333111010	1	5001	111333210010	2
5002	413110101100	3	5002	111223112100	2
...	...	...	...	...	...
11455	111333111000	1	11455	111333111010	1
11456	111333210010	2	11456	111333112100	1
11457	111333211100	2	11457	111223112100	2

**Figure 12.** A part of the network for case study causing TP duplication.**Table 4.** Standard information and description of switches.

Local ID	Standard Information	Description
3	1	Circuit no. of a PAD internal switch
4	2	Circuit no. of a PAD internal switch
5	3	Circuit no. of a PAD internal switch
6	4	Circuit no. of a PAD internal switch
18	2173G791	Pole no. of a switch
19	2173G792	Pole no. of a switch
20	2173G791	Pole no. of a switch connected to DG
21	2173G792	Pole no. of a switch connected to DG

Table 5. New TFs applying the standard information.

Original DMS		
Local ID	TF without Standard Information	TF with Standard Information
1	111333210010	111333210010-1474F971
2	111312342100	111312342100
3	412333321000	412333321000
4	113110101100	113110101100-2173G691
5	413110101100	413110101100-1974F352
6	413110101100	413110101100-2273C982
7	111333211100	111333211100-2075R782
8	311111131100	311111131100
...	...	...
5000	413010101100	413010101100
5001	111333111010	111333111010
5002	413110101100	413110101100-2075S263
...	...	...
11455	111333111000	111333111000
11456	111333210010	111333210010-2075Q801
11457	111333211100	111333211100-2074B621

Table 6 shows the result of creating TFs for all the switches in both systems according to the application of the standard information. The TFs for some switches in both systems are newly created by adding the standard information to the original serialization result. It is noted that the count values are changed to '1' for all the switches after applying the standard information to some switches. This means that there are no duplicated TFs in a system so that every switch can have its dedicated property that is distinguishable from other switches in the system. A mapping table can be created by matching local IDs with the same TF. For example, local IDs '2' and '11456' in the DMS are mapped to local IDs '4' and '1' in the duplicated DMS, respectively. If mappings of local IDs for the last object in a system are performed, then a complete local ID mapping table can be derived.

Table 6. Result of TFs generated by using standard information.

DMS				Duplicated DMS			
Local ID	TF	Standard Information	Count	Local ID	TF	Standard Information	Count
1	111333210010	1474F971	1	1	111333210010	2075Q801	1
2	111312342100	-	1	2	111333221000	-	1
3	412333321000	-	1	3	111333211100	2075R782	1
4	113110101100	2173G691	1	4	113112342100	-	1
5	413110101100	1974F352	1	5	112112332100	-	1
6	413110101100	2273C982	1	6	111333211100	2074B621	1
7	111333211100	2075R782	1	7	113113342100	-	1
8	311111131100	-	1	8	111333211200	-	1
...	...	...	...	...	...	...	...
5000	413010101100	-	1	5000	111333111000	-	1
5001	111333111010	-	1	5001	111333210010	1474F971	1
5002	413110101100	2075S263	1	5002	111223112100	2073H022	1
...	...	...	...	...	...	...	...
11455	111333111000	-	1	11455	111333111010	-	1
11456	111333210010	2075Q801	1	11456	111333112100	-	1
11457	111333211100	2074B621	1	11457	111223112100	2073H872	1

Figure 13 shows the number of duplicated TFs in the test system according to the application of the standard information. It is shown in the figure that the number of

duplicate TFs decreases as the depth, defined as the level of a graph illustrated in Figure 14, increases. This means that more integers obtained by searched nodes result in more distinguishable characteristics of an object regardless of the application of the standard information. Furthermore, it is noted that there are some TFs that are not separable from other TFs at a certain level of depth. However, all the TFs turn into distinguishable ones so that the local ID mapping table can be generated when the depth of search goes to the level of 14 with the application of the standard information. In other words, not all integers in a TF need to be used to indicate the uniqueness of an object. For example, it is possible to create a unique TF for every object and generate a complete local ID mapping table even using only the integer string obtained by searching up to a depth of 14. This enables a reduction in memory space for storing TF strings and the time required for creating TFs even for numerous objects in a large and complex distribution system.

