Foundations of a Metamodel Repository for Use With the IEC Common Information Model

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***Abstract*—The development of the smart grid calls for enhanced power system application interoperability and knowledge management. The IEC Common Information Model (CIM) supports semantic interoperability but multiple identities attributed to common power system resources present challenges to unambiguous metadata model merging within a repository. This paper describes an original methodology for the building of a novel metadata model repository that concentrates our knowledge of enterprise power system resources. We leverage the value of model namespaces and resource description framework (RDF) technology in providing contexts for multiple identities referring to common power system resources. This novel approach aims to develop a more realistic understanding of network reality than repositories depending on a single CIM XML namespace and contributes to engineering an "enterprise ontology" supporting interoperability and business intelligence. We demonstrate this novel approach with reference to National Grid use cases for network operation and planning model management roles.**

***Index Terms*—Common Information Model (CIM) power, interoperability, knowledge management, model repository, software standards.**

I. INTRODUCTION

THIS paper introduces an original methodology for repository management of metadata models conforming to the IEC Common Information Model (CIM) while aiming to contribute to the evolving understanding [1] and development of these software standards. It addresses interoperability at the level of instantiated objects and their identities within metadata models, which is at a lower level than the semantic alignment required for standards harmonization referred to in [2] and [3]. We will use the term *model* following Guizzardi [4] to mean "an abstraction of reality according to a certain conceptualization" and *metamodel* to mean "a model of models" [5]. The *metadata model* is meant as a model of data models and is explained in more detail in Section III.

Power system applications (PSAs) responsible for operational energy management, planning, asset and market management all require interoperability to support smart grid functionality. Their internal data models when processed by CIM adaptors are exported in the form of CIM XML metadata models. We are concerned with developing coherent knowledge representation of the smart grid to support its functionality by creating a CIM XML metadata model repository composed from participating PSA CIM-metadata models. In this sense we view each PSA CIM-metadata model as a partial representation of smart grid reality. Focusing on the use of metadata models we offer an approach to achieving the business intelligence that power system utilities require in the efficient operation of the smart grid.

The smart grid is a cyber-physical entity [6], [7], designed to flexibly respond to changes in variable energy resources, consumer demands and energy markets supported by sharing modeled information between different PSAs [8]. The Grid Code [9] is a regulatory code of conduct for the GB system that formalizes the exchange of such information between distribution network owners (DNOs) and the GB transmission system operator (TSO), National Grid. The importance of information interoperability is reflected by its central position in the National Institute of Standards and Technology (NIST) "Conceptual Architecture Framework" [10] and the European Smart Grid Architecture Model (SGAM) [11] (Fig. 1), both based on the GridWise Architecture Council (GWAC) Stack methodology for interoperability [12].

The requirement for operational, planning and asset management PSAs to coherently exchange information models built from metadata forms the core of smart grid interoperability. This requirement can be further qualified in terms of whether the shared models are: 1) discrete but interface at a given boundary, 2) overlap in part, or 3) overlap entirely. Overlap in this sense, can be taken to mean that the models represent the same electrical network in reality but not necessarily with the same granularity or semantic alignment. For example, we may expect an asset-based model to represent the same electrical network differently to the way it is represented within the Energy Management System (EMS) model due to their different functional requirements.

Business requirements relating to 1) above, were addressed in [13] and [14] with the creation of an entity known as a Regional Model Authority (RMA) Set. The RMA is meant to assert control over the name-identity issue within discrete models and their boundary models that maintain connectivity at network interfaces. The authors concluded as long as the identity of network resources within shared models under the jurisdiction of different RMAs remained unique, there was no requirement for a further means to manage resource name-identity relationships.

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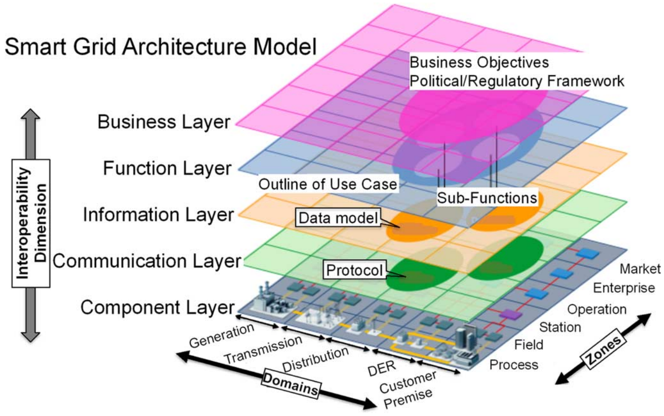


Fig. 1. European smart grid architecture model framework. From CEN-CENELEC-ETSI, [5].

