Implementation of a CIM-Based Semantic Interoperability Strategy for Smart Grid in Mexico

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Abstract: - This paper shows the physical and logical architecture used to implement a Semantic Interoperability Strategy based on the Common Information Model (CIM), IEC 61968, IEC 61970 and related standards for the Smart Grid of the Comision Federal de Electricidad (CFE by its Spanish acronym) in the Valley of Mexico - Centre (DVMC by its Spanish acronym). Methodology, adopted standards and implemented software tools are discussed. A description of the benefits is included and a Web Application is described, that is fully developed and based on the new infrastructure linked to the legacy enterprise systems by CIM Wrappers.

Key-Words: - Semantic Interoperability, Common Information Model (CIM), Smart Grid, Enterprise Architecture, Enterprise Service Bus (ESB)

1 Introduction

Many references describe the Common Information Model (CIM), for example, "The Common Information Model (CIM) is an open standard for representing power system components." [3], as well as "CIM is an Information Model that applies the Object-Oriented paradigm of Software Engineering in order to represent the elements of the real world that are used for the infrastructure, management and operation of the electric systems of Transmission and Distribution, such as cables, lines, transformers, switches, protections, structures, poles, measurements, among others." [1].

The CIM is a generic, open and standard Model defined in a group of standards of the IEC, being the most important: IEC 61970-301, IEC 61968-11 and IEC 62325-301 [3], [1].

Many works related to CIM have been performed for many years, proof of concepts, prototypes, demonstrations, interoperability tests, systems integrations, standardization, extensions to integrate new utility fields, software tools for supporting the adoption process, and successful deployments. Currently, there are some documented case studies related to the present CIM implementation in utilities. The DTE Case Study report [2] introduce that in DTE Energy "Any single integration that used to take 3-4 weeks now can often be done in 3-4 days", also adds that "There is an upfront cost to implementing the CIM message for the first time and determining what part fits for that use case but the total cost of ownership is less because that initial effort is not repeated for every new interface or change".

Many documents show, in different levels, the CIM philosophy, and its adoption process [1], [3], [6], and the direct relation to the Enterprise Architecture is evident [5], [8], and its impact to Smart Grid strategies [4], [12].

In this sense, an implementation of a CIM-Based Semantic Interoperability Strategy in a utility must fulfill many requirements, including: international standardization for information modeling; efficient, secure and standard data interfaces for information exchange; a long term plan to integrate an Enterprise Architecture in order to align systems, business process and strategy objectives, among others.

2 Problem Formulation

The Valley of Mexico – Centre (DVMC by its Spanish acronym) at Comision Federal de Electricidad (CFE) is in charge of electric power supply to at least 2 millions of customers in Mexico City and metropolitan area of The State of Mexico, the most important and populated city in Mexico.

2.1 Point-to-point integration

Many software systems are necessary to operate and manage business process related to the Electric Power System in all levels, control systems, transmission operations, distribution operations and management, stability control and data log, electric flow optimization, commercialization, data monitoring, transactions management, billing, customer relationships management, among many others; traditionally each software system whether from different software companies or home-made. Each component of this ecosystem of "solutions" use a proprietary data format and include valuable information for other system or business process in the value-chain of energy supply, for example, daily demand profile is necessary to dispatch the energy market in a deregulated power industry.

Exchanging data between legacy software systems is always problematic and traditionally a point-to-point strategy is applied.
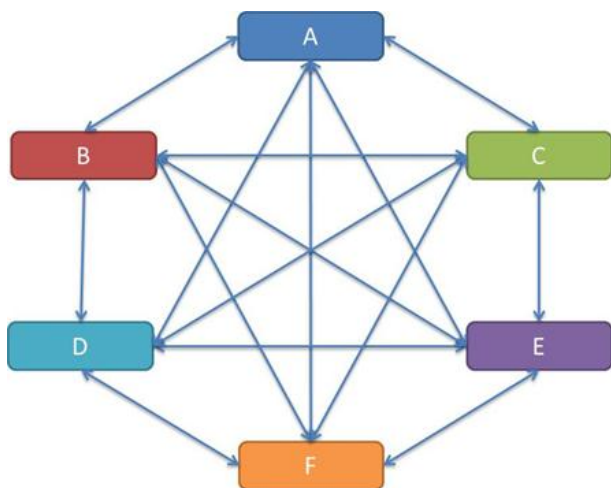

Fig. 1. Traditional point-to-point integration strategy.

