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A CIM-based Incremental Approach for Real-time System Model Update

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SUMMARY

The Energy Management System (EMS) supports many crucial online studies, such as State Estimation (SE), Real Time Contingency Analysis (RTCA) and Voltage Security Assessment (VSA). Control room personnel depend on those study results to maintain situational awareness and to issue switching commands. The quality of real-time studies is highly affected by the accuracy of modelling. Hence, frequent database updates are needed to maintain model accuracy and ensure credible study results.

Due to close coupling, many utilities' EMS models consist of their own and external networks, which include neighboring power grids. Both internal and external networks evolve constantly as new equipment is commissioned and old equipment is retired. While internal model updates can be processed manually by modelers, external model maintenance is a crucial part of utility big data management. This remains a challenge since database nonconformity dramatically hinders information sharing among different entities. As a result, External Model Updates (XMU) are often outsourced to contracting firms and are completed less frequently, leading to excessive costs and reduced model credibility.

In order to address the above challenges, this paper proposes a Common Information Model (CIM) based incremental approach to facilitate XMU. Enhanced from the previously proposed bulk methodology [1], this approach operates only on model differences, while dealing with data nonconformity. Consequently, validation and testing efforts can be significantly reduced without undermining the swiftness in inter-corporate information exchange and utility-specified customization. With easy operability provided by an Application Programing Interface (API) driven CIM application, the CIM based approach is capable of clearly delineating boundaries between internal and external regions and clipping out the areas in need of updating. The new and old external CIM models are compared to detect changes in external grids. Subsequently archived into an incremental project, those changes are merged with American Electric Power (AEP) current models in an EMS modelling tool. With validation and online testing cleared, the incremental changes are deployed to production and XMU is realized.

The proposed approach has been adopted by AEP to facilitate multiple XMUs. The efficiency of external model maintenance can be increased tremendously (while also inhibiting human error) with the incremental procedure delivering precision in importing system updates. The CIM-based approach automates data conversion (as well as model building), and the efficiency of external model maintenance can be increased tremendously, while reducing risks of human error. As a result, the time

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for integrating each XMU has been reduced from weeks to hours, and the external model revision cycle has shortened from years to months. This has dramatically enhanced the credibility of AEP's real-time system model, contributing to a more reliable system to support control room functions. Furthermore, with utilization of CIM standards, AEP exemplifies a versatile approach to automate the maintenance of real-time system model.

As velocity and veracity are both achieved in the proposed XMU procedure, AEP addresses the challenge of utility big data management, while promoting grid interoperability among fellow industrial parties.

KEYWORDS

Common Information Model, Energy Management System, External Model Update, Inter-Control Center Communications Protocol, Supervisory Control and Data Acquisition

1. Background

In order to ensure situational awareness, utilities with transmission networks that closely interact with other companies are required by the North American Electric Reliability Corporation (NERC) to model and monitor neighboring grids [2]. AEP maintains the largest transmission system in the United States, with more than 40,000 miles of transmission lines extending across 11 states. With direct tie connections to 29 external entities, AEP participates in four Regional Transmission Organizations (RTO). Fig. 1 shows AEP's service area.

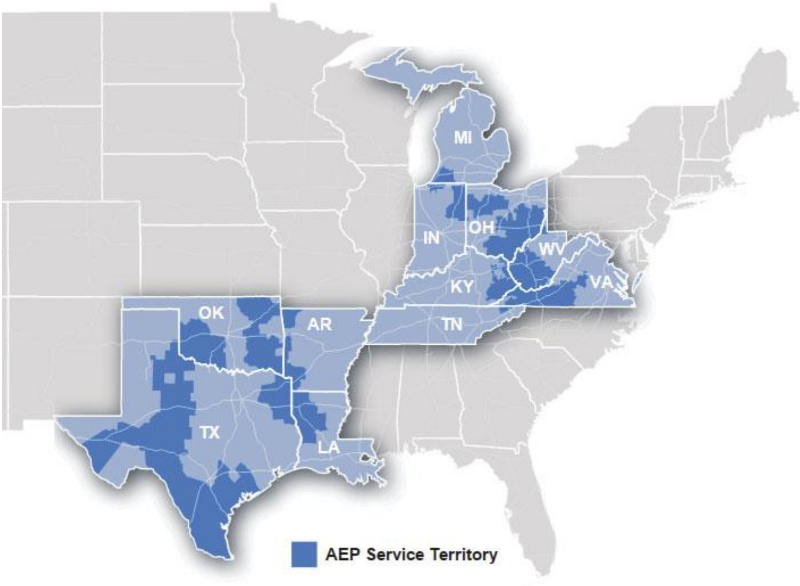

Fig. 1 AEP Service Territory

With evolving system changes, constant XMU information is necessary to realign operational models with external entities. While internal system changes can be manually addressed by modelers, external updates have to be imported from external entities. The diversity in data formatting and variety in model customizations have led to challenges in processing high volumes of modelling changes with desired velocity and veracity [3].