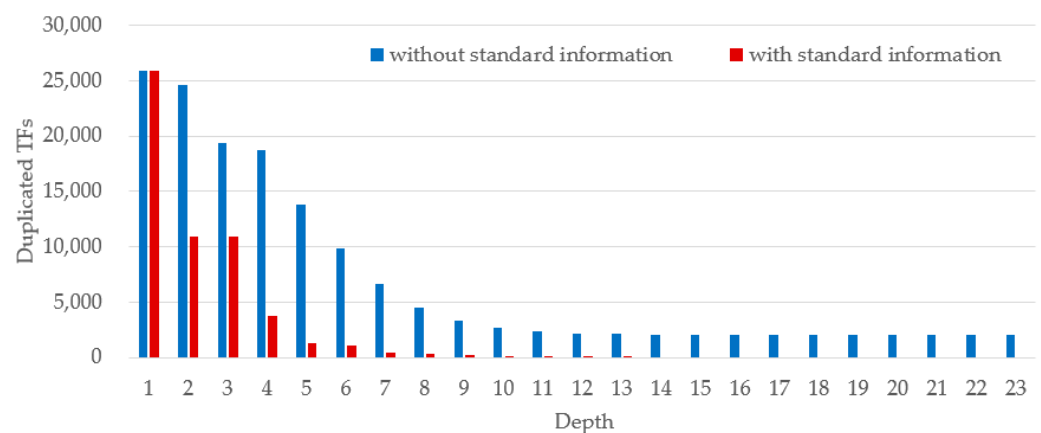


Figure 13. Duplicated TFs in the test system according to the standard information.

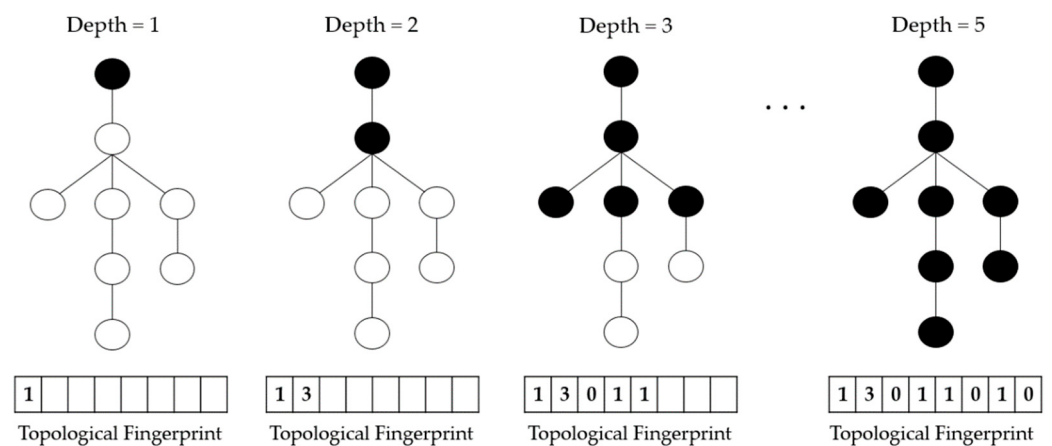


Figure 14. Concept of the depth in a TF for a graph.

6. Conclusions

This paper presents a new local ID mapping scheme using a topology analysis of power system resources in the CIM framework. A TF representing a unique topological characteristic for a power system resource is generated by applying a common search rule for each sorted graph that is created by a common sorting rule. In addition, the concept of standard information is introduced to make duplicated TFs distinguishable from each other. For the case study considering numerous power system resources in a DMS, the proposed scheme can create a unique TF for every resource in a system. In addition, it can automatically generate an accurate mapping table of local IDs issued by each system differently. The proposed scheme can be expected to be utilized for seamless data exchange between different systems. Furthermore, it can significantly reduce the complexity of data

exchange and the time required for the manual creation of a local ID mapping table. With the help of the proposed scheme, system malfunctions due to wrong data interpretation can be avoided and data reliability can be significantly improved through an efficient identification of the same power system resources. The proposed scheme can be applied to systems with sufficient topological information. Further research will be conducted for data exchange between different systems that do not have topological information.

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