2.2 Enterprise Application Integration

Enterprise Application Integration (EAI) replaces these dedicated links with a single communication link called a "message bus". Using middleware services, this provides a mechanism for applications to communicate using a pre-defined message format and requires only a single interface to be written for each application. [3]

For applying the EAI in a utility, many standards and best practices must be adopted, for example generic services loosely-coupled are necessary in order to replace each specialized and highly-coupled interface, a well-defined data model must agree with the meaning of exchanged information, a service oriented architecture (SOA) using the associated technology as Web Services, XML, UML, etc. and an Enterprise Service Bus (ESB) in order to include an efficient, agile and robust data exchange technology in a standardized format.
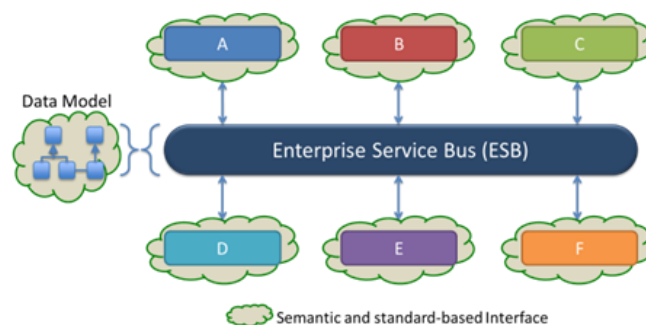

Fig. 2. Enterprise Application Integration strategy using semantic and standard-based interfaces.

In this new paradigm for systems integration, many challenges must be addressed:

- A common data model must agree and must explain the meaning and business process mapping for each exchanged data.
- Duplicity, inconsistency and incompatibility must be resolved [5].
- Avoid specialized and highly-coupled interfaces.
- Changes in one system and new systems integration must have minimal impact on other existing systems.
- Improve the situational awareness and governability about information exchange.
- Allow integrating complex event processing and advanced analytics functions.
- Integrate a secure architecture in order to improve cyber security.

3 Problem Solution

The architecture solution for implementing an Enterprise Application Integration strategy have many options, this section shows the specific architecture selected for the implementation of a CIM-Based Semantic Interoperability Strategy for Smart Grid at CFE in the Valley of Mexico–Centre.

The energy Distribution process at DVMC is managed by many operational systems, the most important are:

- SCADA at the Distribution Control Center.
- Distribution Management System (SIAD).
- Steady state monitoring, and energy quality supervision (SIMOCE).
- Licensing and manoeuvres management (GIL).

- Advance metering infrastructure for customer consumption monitoring (AMI/MDM).
- Geographical Information Systems (SIGED).
- On-Line Simulator for analysis and fast restoration in failure case (SimSED).
- Customer relationship management and services requesting (SICOM and SICOSS).
- Billing (SICOM).

The first implementation of a CIM-Based Semantic Interoperability Strategy for Smart Grid at CFE in DVMC includes the most important information exchanged between some of these main systems.

3.1 Semantic Interoperability
Interoperability refers to the capability of two or more networks, systems, devices, applications, or components to exchange and readily use information securely, effectively, and with little or no inconvenience to the user. [4].

For this paper, Semantic Interoperability refers to second category in the framework defined by the GridWise [8]. The semantic category focuses into what information is exchanged and its meaning. It establishes the understanding of the contained concepts in the data structures of exchanged messages, and integrates knowledge of the business related to the semantics or meaning in the work flow of a process. [1].

