INVESTIGATION OF DATA EXCHANGE REQUIREMENTS FOR COOPERATIVE GRID PLANNING AND OPERATION

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Abstract - IEC 61970 and 61968 together referred as Common Information Model (CIM), are proposed to facilitate integration of EMS applications with proprietary data formats and information exchange between control centers. To use Information and Communication Technology (ICT) systems in an optimized manner, it is necessary to partition the potentially voluminous data into subsets given their sources, expected exchange frequency, and subscribing applications. In response to these requirements, the concept of CIM profiles is brought up by CIMug. In this paper, functions illustrating the dependency between exchange data volume and basic grid parameters for each data profile are presented. A *CIM/XML/RDF* file for a commonly available 40 bus test system modeled according to CIM 13 together with examples provided by standards are used as references. The method is validated by estimating the *CIM/XML/RDF* file sizes of similarly available 100 bus and 60 bus test systems. The contribution of this paper is that it provides ICT system designers with a means to estimate the corresponding requirements for various CIM based data exchange scenarios. The estimations are performed based on commonly known grid parameters such as number of buses, branches, generators, transformers and loads.

Keywords - Grid Operation, Grid Planning, Information Exchange, Data Volume, CIM, XML

1 INTRODUCTION

ELECTRIC power networks are among the critical infrastructures in modern society. Monitoring and control of such grids in order to ensure reliable power delivery are highly dependent on sophisticated Information and Communication Technology (ICT) systems. Most of the recent outages in power systems happened after the ICT systems stop functioning. A typical example is the 2003 great north eastern blackout in US and Canada. The cause was ultimately traced back to the inadequate grid information and situation awareness brought by the failures of some power system supervision applications [1].

In an interconnected power grid, the synchronous system is usually managed by several independent grid utilities. Regardless of organizational settings, control of such an interconnected system becomes a shared responsibility which triggers needs to exchange data between systems or applications that are built upon proprietary data formats. Until recently, these cooperative operation activities are performed based on external equivalent models of interconnected neighbouring networks where the grid details are excluded. This is due to the insufficiency of conventional ICT systems that they are not capable to handle huge amount of data collected from geographically despread locations in a timely and accurate manner. Thanks to the advance in modern ICT systems which brings in possibility for grid utilities to take actions based on detailed information from their neighbouring grid. In response to this need, IEC 61970 and 61968, which are commonly referred as Common Information Model (CIM), are proposed to facilitate integration of EMS applications with proprietary data formats and information exchange between control centers [2]. CIM provides an abstract modeling frame, based on which components that constitute a power grid can be described. The concept of CIM profile is brought up by CIMug to limit the size of the transferred *CIM/XML/RDF* payloads [3]. According to system vendor architecture specifications proposed by IEC, the potentially voluminous data can be partitioned into subsets given different sources, expected exchange frequency and subscribers.

1.1 Purpose

The contribution of this paper is that it provides a means to estimate the requirements on the supporting ICT infrastructure for various *CIM/XML/RDF* based data exchange scenarios. This estimation is performed based on common knowledge about grid, such as size of the network and execution frequency of certain applications.

1.2 Paper outline

The rest of the paper is structured as follows: Section 2 presents a state of art survey of global implementations of CIM based information exchange. Section 3 tackles information modeling within power industry in general, afterwards briefly introduces CIM standards and the concept of CIM profile. Section 4 describes process of exchanging grid information when *CIM/XML/RDF* data format is used. The research methodology and outcomes are presented and discussed in Section 5. The proposed method is validated in Section 6 and the paper is concluded in Section 7.

2 RELATED WORK

On both sides of the Atlantic, efforts are being made to extend the CIM common semantic model and to investigate integration into a wide variety of power systems applications.