Many attempts have previously been made to address those challenges. The Western Electric Coordination Council (WECC) tried using SaveCases to assemble the West-wide System Model (WSM) from data fragments provided by dozens of its Balancing Authorities [4, 5]. Their approach served the purpose. However, it required an extensive amount of clean-up to get rid of human errors caused by inconsistency in model conventions. This was not ideal for recurring XMUs. Eversource Energy utilized CIM standards, in exchange of EMS transmission network data with New England ISO (ISO-NE) to facilitate their external grid upgrades [6]. Nevertheless, the difficulty in conversion between CIM\XML and EMS relational formats prevented them from modelling XMUs frequently. Since 2018, AEP has deployed automated XMU with a CIM-based bulk approach [1]. While overcoming inter-corporate model inconsistency and realizing seasonal XMUs, the Model Authority Set (MAS) splitting and merging process in the bulk approach has contributed to lots of broken cross-reference associations. Association rebuilding is necessary in a vendor-specified EMS modeling environment, which adds to validation and testing effort, as well as incompatibility of the bulk approach to other EMS software. Additionally, MAS splitting increases database size dramatically over time, gradually slowing down the automated XMU process.

The CIM-based incremental approach was proposed and implemented to reduce validation effort, maintain XMU efficiency, and enhance compatibility with other vendor-supplied EMS software.

While sharing the swiftness in model customization and data format conversion, the incremental approach avoided MAS splitting, and only introduced modelling differences to the current EMS model. As a result, the number of broken associations is minimized, discrepancy clean-up became less of a burden, and the vendor-specific EMS modelling environment is no longer a must for the execution of XMUs. Hereby, the general applicability of the proposed CIM-based XMU is enhanced, as entities using different EMS software can now benefit from it.

2. Methodology

The proposed incremental approach is carried out in two different modelling environments: an API-driven CIM application [7] and a CIM-compatible EMS modelling tool [8]. Real-time system models are archived as structured databases in both environments, where each category of components form a class and the component parameters and associations become its attributes. The compatibility between the two allows them to honor the structural definitions from each other. As a result, a CIM formatted database can be easily converted to EMS relational format and vice versa. Hence, the core idea of the CIM-based incremental XMU is simplified to "Extract->Compare->Merge". Fig. 2 illustrates the procedure of implementing the proposed approach.

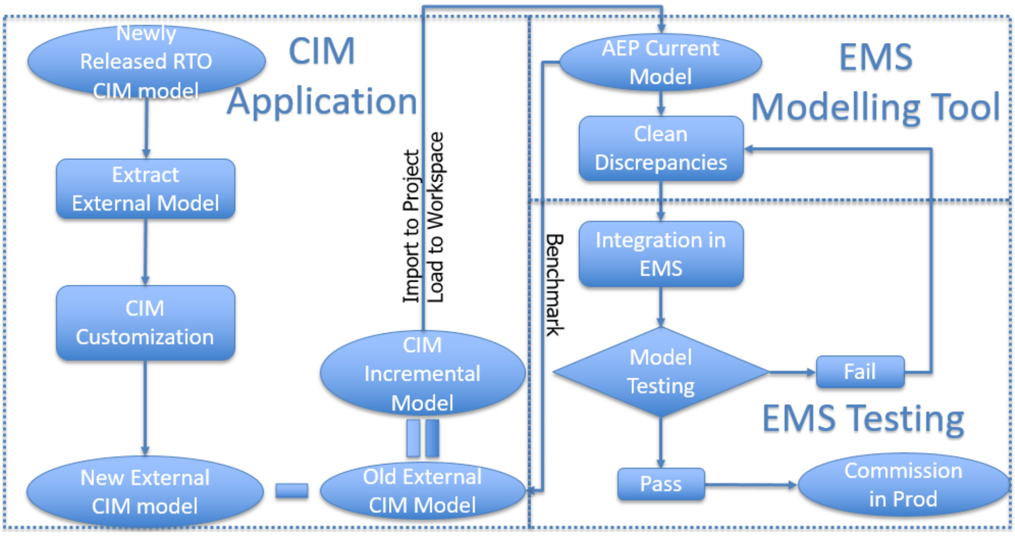

Fig. 2 Procedure of Implementing the CIM-based Incremental XMU

The CIM-based Incremental XMU is implemented via the following steps:

1) Model Extraction: Model boundaries are delineated and external components in need of updating are clipped out from the rest of the RTO model.