3.2 Implemented Architecture
The implemented architecture (Fig. 3) considers an integral solution for the Enterprise Application Integration at DVMC and includes many components, the most important are:

- Generic **Enterprise Service Bus** (ESB) in order to integrate a middleware to abstract the data layer and data sources, and supporting the SOA implementation.
- **CIM-based interfaces** or "CIM Wrappers" as is defined in [1]. Each integrated system by ESB, uses a CIM Wrapper.
- **Data Model Manager** in charge of managing the CIM Profiles governability and ensuring the unification capability of the many partial CIM Profiles.
- **Data Associations Manager** in charge of executing logic associations between legacies ID's of legacy systems.
- **Client application** for CIM Instance consumption. It calculates the Phase Unbalance in Distribution feeders and shows the profile behaviour in time. It includes a database

simulating a "DataMart" for calculated values and to improve the user time response and experience in general.
- **OPC UA interfaces** to integrate real-time and historical data by SCADA and SIMOCE. The CIM Based interfaces include a data access layer implemented by means of OPen Connectivity Unified Architecture standard.
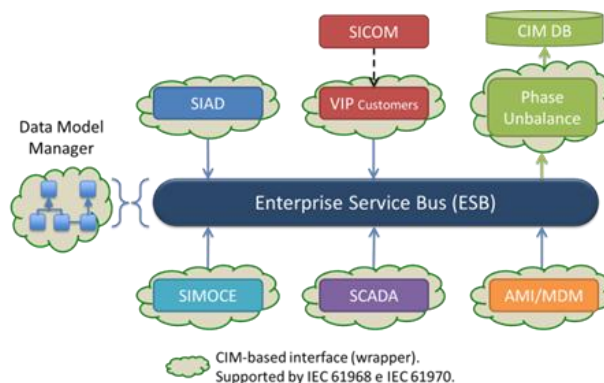

Fig. 3. The CIM-Based Semantic Interoperability Strategy implemented for Smart Grid at CFE in the Valley of Mexico – Centre.

This architecture runs in a cluster integrated by 3 Physical servers considering 28 Cores and 48 GB of RAM (total).

4 Standards and Methodologies
Standardization was the main objective to reach in the DVMC – Semantic Interoperability strategy, some of the most important standards and methodologies are:

Data Model Standards:
- IEC 61970-301 which defines the CIM Base for Transmission Power Systems for use in Energy Management Systems (EMS).
- IEC 61968-11 which defines the CIM extensions for Distribution Power Systems.
- IEC 62325-301 that establishes the extensions for the Electric Market or CME (CIM for Market Extensions).
- IEC 61970-501 which defines a CIM RDF Schema.
- IEC 61970-552 which defines the CIM XML Model Exchange Format.

Interface Standards:
- IEC 61968-1 which defines the interface architecture and general recommendations.
- IEC 61968-9 which defines standard interfaces format (for meter reading and control).
- IEC 61968-100 that specifies interfaces implementation Profiles.

- IEC 62541 which defines the OPen Connectivity Unified Architecture (OPC UA) used in industry for integrating standard interfaces and communication protocols between control systems.

Best Practices:
- Extensible Markup Language (XML) that defines a set of rules for encoding documents in a format which is both human-readable and machine-readable. It is defined by the W3C.
- Resource Description Framework Schema (RDFS Schema) provides basic elements for ontologies description (knowledge representation). It specifies how to formally describe the elements in an XML document.
- XML Schema Definition (XSD) allows to formally describe the elements in an XML document. It is defined by the W3C.
- Web Services is a method of communication between two electronic devices over a network. It is defined by the W3C.
- Windows Communication Foundation (WCF) is a runtime and a set of APIs in the Microsoft .NET Framework for building connected, service-oriented applications.
- Java Message Service (JMS) is a messaging standard that allows application components based on the Java Enterprise Edition to create, send, receive, and read messages. It allows the communication between different components of a distributed application to be loosely coupled, reliable, and asynchronous.
- Service Oriented Architecture (SOA) is a design pattern providing application functionality as services to other applications. It is independent of any vendor, product or technology.
- Business Process Model Notation (BPMN) is a graphical representation for specifying business processes, which is developed by the Object Management Group (OMG).

Methodologies:
- IntelliGrid Methodology for Developing Requirements for Energy Systems [12].
- CIM Extensions method as in [3].
- Unified Modelling Language (UML) to describe CIM components about the electric power system.
- Open Unified Process for incremental development process.
- Business process management (BPM) for implementing a process optimization process.