The development of the CIM standard at US was originally initiated by Electric Power Research Institute (EPRI) with the aim of defining data access semantics for component interfaces in control centers [4]. It has since been incorporated into the IEC 61970 and IEC 61968 standards discussed here. Recent activities supported by EPRI include projects aiming to extend the CIM to support exchange of dynamic power system models for dynamic assessment and planning purposes. This effort supports the NIST Smart Grid interoperability objectives. Work done over 2008 to 2009 on standardizing dynamic model exchange between simulation and EMS applications includes the addition of new classes and attributes to model dynamic characteristics and system parameters, metamodels to specify interconnectivity of dynamic models and associations to equipment in the static models as well as an additional profile which provides a Dynamic Profile Model Group (DPMG) that specifies the dynamic case file for CIM exchange. The DPMG includes the *Equipment Model*, *Topology* and *State Variable* profiles [5]. Related work has focused on model exchange between planning and operations [6], [7] which aim to extend CIM to facilitate exchange of information models such as short-circuit, steady state and dynamic models between planning applications and simulators, operations, EMS, protection and other planning applications. The ongoing development of the CIM and the various extensions place requirements on the methods used for CIM exchange, one such effort is an investigation into the use of data compression such as ZIP for reducing the data volume that needs to be shared between applications [8].

ENTSO is a cooperative organization between TSOs in continental Europe. It is merged by former ETSO which is in charge of electricity market bidding and clearing together with former UCTE that is the coordinator of grid operation. In ENTSO, a typical application that is performed upon CIM based data exchange is Day Ahead Congestion Forecast (DAFC). In DAFC, the production plans coming from electricity biding process for the next day are validated against operation constraints regarding power flow on tie-lines. It comprises a large number of state estimation and power flow calculations that are performed in a hierarchical manner both with single TSO and control block territories. The grid models, relevant state variables and solutions are exchanged between utilities via CIM [9]. The French EDF Group has made a significant effort in incorporating CIM into the automation of various business processes using CIM-based model driver integration. The successes and pitfalls of this integration work are detailed in [10], [11].

3 COMMON INFORMATION MODEL

3.1 Information modeling for power industry

With the ambition to ensure reliable and cost-effective power deliveries, many advanced applications serving for various grid planning and operation purposes are introduced to power industry. During recent decades, the structure of the ICT systems is becoming complex with the involvement of different vendors. Consequently, the maintenance, modification and expansion of such a system are becoming tedious and resource-consuming. To reduce the workload, it is necessary to come up with application-neutral and vendor independent ways of representing data. A unified representation of a physical electric power system could provide an integrated simulation and analysis environment. The applications built upon this common data structure could be integrated and updated with relatively low costs. Moreover, application software development could be facilitated by applying Application Programming Interface (API) [12], [13].

3.2 CIM/XML/RDF

CIM is defined as an abstract model that represents possible objects in an electric utility enterprise typically involved in power system market and operation [2]. By providing a standard way of representing power system resources as object classes and attributes along with their relationships, CIM facilitates the integration of EMS applications developed by different vendors. Object oriented modeling techniques are applied for CIM definition. Specifically, Unified Modeling Language (UML) class diagrams are adopted as a method of visually representing object hierarchies [14]. The eXtensible Markup Language (XML) combined with Resource Description Framework (RDF) provides a file format capable of storing the extended data. By definition, XML is a meta-language that allows the user to design their own mark-up language to describe the structure of data, however, the link between two elements that are not parent or child cannot be denoted by a single XML document. Thus, the RDF is used to provide a framework for data in an XML format by allowing relationships to be defined between XML nodes [15]. The XML syntax uses tags to denote elements. Each element is either expressed as an open and closed tag containing data as:

$$< tag > \ldots contained\, data \ldots < /tag >$$

The attributes of an entry can be expressed in a form of:

$$\begin{gathered} < tag\, AttributeOne = \\ ''Something'', AttributeTwo = \\ ''SomethingElse''/ > \end{gathered}$$