Business requirements relating to 2) and 3) were addressed in [15]. In the case of a model repository, described there as a *shared company data model* (or *Union Model*), there was the need for a third party, hierarchical "Model Naming Authority and Registry".

The concept of a metamodel repository for business information integration is not new [16], and more recently XML as a metadata exchange technology has supported better information integration between component systems [17]. The advantages of semantic interoperability over syntactic interoperability referred to in [18] are now being met by the existence of the IEC CIM standards in the electric utility domain [19]. In the CIM concept, network resources were intended to have only one *Master Resource Identity* (mRID), normally provided by the underlying Resource Description Framework [20] identity statement (rdf:ID). This is optimized to a single-entry modeling environment however, as referred to in [21]. If a unique mRID is not attached to the same network resource at the time of data modeling, identity ambiguities can arise [22]. This can happen where there are multiple points of data entry from PSAs referring to the same power system resource [23]. As this is normal practice, the opportunity for data identity *collision* and *recognition* problems occurs when PSA metadata models are merged within a single CIM XML *namespace* [24]. Containment of all mRIDs within a single namespace also results in loss of resource *genealogy* from the original PSA *context*, requiring extensive effort to reconcile resource identity and alignment within the repository.

The method proposed in [15] relied upon a centralized supervisory mechanism to have the authority to issue a unique mRID where common power system resources were presented within different participant PSA metadata models. In this way these common resources would be aligned within the overlapping parts of shared models by their unique mRIDs. However, the need to maintain an increasingly complex centralised register comprising multi-lateral tables reflecting 1:n relationships between mRID and PSA-derived IDs is deemed impracticable. And as resource *names* are allocated by some PSAs to act in place of an rdf:ID, this could add to the ambiguity of the identity of the resource, increasing time penalties for model processing.

This paper describes a novel approach to metadata model management within a repository that does not require a third party identity registry system or use a single CIM RDF XML namespace. The approach leverages the inbuilt facilities of RDF technologies and builds a repository that preserves PSA metadata models within multiple XML namespaces. Section II describes the philosophy and benefits behind such an approach. Section III sets-up the repository architecture in respect of a standard modeling hierarchy. Section IV describes the application of the repository in relation to practical use cases currently seen as business priorities within National Grid as a system operator. Section V demonstrates the model handling methodology for creating the repository. Section VI addresses how to maintain the repository through time and Section VII draws conclusions.

II. REPOSITORY—PHILOSOPHY AND BENEFITS

In this paper we describe an approach to manage alignment of shared metadata models within a repository by qualifying their objects within an XML namespace derived from each originating PSA. This preserves the context in which a resource was modeled, allowing multiple mRIDs to coexist without data recognition and collision problems. The CIM concept of unique mRIDs is still maintained by placing each PSA metadata model within its own namespace. In this way our approach differs fundamentally from the use of a single CIM XML namespace ("xmlns:cim") as being the only placeholder for resource descriptions. Instead, we see the role of the CIM namespace becoming a container for the CIM model schema identity, for example. In this way we leveraged the value from multiple PSA XML namespaces to give the following advantages:

- Provide a realistic representation of the different metadata models making up the repository
- Provide partitioning of the repository in the way PSAs exchange their CIM metadata model files
- Remove ambiguity over which PSA model components are aligned to compose the repository
- Preserve resource genealogy
- Combine the range of common network resource parameters modeled by different PSAs

Because of its composition from CIM RDF XML metadata models, the repository can act as a *validation gateway* providing an elegant solution to the high cost of managing real data duplication and consistency issues arising from multiple points of data entry across the enterprise. It also offers clear options to synchronize network parameter values from multiple representations of common network resources and business entities. We may also exploit siloed data from applications not previously modeled in IEC CIM, where semantic alignment is available through harmonization, as in the case of metamodels such as IEC 61850.

We propose the combination of *information* provided by object classes conforming to the semantic standard (CIM), *meaning* provided by the arrangement of object classes (according to the metadata model XML schema definitions) and *context* provided by namespaces becomes *knowledge* when coherently combined within the repository. In this way the repository not only supports interoperability but also increases our knowledge, and therefore *understanding*, of the *system under study* (SUS) [25] with increasing resolution as more metadata models are merged and aligned within it. Justification for building this kind of repository is found in the complex landscape of power systems and markets making-up the smart grid. Here, better understanding of power networks is paramount in achieving business objectives faster and more efficiently. This repository model assemblage resembles a *foundational ontology* with the characteristics described in [5]. It offers a "formal specification of a shared conceptualization" to align knowledge of the SUS with reality and provide support for integration of asset, planning, operational and other business functions across the utility.