5 Software Tools
Software tools were used in order to integrate all components, from modelling to automatic code generation.

- Enterprise Architect: CIM modelling, extensions and formal description of information components.
- CIMtool: used by CIM Profile generation and validation. The output could be a RDFS Schema, an OWL or an XSD file that includes the knowledge representation of the information to exchange.
- CIMer: a home-made software tool to create automatically source code from a CIM Profile.
- CIMit: a home-made software tool to create CIM Instances files from a specific data source using a CIM Profile.
- Data Model Manager: a home-made software tool including many basic functions to manage many partial CIM Profiles, for each integrated legacy system

Data Model Manager includes functions to prevent inconsistencies among partial CIM Profiles, for example, many areas should model their organizational structure in the Unified CIM Profile in an organized and harmonized way.
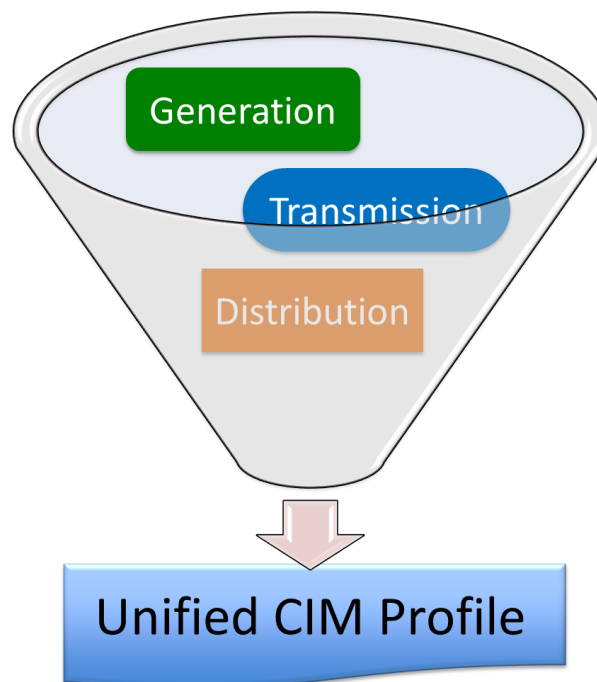

Fig. 4. Unified CIM Profile merging problem.

In this sense, all areas will try to use the same CIM Class to its highest hierarchical level.
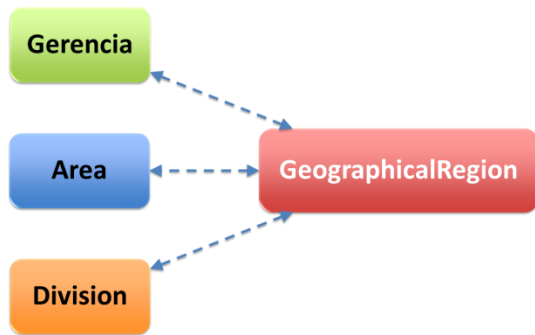
Fig. 5. Unified CIM Profile mapping problem.

Data Model Manager considers these problems and supports the unification ability for each partial CIM Profiles avoiding concepts overlap, errors in mapping and showing ambiguities.

6 Actual Benefits

When an Enterprise Application Integration strategy is implemented using real data, many new ideas are generated in order to integrate advanced functions; functions that previously were very complex due to many limitations of information availability and data consistency.

The first benefit of DVMC Semantic Interoperability strategy is the information availability and the ability to integrate many data sources from legacy systems using each a generic and unique interface. In this case, the developed Data Model Manager includes a Web Graphical User Interface (GUI) to explore the unified data model (CIM based) and CIM extensions, as well as, the ESB queues for each data source (legacy systems).

Fig. 6. The Web GUI for Data Model Manager includes a description of ESB queues for each data source integrated by CIM Wrappers.