An application interpreting XML data must be given knowledge of the syntax and semantics, otherwise there is no possibility to make the interpretation. This requires the tag syntax and semantics of the XML to be expressed as a schema which provides constraints on the structure and contents of an XML document. The XML schema defines elements and attributes that can appear in a document, which elements are child elements, the number of a lower child element for each element type, whether an element can include text, the data types for elements and attributes, whether their values are fixed and if they have default values. Only with a XML document there is no way to denote a link between two elements other than the relationship of *Generalization*. RDF is the language used for expressing the metadata that machines can process simply. RDF is expressed as a special kind of XML document. It is used to provide a framework for data in an XML format by allowing relationships to be defined between XML nodes. Each element can be assigned with a unique ID attribute under the RDF namespace. Adding a resource attribute to an element allows references to be made between elements by having its value refer to another elements ID. Furthermore, while RDF provides a means of expressing simple statements about the relationship between resources, it does not define the vocabulary of the statements. Therefore, RDF schema is introduced to enable interpretation. The RDF schema is a specification language that describes resources and their properties, including how one resource is related to the other, as this information is used in an application specific schema [15]. The above text describes how an object oriented design, or similarly, a CIM class structure can be mapped to CIM/RDF. Given basic knowledge above, an example of how the *CIM/XML/RDF* files are constructed with a purpose to help understanding the conversion. Below is a typical grid component: AC transmission line that is described in *CIM/XML/RDF* text format:

$$
\begin{gathered}
< cim : ACLineSegmentrdf : ID = "\_XX" > \\
< cim : Conductor.gch > 0 < /cim : \\
Conductor.gch > \\
< cim : Conductor.bch > .0004256 < /cim : \\
Conductor.bch > \\
< cim : Conductor.r > 4.973 < /cim : \\
Conductor.r > \\
< cim : Conductor.x > 40.542 < /cim : \\
Conductor.x > \\
< cim : Conductor.length > 0 < /cim : \\
Conductor.length > \\
< cim : IdentifiedObject.name > XXXXX < \\
/cim : IdentifiedObject.name > \\
< cim : IdentifiedObject.localName > XXXX < \\
/cim : IdentifiedObject.localName > \\
< cim : ConductingEquipment.BaseVoltage \\
rdf : resource = "\#\_XXX"/ > \\
< cim : \\
Equipment.MemberOf\_EquipmentContainer \\
rdf : resource = "\#\_XXXXXX"/ > \\
< /cim : ACLineSegment >
\end{gathered}
$$

The outer element represents the modeling target which is *ACLineSegment*. The inner elements represent its corresponding property values which are the conductance, sucseptance, resistances and reactance. A relationship to another object *ConductingEquipment.BaseVoltage* is included as well. The expression of the relationships also has fixed rules. For example the "rdf:resource" is used to identify the reference object and always starts with a non-numeric character as in the example as "_". The "rdf:resource" for reference objects always starts with a "#".

3.3 CIM profiles

There has been work to modularize the potentially voluminous data into subsets aiming at limiting the size of transfer of *CIM/XML/RDF* payloads. In correspondence to these requirements, the concept of CIM profiles is proposed [3]. In this paper, effort is put on providing functions illustrating the dependency between the exchanged data volume and major grid parameters. Network analysis for off-line applications is typically carried out with what is known as bus-branch model where all the zero impedance switching devices are eliminated to form logical buses, and load, generation and regulation parameters have been selected for a single point in time. According to [3], the datasets which are required for system planning and operation can be categorized into different CIM profiles as:

- *Equipment Model*
- *Connectivity*
- *Measurement Specification*
- *Schedule*
- *Status Measurement Set*
- *Analog Measurement Set*
- *Topology*
- *State Variables*

The planning and operation applications beyond the application or utility boundaries are realized by exchanging data sets composed by objects belonging to different profiles according to vendor specification suggested by IEC. Practically, there is no need to update the first four data profiles frequently since the information seldom changes comparing to other profiles. Hereby, they are commonly referred as static model. Figure. 1 below illustrates the data exchange which is categorized according to CIM profile for power flow analysis and state estimation purposes.

Figure 1: Data exchange categorized according to CIM profile for Power flow analysis and State estimation [3].

Power flow analysis can be performed given topology solutions and some scheduling values. Alternatively, it can also be done by combining topology with estimates from state estimator as input. State estimation can be executed upon the knowledge of topology and SCADA information (status and analogy measurements). Sometimes, some scheduling values are also taken into consideration as pseudo measurements with various purposes, such as improving estimation quality or expand grid observability.