Maintained by a model management team working with enterprise architects and PSA management teams, the repository could play a central role in the utility operational and planning infrastructure as it connects to an integration bus, linking participant PSAs. The architecture described in the following section offers insight into how it may also be linked to other business systems to provide a resource for business analytics and intelligence. In this way we aim to balance "technical architecture benefits of data exchange with information architecture benefits of semantic reconciliation" [26]

III. REPOSITORY ARCHITECTURE

After Ogden and Richards' *meaning triangle* [27], we view the CIM RDF XML model exchanged between PSAs and the repository as being *symbolic* of the proprietary PSA data model and *referring to* the reality of the network. Each data model, which serves the functional purposes of the PSA internally, is a proprietary representation (abstraction) of the reality of the power system network. The metadata model in CIM RDF XML, is a representation of the PSA proprietary data model and based on open standards (IEC CIM) that support interoperability. In the repository we consolidate these different metadata representations into a semantically aligned representation of the network reality. This is only possible at the metamodel level of abstraction and is referenced to the IEC CIM standard semantic models [28].

The Object Management Group (OMG) after Henderson-Sellers and Unhelkar [29], have established a four layer hierarchy for the purpose of metamodeling, that we have adopted to explain the relationship of the metadata model repository to power system resources (Fig. 2). We see this hierarchy as neatly fitting the CIM framework we are describing and our repository architecture, with its use of namespace, contributing to interoperability.

The hierarchy defined by the OMG extends to a level of abstraction, M3. While we may use this to indicate the level at which the metadata models of M2 could become instances of a corporate metameta data model (CDM), it is not the current concern of this paper. However, use cases for the repository as a knowledge resource contributing to enterprise business analytics would concern instantiation at this level.

In this sense our design for a metadata model repository is not limited only to power systems and provides insights into building a knowledge repository for other domains as well, by leveraging the *rhetorical nature* of RDF/XML as a technology [30].

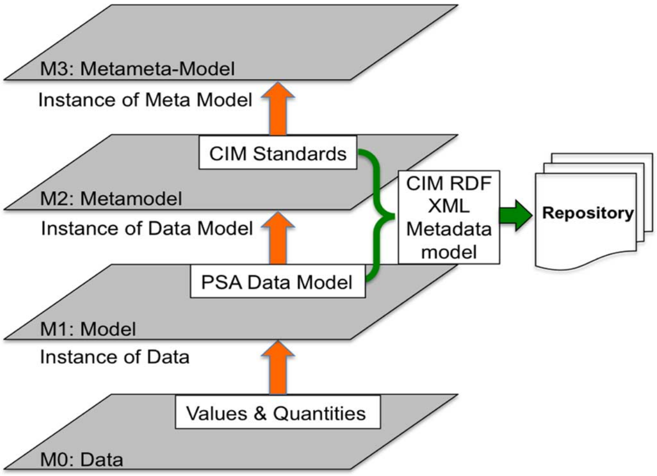


Fig. 2. Repository architecture with respect to OMG four-layer hierarchy.

IV. USE CASE SCENARIOS FOR THE MODEL REPOSITORY

Our use cases concern CIM equipment profiles (CIM.EQ files) and acknowledge that these can differ in their representation of the network depending on whether connectivity information (such as ConnectivityNode instances) is included in the profile used. For example the IEC 61970-452 standard, known as "CPSM profile" does contain connectivity information and is used by operational PSAs, while the ENTSO-E, Edition 1 profile, used by National Grid planning PSAs, does not. The implication of this is we will find different connectivity representations in the CIM metadata files of the same network reality. A legacy of different names given to the same power system resource, data silos within different PSAs referring to common network resources and multiple points of data entry are also to be expected. We must therefore accept that complexity in names, IDs and data referring to common network resources is inevitable. Each PSA will contribute a data representation of network reality in dependence upon its functional perspective, or context. Thus, each PSA will have a different orientation to a common network resource and will describe it only in the partial terms necessary for its functionality.

As a single point of asset naming and identification no longer exits within National Grid for network operation, this work was motivated by the business benefits of resource knowledge reconstruction using a metadata model repository. We based our investigation on the three exchange scenarios described in Section I as follows (Fig. 3):

A. Scenario 1)

This applies to the use of a network model describing the region of the GB network interconnecting with the network of different TSOs, as in the case of model sharing with Coreso [31]. Coreso, as a Regional Coordination Service Centre, combines non-overlapping models from its partners to facilitate operational security studies on cross-boundary power flows.