The second benefit is related to ability to merge incompatible data. Using a BPM strategy, a business

process was described in order to calculate Phase Unbalance from Distribution feeders and the process was automated supported by CIM Wrappers.
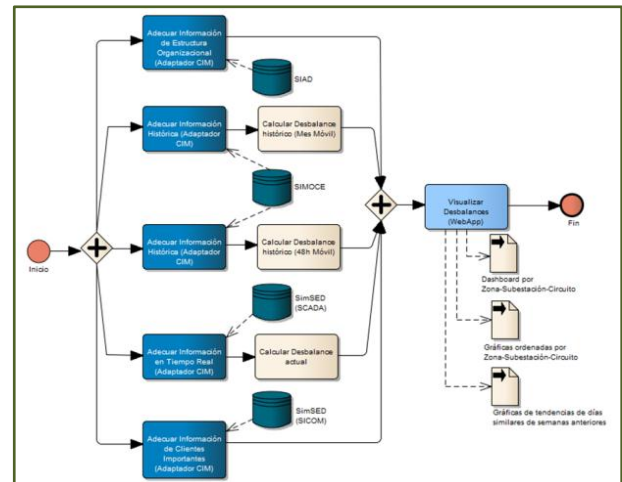

Fig. 7. The BPM diagram showing the process to calculate Phase Unbalance from Distribution feeders.

The application includes 3 time spans: Mobile Month (30 days before now), Mobile 48 Hours (2 days before now) and Real-Time (last acquired value). Mixed data sources includes SIAD (Enterprise organizational structure and electrical hierarchy), SIMOCE (Historical data) and SCADA (Real time data).

The business process for Phase Unbalance correction was completed considering many systems and external interaction, for example work orders for crew management, detailed analysis using on-line simulator, and results validations. Next figure shows a view of the full process.
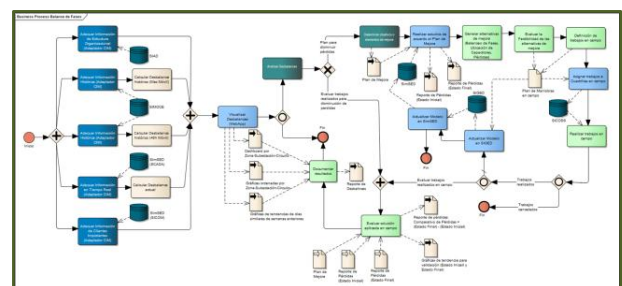

Fig. 8. The BPM diagram showing the full process to Phase Unbalance correction in the electric power distribution system.

The next benefit is about the ability to integrate new functionality, apply changes in any integrated system, even considering replacing any legacy system, having no impact on other existing systems and with no inconvenience to the user.

Finally, total time for systems integration was reduced, from many weeks to only some days and the total time for maintaining point-to-point interfaces was almost eliminated, because now CFE has the know-how about CIM philosophy, Enterprise Application Integration, SOA and standard services, as well as a robust infrastructure to support a CIM-Based Semantic Interoperability Strategy.

7 CIM-Based Solutions

Considering new capabilities, a new application was completely developed, CIM-Based using the current semantic interoperability strategy implemented at DVMC.

The main objective of the new solution is to integrate functions oriented to decision support at Distribution Control Centers for losses reduction by means of Phase Unbalance correction.

First question resolved is: Related to Phase Unbalance in Distribution feeders (Current, Real Power, Reactive Power and Voltage); which areas and feeders show the worst behaviour today?

Next figure shows the GUI for a dynamic dashboard for Phase Unbalance counting. It includes two time spans: Mobile Month and Mobile 48 Hours. Each parameter counted considers three levels and light colours code: Good, not Good and Bad.
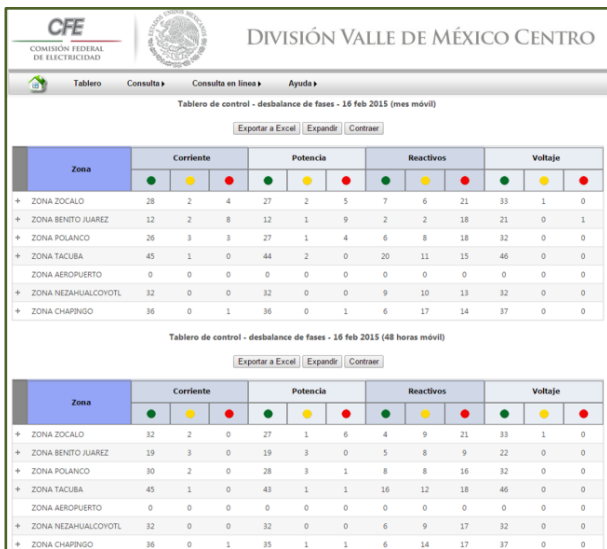

Fig. 9. Phase Unbalance dynamic dashboard.