2) CIM Customization: The external model is aggregated and extended to be inclusive of all necessary information in the CIM application. All the extensions are to be declared in a Resource Description Framework Schema (RDFS) document [9] for the EMS modelling tool to recognize.

3) Model Comparison: The newly customized external model is compared with the old one from previous XMU and an incremental model containing all the differences is produced.

4) Increments Merging: This CIM incremental model is imported as a project file and merged with AEP's current EMS model, so all the modelling changes can be installed.

5) Modelling/EMS Validation: To pass modelling validation, SQL scripts are written to reconnect the limited number of broken associations; To pass EMS validation, the post-XMU model must go through peer review and a two-week testing run, during which online study contents are amended to reflect the XMU changes.

6) Commission: the XMU integrated model is deployed in the production system after passing peer review and finishing testing without encountering issues.

With RTOs releasing CIM-formatted regional model periodically, the above steps are repeated seasonally to keep AEP's EMS model up-to date. For AEP footprints interacting with multiple RTOs, several XMUs are needed to bring the model completely in sync with reality. The following chapters will elaborate each step of the CIM-based incremental XMU.

3. Boundary Delineation

As the first step of XMU, the boundary between internal and external grids needs to be identified so that components in need of updating can be clipped out from the RTO released regional model. Generally, AEP's external grids consist of neighboring companies with footprints which are crucial to online studies. Within the footprint of AEP West (AEPW), which is vast and heavily interconnected, AEPW shares tie-lines with 11 Southwest Power Pool (SPP) companies and six Midcontinent Independent Operator (MISO) companies. Those external companies have direct coupling to AEP's western footprint, are considered essential and are modelled in detail in AEP's EMS. With real-time measurement data streamed in via Inter-Control Center Communications Protocol (ICCP), their network devices participate in AEP's online studies and affect the solution quality. Hence, those essential companies are targets of XMU.

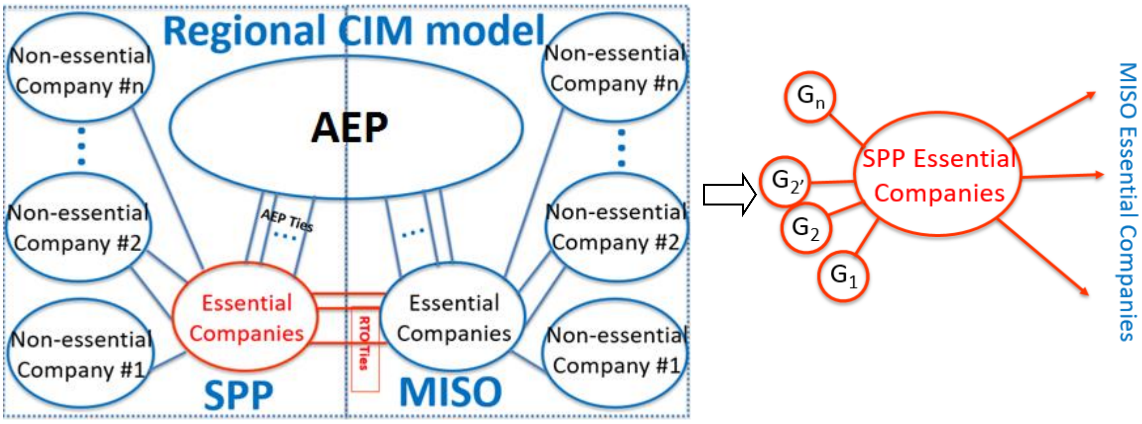

Fig. 3 Separating AEP External Contents from SPP Regional CIM model

Currently, AEPW needs two XMUs seasonally to complete the updating of all external EMS components. Extra work will be accomplished in the future to merge those two XMUs into one. XMU regards tie-lines between AEPW and external companies as internal, thus not to be updated. For SPP XMU particularly, tie-lines between SPP essential companies and MISO essential companies are considered as components of AEPW's SPP external network. Therefore, these are included in the SPP XMU. Non-essential SPP companies are not modelled in detail in AEP's EMS, thus those with their tie-lines connecting to essential SPP companies are equalized to pseudo units. The process of separating the external grid in the SPP XMU is displayed in Fig. 3, where XMU-targeted components are highlighted in red. Boundary management concerning tie-lines and pseudo units is detailed in sections 3.1 and 3.2.