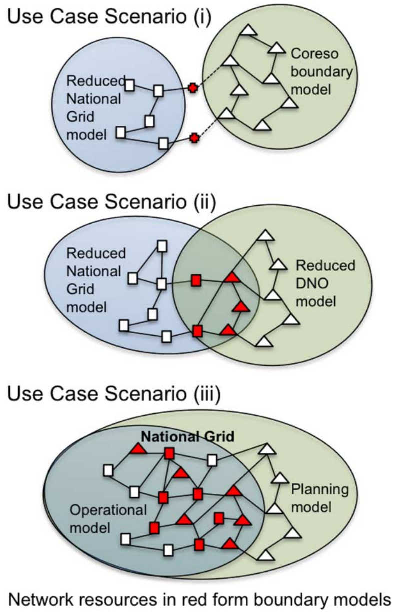


Fig. 3. Schematic diagrams of use case scenarios.

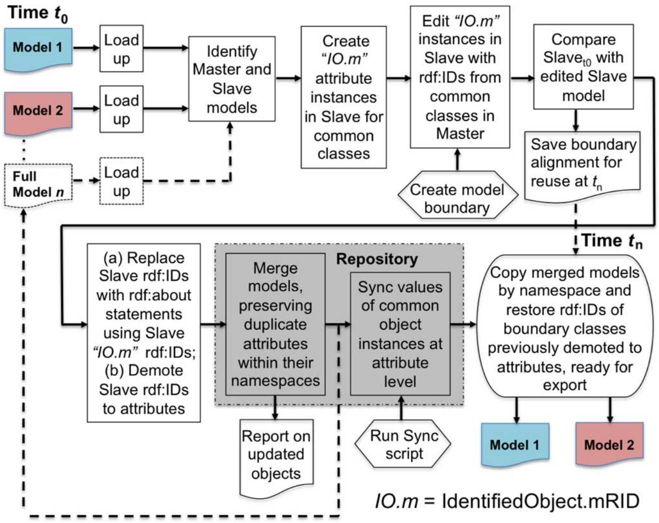


Fig. 4. Model exchange process for two models loaded from different power system applications.

Thin boundary models containing fictitious interconnection nodes are maintained by the European Network of Transmission System Operators for Electricity (ENTSO-E) [32], [34]. They are used by ENTSO-E members to enable model interconnection for wide area network studies involving other European national transmission systems. This type of boundary model is merged within the National Grid CIM RDF XML metadata model before export to Coreso to facilitate easier interconnection with models provided by neighbouring utilities.

B. Scenario 2)

This applies to the exchange of network metadata models between DNOs and National Grid. Reduced models describing only the network equivalent at thick network boundaries, covering the National Grid owned Grid Supply Point (GSP) supergrid transformers to the DNO step-down transformers, are exchanged to support cross-boundary security analyses and operational visibility. In this process, parameter information is used for fault level and thermal assessments. Infrastructure changes reflected within the models are merged into the existing operator model to update network awareness.

C. Scenario 3)

This applies to the synchronization of common network parameters modeled by different PSAs within the same utility, sometimes described as seeking "one version of the truth". Alignment of the National Grid Offline Transmission Analysis (OLTA) planning application model with operational online management systems such as the EMS, are examples of this use case. In this process, power system resources with different PSA genealogies and identities, would be aligned across their respective CIM RDF XML metadata models exported from each PSA. Alignment of common resource attributes presented within the objects of the metadata models would then make possible the option to synchronize or rationalize resource parameter values.

All of these model exchanges currently require considerable manual effort when approaches not involving common semantic metamodels are used to achieve alignment. In the case of scenarios 2) and 3), the operation currently takes several man-weeks of power system engineer's time and is therefore very costly. Automation of the following methodology could not only reduce the cost of such processes but also support efficient interoperability and understanding required for a smarter grid. We see this as a step towards "dynamic adaptation" of a repository-based ontology and Model Driven Architecture (MDA) [33].

V. REPOSITORY CREATION METHODOLOGY

An overview of the model exchange process is presented in Fig. 4. This process is valid for the thin boundary between models described in scenario 1) but the option to synchronize parameter values for aligned representations of common power system resources becomes possible within scenarios 2) and 3) and are the focus of the remaining discussion. We based our demonstration on full CIM.EQ models exported in CIM RDF XML from the CIM adaptor interfaces of the National Grid OLTA PSA, (Model 1) and EMS PSA (Model 2), *representing* Operational Planning and Energy Management System data models, respectively. Some XML values have been altered for clarity. Both models were constrained to the ENTSO-E Edition 1 profile and loaded into a metamodel handling application used for model visualization, comparison, merging and validation functions. It would be impractical to display the full models used in our demonstration, as they are composed of more than 200 000 objects in each model, so edited sections of the metadata model code chosen to exemplify the principles of creation and use of the repository are given in the following figures. We estimated no more than approximately 4% of objects within these National Grid CIM.EQ models would actually align, the rest of the objects being unique to each model's equipment inventories.