For decision support, the analyst user can drill-down information and obtain detailed data, for example the feeders in red, average of per cent Phase Unbalance, average of Power Factor (PF) and capacitor compensation required to reach a PF>0.96.
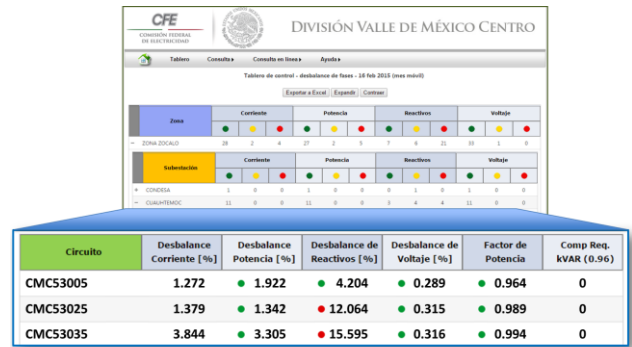

Fig. 10. Detailed information about Phase Unbalance in the same dynamic dashboard.

Next resolved question is: In a region (composed by many substations) or in a substation, how is the Phase Unbalance behaviour?

Next figure shows the average of Phase Unbalance for each feeder in a region, 4 similar graphs show each parameter (Current, Real Power, Reactive Power and Voltage) the user can reorder by each parameter and change between per cent or total magnitude. It includes three time spans: Mobile Month (Blue), Mobile 48 Hours (Orange) and Real time (Green).
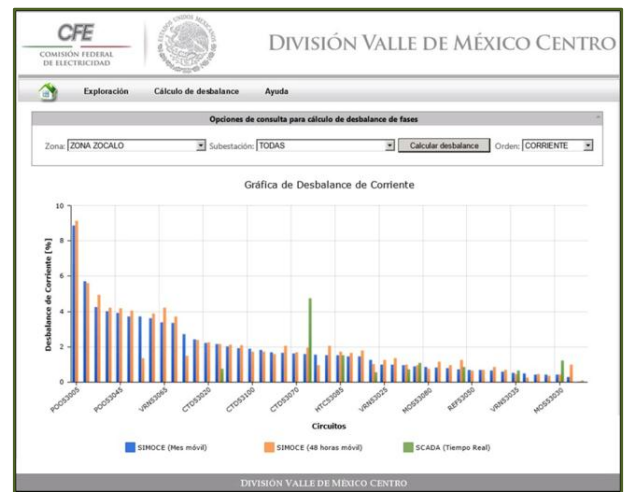

Fig. 11. Phase Unbalance for a region: Zone ZOCALO at DVMC.

Depending on user selection, the graph could show only feeders for a single substation; next figure shows the average of Phase Unbalance for Current (in percent mode), including only the feeders in a distribution substation at DVMC.

User could change criteria in order to obtain more details. Basic functions as zoom in, zoom out, panning and JPG export are included.
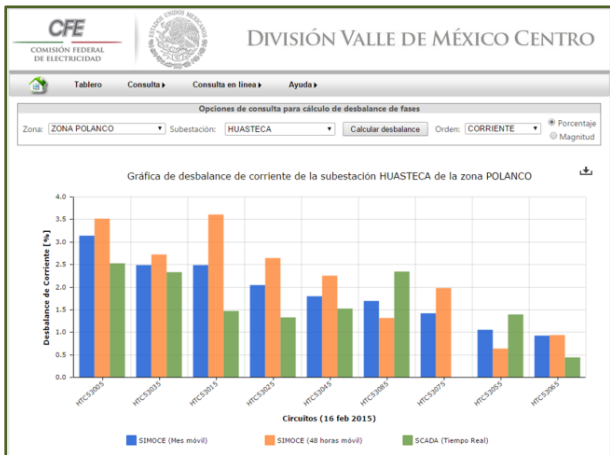
Fig. 12. Phase Unbalance for a Substation: Zone POLANCO, Substation HUASTECA at DVMC.