4 INFORMATION EXCHANGE SUPPORTING ICT SYSTEMS

In practice, the power grid information exchanges are performed over FTP services. To further limit data communication payloads, the exchanged files are usually compressed. Hereby, the process of compression and decompression should be considered in the implementation of supporting ICT systems. Furthermore, CIM is proposed as an information model that facilitates interoperability between different proprietary data formats rather than a standard approach to replace the existing vendor specific data model. Consequently, the CIM based information exchange should begin with an export process where the grid models described in vendor specific languages are converted to CIM models and end with an import process translating CIM based model to another proprietary format. In order to design ICT systems with sufficient performance to meet these needs, all process mentioned above need to be taken into consideration in the requirement engineering phase of SCADA/EMS system implementation.

5 FUNCTIONS FOR DATA VOLUME ESTIMATION

5.1 Methodology

When an application that requires information exchange is designed, it is very important to have an estimation of exchanged data volume before implementing the supporting ICT systems. If the data exchange involves CIM, the estimation should be based on the interpretation of IEC standard as well as power system common practices. The aim of this study is to come up with a toolbox in designing ICT systems which is capable to estimate the data volume required for different applications. The *CIM/XML/RDF* file (with CIM version 13) for a commonly available 40 bus test system used in CIM interoperability tests is taken as reference together with example *CIM/XML/RDF* text provided by standards. It is important to clarify here that our study only covers the objects from the aforementioned references which limits it to some commonly used components to construct power system model, not necessarily the entire CIM model as described in IEC 61970-301. The number of bytes are counted for each data object and as a further step, the dependency of data volume for each particular data profile are demonstrated by a function where expected data volume could be estimated given basic grid information as input. Specifically, they are:

- x: number of buses
- y: number of branches
- z: number of transformers
- m: number of generations
- n: number of loads

To come up with reasonable overall data volume estimation, it is necessary to quantify possible data amount for modelling each component. Our investigation begins with *Association* which describes relationship between grid components. *Association* to another class with an ”rdf:resource” infers that one shall search for that class and track down to lower level until there are no further *Associations* to other classes indicated by another ”rdf:resource”. In this way, all the classes included in the file can be exhausted and listed up with *Associations*. The applied method is rather similar to a ”reverse engineering” process of CIM modelling approach defined in the IEC 61970-301. Below is an example showing the *Associations* between *Terminal* and related objects. The classes marked with green indicate the *Association* relationship continues to other objects, while the transparent classes infer that there is no further *Association* to other objects. *Association* only contains metadata, there is no raw information included.

Figure 2: *Terminal* as an example showing the identifications of all its corresponding *Associations* to other CIM classes.

Apart from *Associations*, the *Attributes* included in each class contribute significantly to data volume as well. *Attributes* can either be native or inherited. For each *Attribute*, there is descriptive information as well as raw information which is different to *Association*. To provide a universal solution for all the possible CIM based applications, the data volume investigations are conducted individually for each CIM profile and the total required file size for one particular application could be estimated by the sum of data amount from every relevant profile. The *Schedule* profile is excluded from our work since there is no *CIM/XML/RDF*file available as example and it does not exist in 40 bus test system as well.

In the end our method is validated by other commonly available test systems that also follow CIM version 13. The logical chain for our work is presented as:

Figure 3: Method for designing and validating a toolbox for CIM based information exchange data volume estimation

5.2 Equipment Model profile

There are in total 23 classes categorized as *Equipment Model* profile presented in 40 bus system. The purpose of this study is to provide an estimation of data volume rather than an exact calculation, so some of the classes that of little data are neglected. Only the classes that contribute large data volumes are listed below in Table 5.2. The bytes in the table include both metadata and raw data, the reason not to specify the distinction is that the amount of bytes required for raw data is generally very low compared with metadata. For those classes whose quantities cannot be deducted directly given basic grid information, some derivations are done as below:

Breaker The number of *Breaker* can be assumed as two for each line and one for each generating unit, load and compensation unit. Therefore, the number of *Breaker* can be derived as 2y+m+n

Disconnector The number of *Disconnector* can be assumed to be double the number of *Breaker*s, which is 4y+2m+2n

Substation The number of *Substation* can be approximated to the number of transformers which is z

TransformerWinding The number of *TransformerWinding* can be assumed as two times the number of transformers assuming only two-winding transformers are involved. The number of *TransformerWinding* is 2z

