On-Line Simulator for Decision Support in Distribution Control Centers in a Smart Grid Context

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Abstract: - This paper shows the physical, logical and functional architecture designed for integrating an On-Line Simulator of Electrical Distribution Networks (SED by its acronyms in Spanish) for decision support in Distribution Control Centers in Mexico. The main objective is the integration of engineering functions for distribution networks (power flow, short circuit, optimal reconfiguration, reliability, among others) and an Expert System (Case Based Reasoning) in order to support the processes of information analysis, decision making and training on the job at Regional Control Centers of Comision Federal de Electricidad (CFE by its acronyms in Spanish). The On-Line Simulator is installed, updated and in operation in a Distribution Control Center (Zona Tampico) and in a Regional Center for analysis and monitoring (Division Golfo Centro). Currently the On-Line Simulator is in use to establish the Semantic Model (CIM based) in order to integrate the CIM interoperability architecture for systems supporting Operations for Distribution Networks in Mexico.

Key-Words: - Simulator, CIM, Smart Grid, Electrical Distribution Network, Real-Time data, On-Line data, SCADA, DMS, optimal restoration, Decision Support System.

1 Introduction

Nowadays, Distribution Control Centers are equipped with SCADA systems that in case of failures, allow monitoring and operating equipment for sectioning. It can be done either by remote controls or manually, in such a case, it is carried out by sending crews directly to the potential point of failure. The ability to respond to failures or events depends directly on the knowledge and experience of the Operator on duty; this knowledge and experience is mainly acquired in the Distribution Control Center with on-line training or on the job training, therefore, the Operators do not have the opportunity to experiment, analyze and compare results of several configurations. This operation scheme inhibits carrying out tests for reconfigurations of Distribution Networks in order to observe behaviors as well as analysis of reliability indices and thus support decision making.

In this context, the On-Line Simulator is an engineering tool that allows studies of behavior and short-term prediction with updated on-line information in order to establish normal and contingency operation plans, optimal restoration strategies supported by calculation of indices and objective functions as well as automatic verification of safety and operational levels (voltage profile, load profile, loss minimization, among others).

2 Electrical Distribution Network

The Electrical Distribution Network is the National Electrical System, located within a certain geographical area, which counts on facilities in high, medium and low voltage, in order to supply the electrical service to customers of the Utility in different voltage levels.

The Distribution Control Centers in Mexico are built to operate, monitor and ensure the electrical supply in medium and low voltage according to already established commitments with customers, fulfilling the basic objectives of security, continuity, quality and economy.

The basic functions of the Operators at Distribution Control Centers are as follows:

- Operating and supervising the Distribution Network under their responsibility, considering safety, quality, continuity and economy in accordance to policies and rules of the National Electrical System.

- Analyzing requests for operations and approving equipment licenses.
- Managing licenses in equipments in the Distribution Network.
- Analyzing and coordinating work force to integrate new installations.
- Updating the one-line diagrams of substations and circuits.
- Analyzing events and disturbances that affect energy supply and developing contingency plans.
- Supervising the accomplishment of customer commitments in medium and high voltage circuits.
- Following up availability of electrical service and installed equipment (RTU's, remotely sectioning, reclosers, transformers, etc.).
- Responding to requests from users in high voltage (operations, restoration and quality of energy).

Summarizing, an Operator must supervise the accomplishment of various indices for each objective:
- **SECURITY**: Reliability, Availability.
- **CONTINUITY**: Time of Interruption for User, Restoration Time, Licenses.
- **QUALITY**: Harmonics, Voltage Sags, Unbalance, Swells, Flickers.
- **ECONOMY**: Productivity, Losses, Costs.

Considering traditional tools used in Distribution Control Centers, estimation and supervision of some indices are not a simple task, since it involves the use of complex mathematical models, numerical analysis and calculation sequences that can consume a lot of time and resources. Thus, the need to design, integrate, install and operate a computer tool in order to support the substantive work of the Operators and with it contribute to strategic plan as well as improving productivity and competitiveness levels.