The process begins at a given time (say t_0) by loading two PSA metadata models into the metamodel handling application.

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-
syntax-ns#"
xmlns:cim="http://iec.ch/TC57/2009/CIM-schema-cim14#"
xmlns:olta="http://www.nationalgrid.com/olta/2009/CIM-
schema-cim14#"
xml:base="http://www.nationalgrid.com/repository/">

<olta:Substation rdf:ID="_XXX1">
  <olta:IdentifiedObject.aliasName>AZKABN
    </olta:IdentifiedObject.aliasName>
  <olta:IdentifiedObject.name>AZKABN275KV
    </olta:IdentifiedObject.name>
</olta:Substation>

<olta:PowerTransformer rdf:ID="_XXX1.1">
  <olta:IdentifiedObject.aliasName>SGT3
    </olta:IdentifiedObject.aliasName>
  <olta:IdentifiedObject.name>AZKA SGT3
    </olta:IdentifiedObject.name>
</olta:PowerTransformer>

<olta:TransformerWinding rdf:ID="_XXX1.1.1">
  <olta:TransformerWinding.MemberOf_PowerTransformer
rdf:resource="#_XXX1.1"/>

        <!--Transformer winding parameters would appear here--!>

</olta:TransformerWinding>
</rdf:RDF>
```

Fig. 5. Model 1: Section of OLTA CIM RDF XML metadata model for a transformer winding within the Azkaban Substation. rdf:IDs have been simplified for clarity. Winding parameters not shown for simplicity.

```
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-
syntax-ns#"
xmlns:cim="http://iec.ch/TC57/2009/CIM-schema-cim14#"
xmlns:ems="http://www.nationalgrid.com/ems/2009/CIM-schema-
cim14#"
xml:base="http://www.nationalgrid.com/repository/">

<ems:Substation rdf:ID="_YYY1">
  <ems:IdentifiedObject.name>AZK
    </ems:IdentifiedObject.name>
</ems:Substation>

<ems:PowerTransformer rdf:ID="_YYY1.1">
  <ems:IdentifiedObject.name>AZK SGT1
    </ems:IdentifiedObject.name>
  <ems:Equipment.EquipmentContainer
  rdf:resource="#EMS_Substn7"/>
</ems:PowerTransformer>

<ems:TransformerWinding rdf:ID="_YYY1.1.1">
  <ems:IdentifiedObject.name>AZKSGT1
    </ems:IdentifiedObject.name>
  <ems:TransformerWinding.PowerTransformer
rdf:resource="#_YYY1.1"/>