3.1 Tie-lines

Splitting of tie-lines is the first step of extracting the external model. By CIM formats, tie-lines constitute a line segment with two terminals connecting to near and remote stations. For AEP ties, namely tie-lines between AEP stations and external ones, the split-off points locate at the remote terminals, as demonstrated in Fig. 4a. On the other hand, for RTO ties that link stations positioned in two different RTOs, the split occurs at near terminals, as exhibited in Fig. 4b. After splitting, the remote terminals of AEP ties remain in the external model, while the near terminals of RTO ties are excluded from XMU.

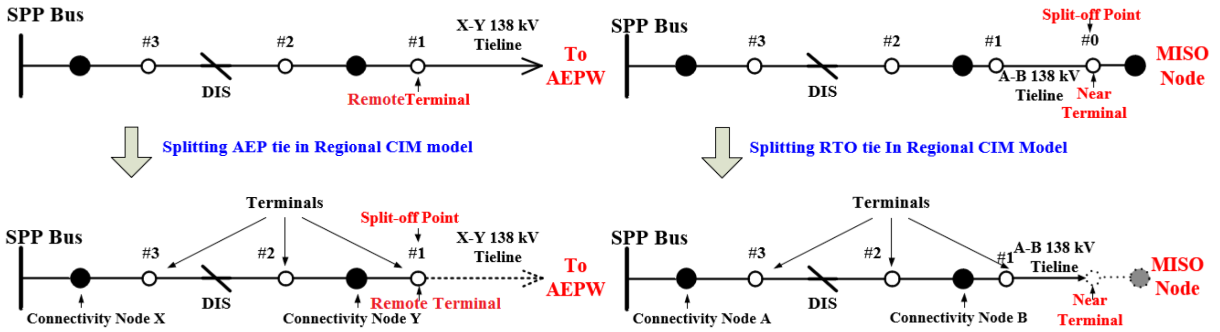

Fig. 4 a, Splitting AEP ties in Regional model; b, Splitting RTO ties in Regional Mode

3.2 Pseudo Units

Pseudo Units are used to equivalize non-essential interconnections. They mark the boundary of AEP's EMS monitoring scope. Considered as pure injections to the grid, they are completely off-regulation with generator-specified parameters defaulted to zero. Replacing the lines linking essential and non-essential companies, they inherit the line ratings as their own, so that flow injection to AEP's EMS can be reasonably regulated. Fig.5 used pseudo units to explain the network equivalization and delineation of EMS monitoring boundary.

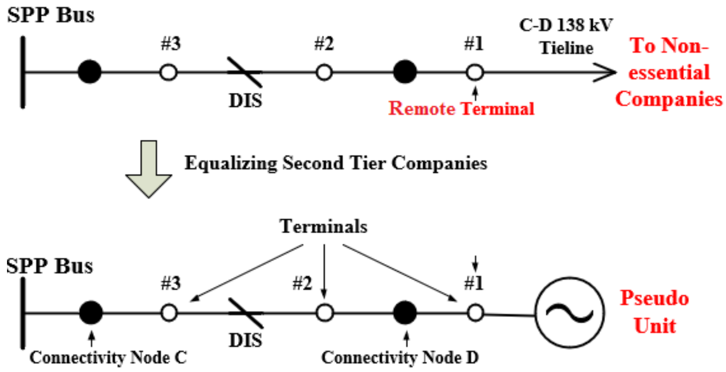

Fig. 5 Equalization and Boundary Delineation by Pseudo Units

With tie-lines cut open and EMS border marked by pseudo units, the external network for XMU is extracted from the RTO model. Usually, the extracted model size is one third of the regional one, easing the procedure of adding utility specified customizations.

4. Model Customization

Following the RTO convention, the regional model is highly equivalized and omits many utility-specified details to ease data exchange. Hereby, the external model derived from it requires extensive customizations before commission to EMS. Those customizations include information aggregation to supplement necessary modelling details, CIM extension to declare AEP-specified attributes and RDFS profile revisions to formalize those supplementations and extensions.

4.1 Information Aggregation

The EMS database contains multiple layers of modelling, including a network model, Supervisory Control and Data Acquisition (SCADA) model and ICCP model. The network model defines topology. The SCADA model allocates measurements. The ICCP model realizes data exchange between AEP and external entities. Mostly, the external model comes with only basic network information. Details concerning SCADA, ICCP and even references that regulate online operation are to be supplemented using catalogue files and real-time exports from the RTOs. Fig. 6 illustrates the process.