3 Logical Architecture

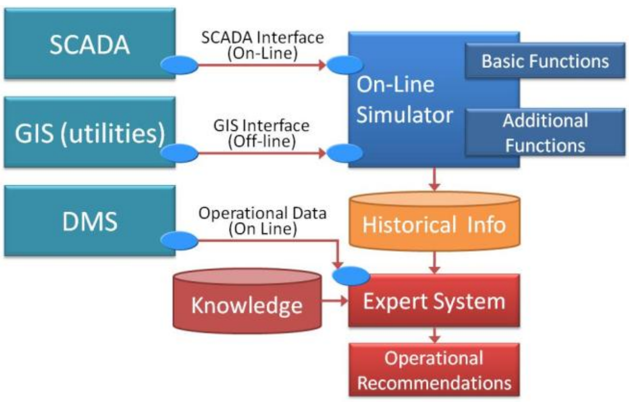

Fig.1. On-Line Simulator - Logical architecture.

Figure 1 shows the logical architecture with which the On-Line Simulator of the Electrical Distribution Network was conceptualized and accordingly developed. It shows the interfaces to data access from other systems, the most important are:

- **SCADA Interface**. It gets information in real-time of control devices in substations and in Distribution Networks (as fast as remote media allows). It considers measurements as well as status of switches (reclosers, protections, switches, RTU's).
- **GIS Interface**. It extracts and prepares off-line, georeferenced information of the network topology, considering its location and electrical, physical and geometrical data. The manufacturer data and electrical parameters are completed by using a library of standard equipments from construction standards as well as manufacturer manuals.
- **Operational Data Interface**. In case of failure, it extracts, on-line, operational information of devices in the network that are involved in the failure and those devices that can support the solution through load transfer (load profile, failure records and maintenances).
- **Basic Functions**. The core of the On-Line Simulator considers the engineering functions for distribution networks included natively on the NEPLAN software tool for network planning, which was evaluated, selected and integrated through a specially developed and validated architecture [4].
- **Additional Functions**. In order to consistently access the diverse tools of the On-Line Simulator, several functions were designed, integrated and validated for maintaining reliable operation; among the most important are the manager of shared memory [6] [7] [8] [10] [11], the manager of transactions, real-time data analyzer and the manager of users, roles and privileges,
- **Historical Information**. The data collected in real-time are permanently stored in a persistent database, in order to have the ability to re-create events and situations that occurred at any previous time.
- **Knowledge**. This database has the knowledge that includes procedures applied by a skilled Operator of the Distribution Network as well as information of the Very Important Clients (hospitals, government, industries and malls, among others). With this information, the Expert System is provided with the ability to analyze and evaluate potential restoration strategies.

- **Expert System**. Artificial Intelligence tool with Case Based Reasoning (CBR) which, in the event of a failure or disturbance in the network, it emits a recommendation for restoration that considers calculation of indices and objective functions; as well as automatic verification of safety and operational levels such as voltage profile, load profile and loss minimization, among the most important.
- **Operational Recommendations**. Optimal restoration strategy which is supported by automatic calculation of restoration alternatives and evaluation of each one of the technically feasible alternatives in order to establish "the best solution", considering besides technical indices and target criteria, the Very Important Clients who will be out of service during the repair of the failure.

4 Physical Architecture

There are two levels of Distribution Control Centers, the local control in the Sub-geographical Regions or Zone (known as “Zona” in Mexico) and an upper level for coordination and logistics in the Geographical Region (known as “Division” in Mexico).

4.1 Zone

The On-Line Simulator in its Zonal configuration allows access to data from SCADA systems with three options: real-time data replication technology, DNP 3.0 protocol master/slave or OPC (OLE for process control) data interface.

Once real-time data has been acquired, data are packaged and sent to On-Line Simulator installed in the Division, in this way, the Regional system will accumulate the total of SCADA data of all the Distribution Control Centers.