TapChanger The number of *TapChanger* can be estimated as two times the number of transformers which is 2z

VoltageLevel The number of *VoltageLevel* can be deducted as two times the number of power transformers which is 2z

Class	*Quantity*	*Bytes/Item*
SynchronousMachine	m	1140
Power Transformer	z	323
Substation	z	276
VoltageLevel	2z	385
TrandformerWinding	2z	997
TapChanger	2z	961
Breaker	2y+2z+m+n	497
Disconnector	4y+4z+2m+2n	452
ACLineSegment	y	611
BusbarSection	x	344

Table 1: *Equipment Model* profile data volume estimation

ID are identifications assigned by users to name their grid components. All equipment names from 40 bus test are of 32 characteristics, according to our observation the names counts about 20 % of the bytes in total. Thus, the ID_{length} which could contribute substantial amount of data has to be taken into consideration. The data volume of *Equipment Model* profile can be estimated as:

$$F_1 = (1 + \frac{0.2(ID_{length} - 32)}{32}) \times (344x + 3413y + 8087z + 2541m + 1401n)$$

5.3 *Connectivity profile*

The interconnections of grid components are specified in *Connectivity* profile. CIM does not model interconnections by associating components directly to the others but instead uses *ConnectivityNode* to express the connectivity. Besides *ConnectivityNode*, CIM also introduces *Terminal*, which is relevant to define points of connectivity related measurements, for example, voltage, current and power flow, to avoid ambiguity. The *Connectivity* profile using the aforementioned two classes to express the linkage and connection of the entire grid together with the association of the measurement to the physical components. The quantity of these two classes can be estimated as:

Terminal The number of *Terminal*s can be defined as the sum of the number of *Terminal*s of all the relevant equipments. There are two *Terminals* for each *ACLineSegment*, *Transformer*, *Breaker* and *Disconnector*. For each *Generator*, *Load* and *BusBarSections*, it is assumed that there is only one *Terminal* as connection point. With these assumptions, the total quantity of the *Terminal*s can be estimated as x+14y+14z+7m+7n

ConnectivityNode It is assumed that there are two *Terminal*s connected to one single *ConnectivityNode*, the number of *ConnectivityNode* are estimated as half of the number of *Terminal*, which is (x+14y+14z+7m+7n)/2

Class	*Quantity*	*Bytes/Item*
Terminal	x+14y+14z +7m+7n	375
ConnectivityNode	(x+14y+14z)/2 +(7m+7n)/2	330

Table 2: *Connectivity* profile data volume estimation

Data volume of *Connectivity* profile is:

$$F_2 = (1 + \frac{0.2(ID_{length} - 32)}{32}) \times (540x + 7560y + 7560z + 3780m + 3780n)$$

5.4 *Measurement Specification profile*

The *Measurement Specification* profile includes classes that defined the types of measurements, location of the measurements and other auxiliary information. Five objects related to this profile are identified, however only the two of them with significant contribution to data volume are listed in Table 5.4.

Analog It is assumed that each bus bar and transformer winding has one voltage magnitude measurement. Real, reactive and apparent power measurements are collected from other conducting equipment such as generator, transformer, load and transmission lines. Besides, measurement transformers are deployed at both ends of the transmission line. Given the aforementioned assumption, the number of *Analog* can be derived as x+6y+5z+3m+3n

Discrete The number of *Discrete* can be the sum of number of *Breaker*, *Disconnector* and *TapChanger* which is 6y+2z+3m+3n

Class	*Quantity*	*Bytes/Item*
Analog	x+6y+5z+3m+3n	568
Discrete	6y+2z+3m+3n	381

Table 3: *Measurement Specification* profile data volume estimation

Data volume of *Measurement Specification* profile could be estimated as:

$$F_3 = (1 + \frac{0.2(ID_{length} - 32)}{32}) \times (568x + 5694y + 3602z + 2847m + 2847n))$$

5.5 *Analog and Status Measurement Set profile*

The purpose of *Analog Measurement Set* and *Status Measurement Set* is to publish measurement data to subscribers. They consist of a complete set of status indications and analogy measurements at a given time point. The measurements have relations with the *PowerSystemResource* and *Terminal* where source of measurement are specified. The *MeasurementValue* class contains the actual values from SCADA systems which is the typical input to state estimation or other off-line applications. The quantity of *AnalogValue* and *DiscreteValue* are the same as those of *Analog* and *Discrete* classes respectively.