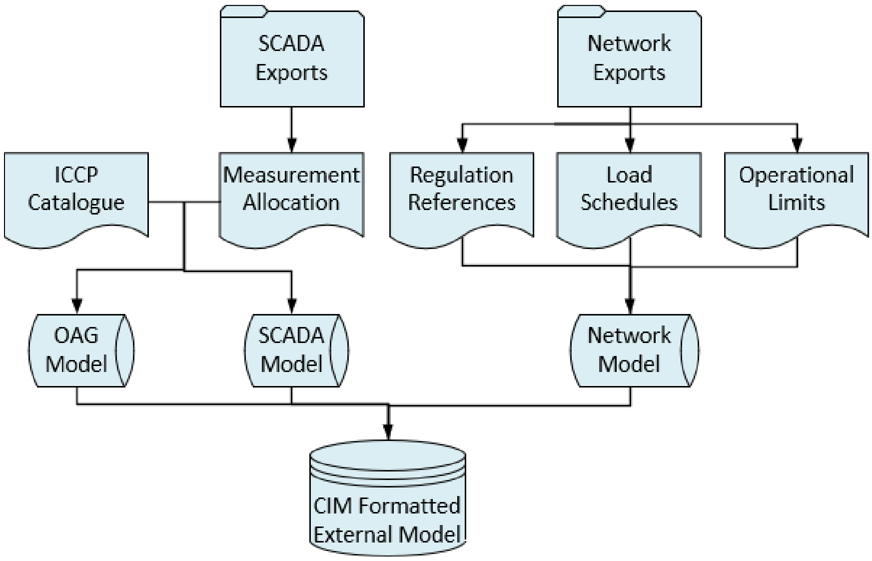

Fig. 6 Aggregation to Include SCADA, ICCP and Network Regulation Data in External Model

The ICCP Catalogue, SCADA and network exports shown in Fig. 6 are converted to a group of mapping files by the RTO. They correspond with ICCP object names, measurements and schedules to specified network devices. Via Python scripts, such correlations are reflected in CIM as user-defined associations linking existing objects and newly created ones. The newly created objects complete the network layer and supply the ICCP and SCADA information to the external model. To clearly describe the relationships among multiple layers of modeling, more utility-specified attributes need to be extended in the CIM.

4.2 CIM Extension

CIM extension is an effective way to act on the XML-formatted database and brings in new classes of objects. Fig. 7 displays the extension of the AEP-specified class "EquipmentGroup". Each object of "EquipmentGroup" is assigned to telemetered equipment and hosted by a SCADA-observable substation. As name uniqueness is rare among telemetered devices harbored in the same station, "EquipmentGroup" differentiates their device types and clarifies their identity for ICCP mapping. Serving as a three-way bridge interconnecting network, SCADA, and ICCP, class "EquipmentGroup" is essential for real-time operation.

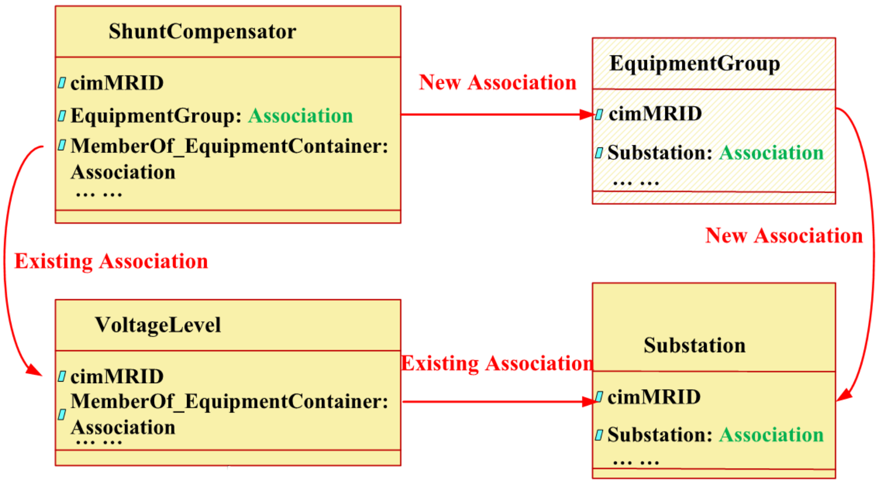

Fig. 7 Extension of class 'EquipmentGroup"

Each object in CIM, either provided by RTO or extended by AEP, shall be assigned a unique ID, namely “cimMRID”. The cross-reference links between objects are established by pinpointing each other’s “cimMRID”. With a handful of new classes introduced and cross-referenced to CIM standard, all AEP required customizations are meshed into the external model in which close interactions among ICCP, SCADA and network are expounded. The CIM extensions eliminate ambiguities in model interpretation and align the external model with an AEP-specified format. With proper documentation in the CIM profile, the objects and associations in the external model will be honored by the EMS modeling tool and be ready for model merging.