When a correction in the real electric power distribution system is applied, the verification of the correction is very important in order to validate field actions and their repercussions in losses reduction. The new resolved question is: How the action impacts the electric Phase Unbalance daily profile?

Next figures (Fig. 13 and Fig. 14) shows the behaviour of the daily profile for each parameter (Current, Real Power, Reactive Power and Voltage), graph can be parameterized by a previous date (more than 4 weeks before) and an additional date (between previous date + 4 weeks and now). In this graph, an analyst can compare real impacts in the electric Phase Unbalance for the same weekday, for example the 4 Mondays of the past month against the Monday of the past week.
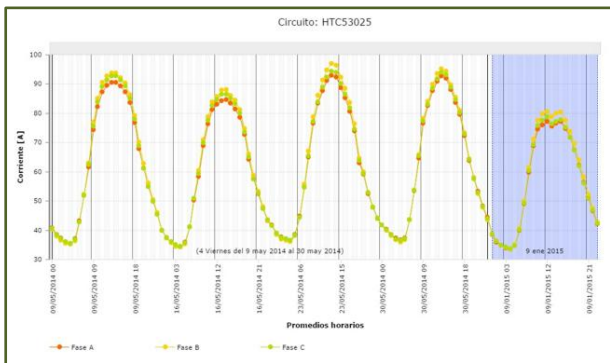

Fig. 13. Feeder daily profile comparison (Current). Zone POLANCO, Substation HUASTECA, Circuit HTC53025 at DVMC.

This profile graph shows evidence of real impact related field actions and its repercussions in losses reduction.
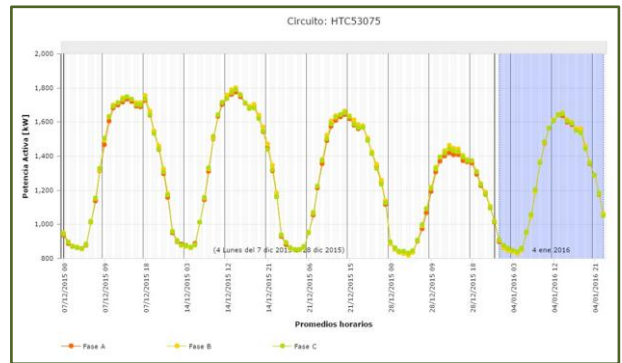

Fig. 14. Feeder daily profile comparison (Real Power). Zone POLANCO, Substation HUASTECA, Circuit HTC53075 at DVMC.

Additionally, when a failure occurs in the electric power distribution system, it is mandatory to have a data source for very important affected customers. The new question resolved is: How many and which VIP customers were affected for an event?

Next figure shows the VIP customers information associated to each feeder.

Fig. 15. VIP customers information for Circuits of Substations in Zone POLANCO at DVMC.

8 Conclusions

CIM adoption process is not an easy path, it is necessary to integrate a great strategy, robust infrastructure, mature standards, best practices, formal methodologies and expert people in order to reach real objectives.

Shared knowledge, experiences and results are very important for scientific community; DTE Energy proposes "Also, organized meetings and events to get multiple utilities in a room to share and develop common requirements and semantic models would have been beneficial" [2].

Experience in CIM adoption processes shows positive results in the majority of the cases because the common modelling by itself minimizes the inconsistency mistakes and duplicity of information.

Smart Grid will be a great and complex system of systems interacting together; a Semantic Interoperability strategy is an essential component for power grid modernization.

Implementing a Semantic Interoperability strategy in a utility, new advanced functions will be available to develop in a near future, such as demand side response, real time pricing and demand peak shaving, among others.

Acknowledgements

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