        <!--Transformer winding parameters would appear here--!>

</ems:TransformerWinding>
</rdf:RDF>
```

Fig. 6. Model 2: Section of EMS CIM RDF XML metadata model for a transformer winding within the Azkaban Substation. rdf:IDs have been simplified for clarity. Winding parameters not shown for simplicity.

Figs. 5 and 6 show part of the CIM RDF XML relating to a common substation, power transformer and one of its windings, modeled by the two PSAs. The divergence in names and rdf:IDs given to the same network resource is clear. Namespaces are declared in the model headers and preserved in the subsequent code to identify the PSA responsible for the model and thus the genealogy of the name-identity coupling given to a resource.

The model handling tool utilises embedded RDF operations to carry out updates between two models using *incremental* models as far as possible. Because the direction of update is important, it is necessary to select which of the two models are Master and Slave, to determine which model becomes the incremental to the other. We selected the more detailed offline, planning model from the OLTA PSA as our Master. As the repository becomes composed of a mosaic of merged models it will default to the role of Master model.

We began by creating the boundary that will link these first two models together within the repository. As the ability for automated reasoning to 100% confidently recognise identical objects with heterogeneous identities within different metadata models has not yet been developed, we found it is necessary for human intervention to carry out the initial steps in the model alignment process, as in [23]. Automation may speed-up the alignment process in future but not entirely remove the need for human intervention until 100% accurate. The pattern-matching process is not one of simply identifying the common semantic describing the power system resource object, but also the associated metadata of its identity and name(s). This process is concerned with instantiated objects within metadata models and thus sits at a lower level than semantic harmonization.

We injected attribute statements into the class definitions of the objects of the Slave model to act as "hooks," that will link it to the master model. The use of the "IdentifiedObject.mRID" attribute from the CIM reference metamodel was used here, avoiding the need for a proprietary model extension. We then copied the rdf:ID values of the common classes from the Master model into the string space of these "IdentifiedObject.mRID" attributes. This step is equivalent to marking or creating the boundary that will link the two models together. By comparing the newly edited Slave model with its original version we identified just those classes that constituted the boundary with the Master model. Each boundary model class showed the rdf:ID of the Slave class as well as the ".mRID" attribute reference to its corresponding Master model class object rdf:ID value (Fig. 7). This boundary alignment file is saved for re-use at the time a version of the Slave model is exported from the repository.

Before we merged Master and Slave models into the repository, the rdf:ID values of the Slave boundary model classes were demoted to become attributes of the power system resource class to which they apply; and were replaced with the rdf:ID values (now semantically equivalent to the mRID in the CIM reference metamodel) of the corresponding class object in the Master model. Slave object attributes then became "resources" to the Master class object. This prepared common class objects and associated attributes within each model for merging into the repository by the handling tool.

Utilising an embedded RDF operation, merging of the models used the Slave model as a *difference file* to the Master model. In our demonstration of the repository, we augmented the detail of the Master model which required the difference file to contain *forward* differences. *Reverse* differences would remove objects in the Master model, targeted by Slave model "rdf:about" statements.

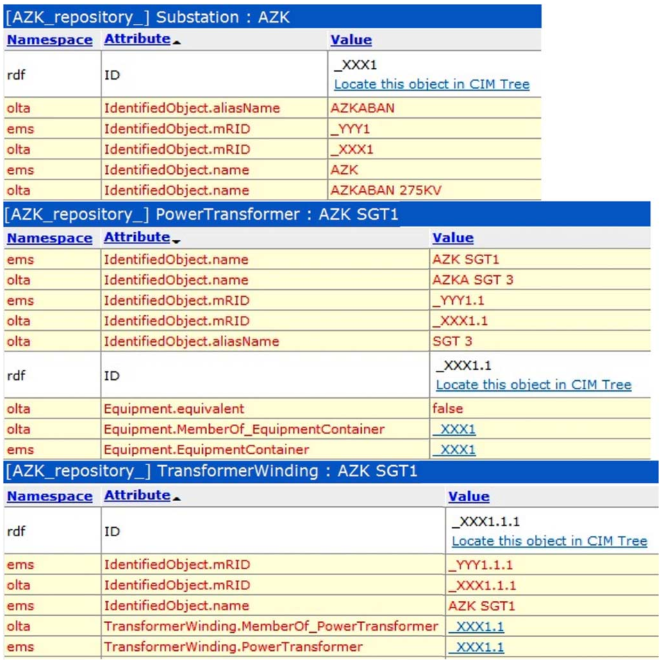
```
<?xml version="1.0" encoding="UTF-8"?>
<rdf:RDF
xmlns:base="http://www.nationalgrid.com/repository/"
xmlns:cim="http://iec.ch/TC57/2009/CIM-schema-cim14#"
xmlns:dm="http:://iec.ch/TC57/61970-552/DifferenceModel/1#"
xmlns:ems="http://www.nationalgrid.com/ems/2009/CIM-schema-
cim14#"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:olta="http://www.nationalgrid.com/olta/2009/CIM-
schema-cim14#">

   <dm:DifferenceModel rdf:about="">
      <dm:reverseDifferences rdf:parseType="Statements">
      </dm:reverseDifferences>
      <dm:forwardDifferences rdf:parseType="Statements">

         <rdf:Description rdf:about="_YYY1">
            <olta:IdentifiedObject.mRID>_XXX1
              </olta:IdentifiedObject.mRID>
         </rdf:Description>

      <rdf:Description rdf:about="_YYY1.1">
            <olta:IdentifiedObject.mRID>_XXX1.1
            </olta:IdentifiedObject.mRID>
         </rdf:Description>

         <rdf:Description rdf:about="_YYY1.1.1">
            <olta:IdentifiedObject.mRID>_XXX1.1.1
             </olta:IdentifiedObject.mRID>
         </rdf:Description>