4.3 Profile Revision

The RDFS profile serves as translator between the CIM application and the EMS modeling tool. In order to be recognized by EMS, every class and attribute of the external model, no matter standard or customized, should be declared in the RDFS profile. By creating separate namespaces for user-defined extensions [10], the RDFS document formalizes the specified CIM ontology, while delineating AEP customized components from CIM standardized ones. As utilities rarely introduce architectural changes to EMS databases, the RDFS profile requires little maintenance, once finalized. It can be used repetitively and serve to validate all required customizations in the external model. Fig. 8 elaborates declarations in the RDFS profile concerning class “EquipmentGroup” and its cross-referenced shunts and substations.

```
<rdf:Description rdf:about="http://iec.ch/TC57/2007/CIM-schema-cim12#ShuntCompensator.EquipmentGroup">
  <cims:inverseRoleName rdf:resource="http://iec.ch/TC57/2007/CIM-schema-cim12#EquipmentGroup.ShuntCompensator" />
  <cims:multiplicity rdf:resource="http://iec.ch/TC57/1999/rdf-schema-extensions-19990926#M:0..1" />
  <rdfs:comment>EquipmentGroup</rdfs:comment>
  <rdf:type rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#Property" />
  <rdfs:label>EquipmentGroup</rdfs:label>
  <rdfs:range rdf:resource="http://iec.ch/TC57/2007/CIM-schema-cim12#EquipmentGroup" />
  <rdfs:domain rdf:resource="http://iec.ch/TC57/2007/CIM-schema-cim12#ShuntCompensator" />
</rdf:Description>
<rdf:Description rdf:about="http://iec.ch/TC57/2007/CIM-schema-cim12#EquipmentGroup.Substation">
  <cims:inverseRoleName rdf:resource="http://iec.ch/TC57/2007/CIM-schema-cim12#Substation.ChildEquipmentGroup" />
  <cims:multiplicity rdf:resource="http://iec.ch/TC57/1999/rdf-schema-extensions-19990926#M:0..1" />
  <rdfs:comment>
    Substation
  </rdfs:comment>
  <rdf:type rdf:resource="http://www.w3.org/1999/02/22-rdf-syntax-ns#Property" />
  <rdfs:label>Substation</rdfs:label>
  <rdfs:range rdf:resource="http://iec.ch/TC57/2007/CIM-schema-cim12#Substation" />
  <rdfs:domain rdf:resource="http://iec.ch/TC57/2007/CIM-schema-cim12#EquipmentGroup" />
</rdf:Description>
```

Fig. 8 RDFS Declaration of Class “EquipmentGroup” and Its Cross-References

5. Incremental Installation

With the external model fully customized to satisfy AEP specification, the installation process begins. Starting with CIM comparison, the result is an incremental model obtained in CIM format. This is followed by merging, in which the incremental model is converted to an EMS project and loaded into the EMS modelling tool. At last, cross-reference links are established to bring in newly added EMS objects, which is a major step to clean up errors and realize modelling validation.

5.1 Compare and Merge

Via model comparison, the CIM application generates an incremental database that archives modelling differences into three categories: Added, Updated and Deleted. This incremental database is XML-formatted and editable by users. With each category of modelling changes grouped in specified sections, the incremental database is easy to parse. Structured similarly to the RDFS profile, modelling differences on AEP extensions stand out from RTO standardizations with separate namespaces. Therefore, any possible errors overlooked during the customization process can be caught easily. Fig. 9 illustrates the process of acquiring the incremental model via CIM comparison and merging incremental changes with AEP’s current model via EMS project loading.