Class	*Quantity*	*Bytes/Item*
AnalogValue	x+6y+5z+3m+3n	308
DiscreteValue	6y+2z+3m+3n	320

Table 4: *Analog Measurement Set* profile and *Discrete Measurement Set* profile data volume estimation

Data volume of *Analog Measurement Set* profile and *Discrete Measurement Set* profile can be estimated as

$$F_4 = (1 + \frac{0.2(ID_{length} - 32)}{32}) \times (308x + 3808y + 2180z + 1884m + 1884n)$$

5.6 *Topology profile*

The *Topology* profile is the output of a topology processor or a tool where the bus-branch topology model are generated. It is dependent on the status input and is always referring to an equipment dataset. The topological solution is based on *TopologicalNode* and *Terminal* classes. Disconnecting equipment, such as switches, generators, and transmission lines, is made by setting the attribute *Terminal.Connected* to false. The *Topology* profile comprises mainly the class *TopologicalNode* and *TopologicalIsland*. In normal operation, the power systems contains limited number of islands, hereby, the data generated by modeling *TopologicalIsland* is neglected in this study. The number of *TopologicalNode* is the same as the number of bus bars which is x. According to CIM, there is 314 bytes data generated to model one *TopologicalNode* item, the data volume of *Topology* profile can be estimated by:

$$F_5 = (1 + \frac{0.2(ID_{length} - 32)}{32}) \times 314x$$

5.7 *State Variables profile*

The *State Variable* profile is the solution of state estimator or power flow can be made available either to neighbouring grid utilities or to other applications. In theory, the *State Variable* profile could cover all the possible solutions from power flow or state estimation. In this paper, the studied case only contains data object describing injection power, power flow along transmission lines together with voltage phasor. For simplicity, each bus bar is assumed to have one voltage phasor measurement together with injection powers and the each *TransformerWinding* or *ACLineSegment* corresponds to one state in terms of power flow values.

Class	*Quantity*	*Bytes/Item*
SvInjection	x	351
SvVoltage	x	243
SPowerFlow	y+2z	235

Table 5: *State Variable* profile data volume estimation

Data volume of *State Variable* profile could be estimated following the equation below

$$F_6 = (1 + \frac{0.2(ID_{length} - 32)}{32}) \times (594x + 235y + 470z)$$

6 VALIDATION

The method is validated by estimation of the file size of similarly available 100 bus and 60 bus test systems. The available *CIM/XML/RDF* file for both models only contain *Equipment Model* and *Connectivity* profile, which means only F_1 and F_2 can be validated. See Table 6 for detailed results.

Parameters	*100 bus model*	*60 bus model*
x	100	101
y	137	44
z	47	58
m	32	48
n	64	57
ID_{length}	32	32
Actual Size	**2.29MB**	**1.44MB**
Estimated Size	**2.24MB**	**1.48MB**

Table 6: Validation results

The major estimation deviation of these two system could be traced back to the fact that these two *CIM/XML/RDF* file contain data object describing operational limits which are not captured in F_1. However, the insignificant deviation observed from results prove that our estimation has good accuracy, the deviations from actual file size are 2.4% for 100 bus model and 2.3% for 60 bus model. This method provide a easy means to estimate the data volume for the information exchange based on CIM. Given this information,the data exchange requirements posed by certain applications on the supporting ICT system could be further elicited.

7 CONCLUSION AND DISCUSSION

A Toolbox where the data volume for CIM version 13 based information exchange can be estimated is presented in this paper. To further capture communication network performance requirements, specifically throughput, the estimated data volumes need to be combined with expected data update frequency. Taking globe state estimation for multiple grid utilities as an example. Typically, the estimation input are collected from local SCADA systems and ICCP from neighbouring utilities. Assuming this particular state estimation is expected to run in every five minutes, it poses a requirement of updating topologies and analogy measurement sets for the entire grid within five minutes. Given the data volumes for each relevant data profile, the requirements for supporting ICT systems could be further defined.

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