           </dm:forwardDifferences>
   </dm:DifferenceModel>
</rdf:RDF>
```

Fig. 7. Boundary alignment model. Forward differences identify Substation, Power transformer and Transformer winding boundary objects.

At this point we leveraged the value of context by preserving the XML namespaces containing each metadata model. Maintaining separation between the models in this way enabled us to clearly identify respective PSA metadata contributions to the repository as described in Section III, and enabled the comparison, synchronization, or rationalization of attribute parameter values of common objects, subsequently. Partition of repository models in this way also assists with the export process described below.

Fig. 8 shows the report in the model handling tool of the merge between the sampled sections of Master and Slave metadata models. We can see the two PSA models of the transformer winding aligned within the same transformer and substation, which would allow us to examine the range of attributes (not shown here) associated with this common network resource. At this juncture, the repository has been created within the model handling application. We can reiterate the process linking additional metadata models into the repository model or run a script designed to synchronise the parameter values of the common object attribute instances as appropriate. Parameter synchronization would be similar to an RDF "update" operation between Master and Slave models but at the attribute level. This does not imply the update direction need be from Master to Slave however, such as in cases where the Slave updates the Master.

As the repository is composed of models partitioned by namespace it is possible to separate, copy or extract any model, filtering it by namespace. Updating PSA data models after parameter synchronization in the repository is possible by re-importing its metadata model through the CIM adaptor. Before a Slave model is exported (at time t_n in Fig. 4), it is necessary to restore the status of boundary object rdf:IDs to their original value by promoting them back from attribute level to rdf:ID statement level (or CIM:mRID). These objects are identified from the boundary alignment file created before the model was merged into the repository. This process would be automated within the repository management application and is shown in summary in Fig. 9.



[AZK_repository_] Substation : AZK

Namespace	Attribute	Value
rdf	ID	_XXX1 Locate this object in CIM Tree
olta	IdentifiedObject.aliasName	AZKABAN
ems	IdentifiedObject.mRID	_YYY1
olta	IdentifiedObject.mRID	_XXX1
ems	IdentifiedObject.name	AZK
olta	IdentifiedObject.name	AZKABAN 275KV

[AZK_repository_] PowerTransformer : AZK SGT1

Namespace	Attribute	Value
ems	IdentifiedObject.name	AZK SGT1
olta	IdentifiedObject.name	AZKA SGT 3
ems	IdentifiedObject.mRID	_YYY1.1
olta	IdentifiedObject.mRID	_XXX1.1
olta	IdentifiedObject.aliasName	SGT 3
rdf	ID	_XXX1.1 Locate this object in CIM Tree
olta	Equipment.equivalent	false
olta	Equipment.MemberOf_EquipmentContainer	_XXX1
ems	Equipment.EquipmentContainer	_XXX1

[AZK_repository_] TransformerWinding : AZK SGT1

Namespace	Attribute	Value
rdf	ID	_XXX1.1.1 Locate this object in CIM Tree
ems	IdentifiedObject.mRID	_YYY1.1.1
olta	IdentifiedObject.mRID	_XXX1.1.1
ems	IdentifiedObject.name	AZK SGT1
olta	TransformerWinding.MemberOf_PowerTransformer	_XXX1.1
ems	TransformerWinding.PowerTransformer	_XXX1.1

Fig. 8. Screen shots from model handling tool showing alignment of Substation, transformer and transformer winding CIM metadata model objects within repository.

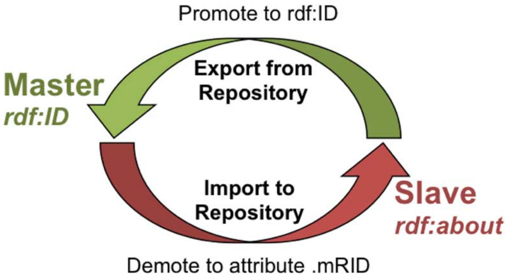
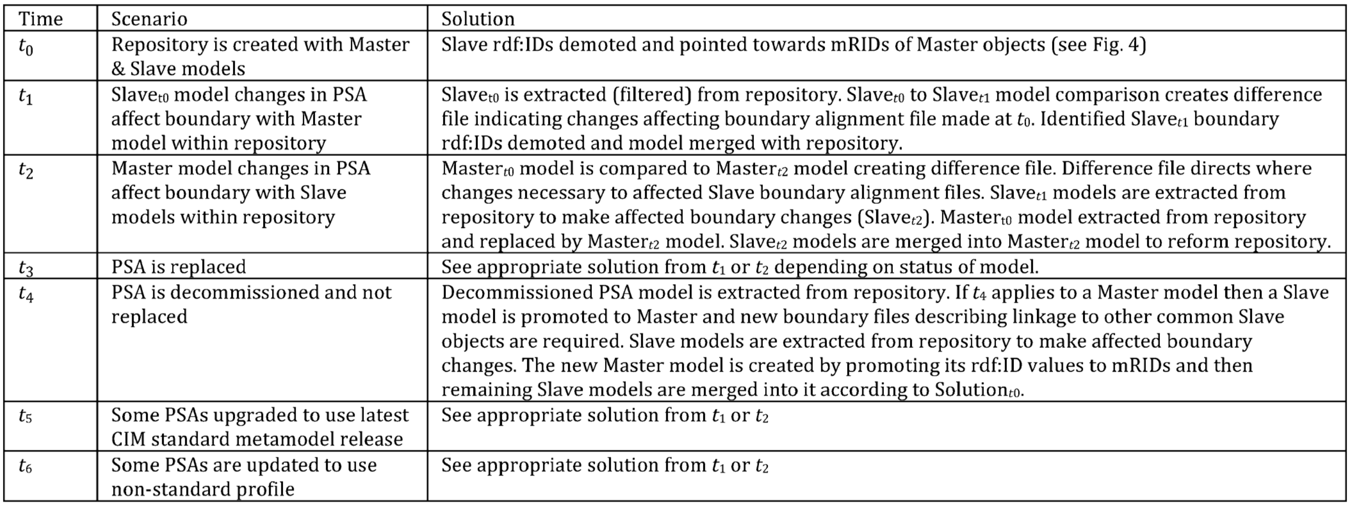


Fig. 9. Transformations required to update model boundaries by repository management application.

VI. REPOSITORY MAINTENANCE THROUGH TIME

The use of CIM is understood to apply to a snapshot in time and metadata models will instantiate objects differently as the PSA models they represent change through time in accordance with network resource outages and connectivity. The CIM metadata model repository stands for temporal network reality and so requires a methodology to remain a true representation of the network reality it models. The biggest impact upon the repository will arise from changes to the model boundaries linking the repository together. Changes made here from any contributing model affect repository integrity and require an additional set of actions to those described in Fig. 4. Changes to objects outside of the model boundaries are important in terms of truth to reality but do not impact upon repository integrity.