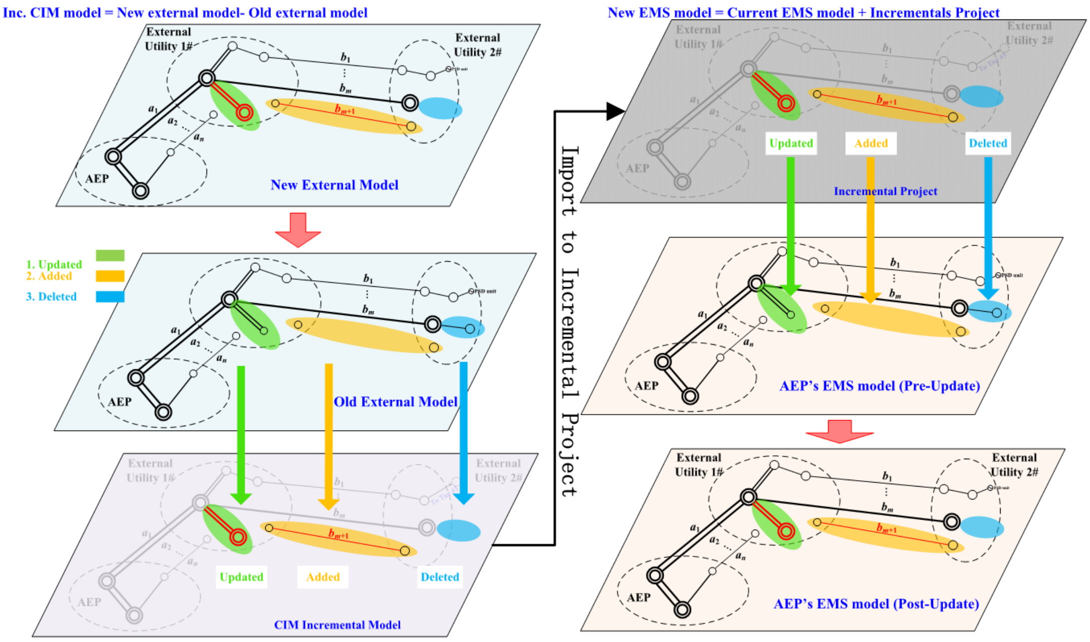

Fig. 9 Incremental Integration via Comparison and Loading

The old external model depicted in Fig. 9 refers to the customized external model used for the previous XMU. At times, some emergency projects affecting AEP external grids are deployed between XMUs. Under those circumstances, extra edits on the old external model are necessary to reflect those projects. Thanks to the strong API capability and explicit interpretation enabled by the RDFS profile, data transfer between EMS and CIM is simplified and benchmarking the CIM model with EMS becomes effortless.

The CIM incremental database associates modelling differences with corresponding network or SCADA devices labelled with cimMRIDs. It is translated to an EMS incremental project, once deemed reliable and inclusive of all necessary XMU changes. The RDFS profile plays the crucial role during the translation and ensures that each CIM class is mapped to the right EMS table. Consequentially by matching cimMRID, each XMU change finds its way to the right EMS component as the incremental project is loaded on top of the MAS that hosts AEP's current model.

5.2 Clean-up

The newly imported objects need to be meshed into EMS database with cross-reference links. As indicated in Fig. 10, newly imported "EquipmentGroups" are missing "EquipmentGroupType", which is an internal reference facilitating the communication between the telemetered device and the ICCP model. Being an internal reference, "EquipmentGroupType" is never part of CIM standardization nor customization. Hence its relations to external "EquipmentGroups" are to be maintained in the EMS modelling tool, alone, as part of merging process. The installation of incremental updates will not invalidate cross-reference links between internal components and commissioned external ones. The maintenance effort is limited to building links to bring in new external components. With XMU performed seasonally, instances of massive additions are few. The construction of a handful of cross-reference links can be automated with Structured Query Language (SQL), as suggested in Fig. 10. Modelling validation is achieved during the process and the EMS model shall then be exported to the testing environment.

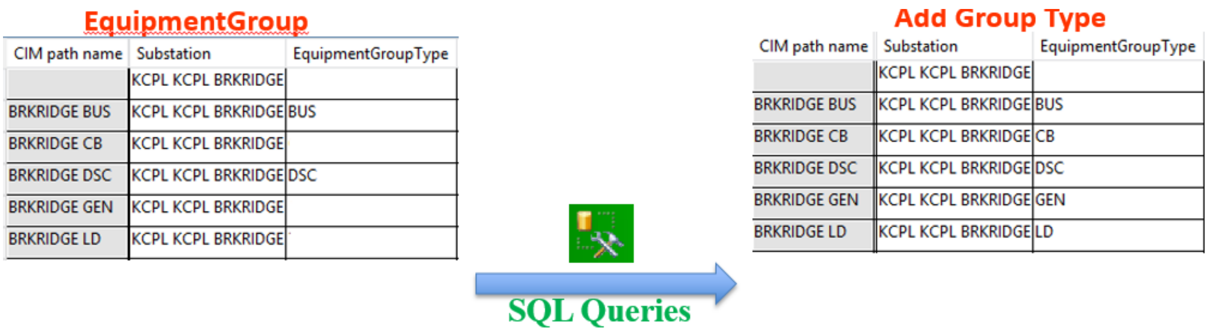

Fig. 10 Building Cross-reference links to assign EquipmentGroupType to External EquipmentGroup

6. Validation and Commission

AEP EMS/SCADA team has applied the proposed incremental approach to fulfill five XMUs: three times in SPP and twice in the Pennsylvania-New Jersey-Maryland Interconnection (PJM). As the last step before commission, a two-week testing run is conducted, during which the updated EMS model undergoes peer review, with displays updated to reflect XMU edits. Online study contents, such as contingency and Line Outage Distribution Factors (LODF) definitions are amended as well, to accommodate system condition changes brought by XMU. Loaded in a testing EMS server, the updated real-time system model supports online applications as it would in the production server. As presented in Fig. 11, major applications in our EMS system, including Real Time State Estimation (RTNET), Real Time Contingency Analysis (RTCA) and Real Time Line Outage Distribution Factor Calculation (RTLODF) are functioning properly. Moreover, the alarm system is providing notifications in real time for system violations — an indication that the measurements are mapped correctly and working properly. With all EMS applications functioning as expected, the post-XMU model is deployed to production.

In contrast to the bulk approach, in which thousands of equipment elements are replaced, the CIM-based incremental approach confines database upgrade to only hundreds of XMU-targeted modelling changes. As a result, the time consumption on updating display and online study definitions is reduced. Chances of human errors are further reduced, as well. Moreover, thanks to the incremental CIM model, XMU changes can be archived, just as the manually maintained internal ones. With every modelling change traceable, the efficiency of managing real-time operation models enhances significantly.

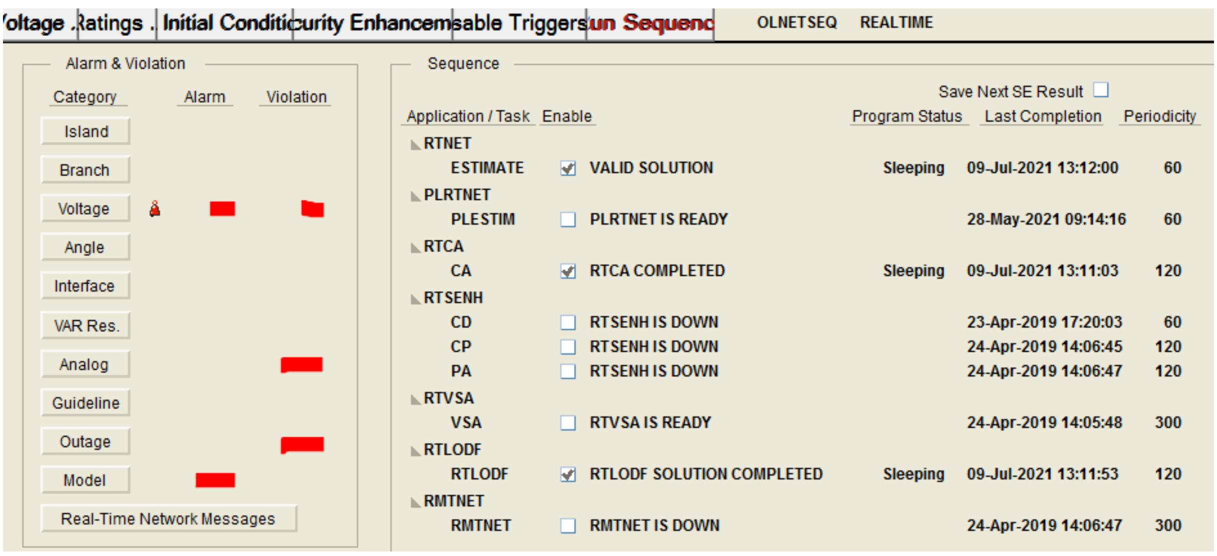

Fig. 11 Valid State Estimating Results and Completed RTCA in Real-time

7. Conclusion

This paper elaborates a CIM based incremental approach for external model update. With the systematic procedure concerning model customization and boundary management preserved, the proposed incremental approach smooths cross-entity model exchange and yields a highly accurate EMS model, just as the bulk approach does. Contrary to the bulk approach, the incremental approach only targets external modeling changes. This enhances XMU efficiency even more, by reducing post-merge effort, such as validation error clean-up and online study definition revision. In addition, as the process is consolidated by CIM standards and the majority of modeling work is completed in the CIM application, the proposed approach demonstrates enhanced versatility due to compatibility with a wider range of vender-supplied EMS tools. With the CIM-based incremental XMU performed seasonally in all three areas of its footprint, AEP catches up with RTOs in deploying the most up-to-date database through production.

The contributions can be summarized as following:

1) Via incremental updating, the proposed approach further speeded up a cumbersome, yet crucial part of regular EMS database maintenance, saving much time while minimizing modeling errors. As a result, the credibility of EMS model and online study results are dramatically enhanced.

2) The proposed approach presents enhanced applicability to a wider range of utilities due to the introduction of incremental modelling on top of the application of the CIM standards, as it became compatible with various EMS modeling tools while maintaining model interoperability across different entities.

3) This documented approach provides an answer to the challenge concerning utility big data management under the growing complexity of today’s highly interconnected grids, as it achieves veracity and velocity simultaneously, in spite of data volume and variety.

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