TABLE I



Time	Scenario	Solution
t_0	Repository is created with Master & Slave models	Slave rdf:IDs demoted and pointed towards mRIDs of Master objects (see Fig. 4)
t_1	Slave$_{t0}$ model changes in PSA affect boundary with Master model within repository	Slave$_{t0}$ is extracted (filtered) from repository. Slave$_{t0}$ to Slave$_{t1}$ model comparison creates difference file indicating changes affecting boundary alignment file made at t_0. Identified Slave$_{t1}$ boundary rdf:IDs demoted and model merged with repository.
t_2	Master model changes in PSA affect boundary with Slave models within repository	Master$_{t0}$ model is compared to Master$_{t2}$ model creating difference file. Difference file directs where changes necessary to affected Slave boundary alignment files. Slave$_{t1}$ models are extracted from repository to make affected boundary changes (Slave$_{t2}$). Master$_{t0}$ model extracted from repository and replaced by Master$_{t2}$ model. Slave$_{t2}$ models are merged into Master$_{t2}$ model to reform repository.
t_3	PSA is replaced	See appropriate solution from t_1 or t_2 depending on status of model.
t_4	PSA is decommissioned and not replaced	Decommissioned PSA model is extracted from repository. If t_4 applies to a Master model then a Slave model is promoted to Master and new boundary files describing linkage to other common Slave objects are required. Slave models are extracted from repository to make affected boundary changes. The new Master model is created by promoting its rdf:ID values to mRIDs and then remaining Slave models are merged into it according to Solution$_{t0}$.
t_5	Some PSAs upgraded to use latest CIM standard metamodel release	See appropriate solution from t_1 or t_2
t_6	Some PSAs are updated to use non-standard profile	See appropriate solution from t_1 or t_2

Changes to PSA metadata models are reflected in their forward and reverse differences, evident from a comparison between two models of different creation times. If these changes concern the boundaries of a Slave model, there is less maintenance required to the repository because these are limited to the scope of the Slave model. Changes to the Master model boundaries have higher impact due to its linkage to other metadata models within the repository. In Table I we have summarized a range of repository maintenance solutions involving actions that could occur over a range of different scenarios for times t_1 to t_6. Time t_0 represents when the repository is created, as shown in Fig. 4.

VII. CONCLUSIONS AND FURTHER WORK

In this paper we have described an original methodology to build a novel metamodel repository. We demonstrated its validity using the IEC CIM to combine the network reality of two important operational and planning PSAs.

We have described the utility enterprise benefits for a range of use cases and have initially demonstrated that the proposed methodology is superior to other approaches using a single XML namespace and requiring the use of third party name and identity registers. The novel approach that we have presented in this paper leveraged standard operations in RDF, giving us opportunities to engage with semantic web and ontology engineering technologies in future.

We see the building of knowledge within the repository, as a greater number of metadata models merge into it, as evolutionary. Furthermore, the use of metadata for resource knowledge management, supports power system interoperability at a higher level than possible through approaches focusing only on data. We also see potential for CIM extension with additional metadata to guide the identification of model boundaries before the merging process to reduce time spent on manual intervention. But however fast and accurate pattern-matching routines may be, human supervision will still be required to confirm the identities of object ID instances in the absence of true Artificial Intelligence.

Further demonstration of the superiority of this novel approach will include the extraction of combinations of model parameters from the repository for business intelligence applications. The alignment of other model profiles, such as for graphics, could also widen the scope of repository applications.

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