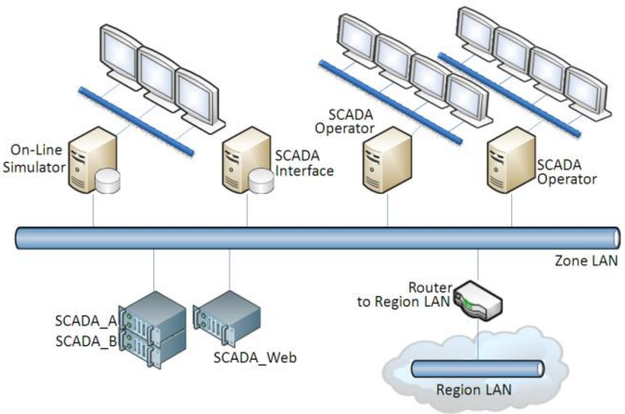

Fig. 2. On-Line Simulator - Physical architecture of Tampico Zone.

4.2 Region

The On-Line Simulator in the Region, in addition to accumulating real-time data from all of their Zones, it is also an identical and independent kind of operation so that at Region level it has the ability to analyze normal and contingency exercises, considering the interconnections or restoration alternatives between multiple Zones or even considering the effect of high voltage networks.

Additionally, for the Region, the On-Line Simulator was integrated into a center for monitoring and analysis, which has the capability of real-time monitoring for all the remote SCADA that conform a Geographical Region. Thus, it has the ability to analyze the entire Regional Distribution Network in real-time, considering the real operation and recovering restoration strategies issued by the Expert System.

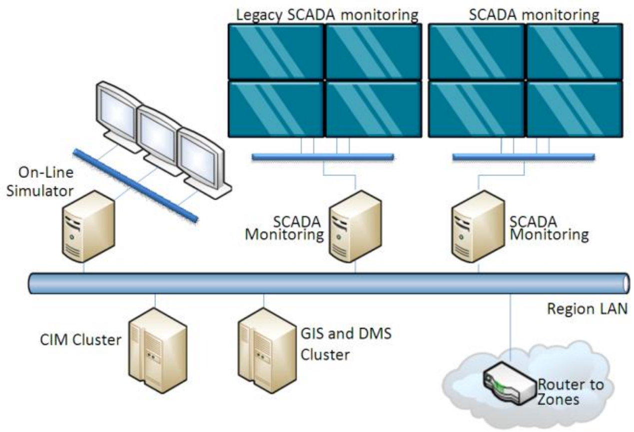

Fig. 3. On-Line Simulator - Physical architecture of Division Golfo Centro.

5 Expert System

The integrated Expert System [4] executes the following sequence:

- Through permanent monitoring of SCADA information and comparing the data measured in field against the current configuration of the Distribution Network, it is automatically detected when an event occurs classified as "unusual" or contingency, which may be due to a failure or a disturbance.
- When an event is detected, it automatically displays a message informing to the Operator the current situation with the involved circuit; the On-Line Simulator requests confirmation to execute the algorithms of the Expert System.

- If the Operator ignores or cancels the warning, the automatic execution is canceled and the On-Line Simulator returns to normal operation (for example for planned maneuvers or opening/closing of reclosers).
- If the Operator confirms that an event is "unusual" or that it is a contingency, the On-Line Simulator asks for location of failure in the Distribution Network, building the "failure scenario" and canceling the automatic SCADA update to NEPLAN.
- The On-Line Simulator uses the NEPLAN module "Strategy for optimal restoring" for building restoration options, considering 4 target criteria.
- The On-Line Simulator gets the response of NEPLAN and sends it to the Expert System.
- The Expert System receives the request for execution along with refined technical information of the 4 options for restoration and applies two analysis:
    - With a Case Based Reasoning (CBR) algorithm it finds the "nearest neighbor" of the “optimal solution” (zero losses, all loads resupplied, without load profile or voltages violations, among others).
    - It evaluates the "nearness" of each of the 4 alternatives and rates each one.
    - It retrieves the list of Very Important Clients who will be disconnected (out of service) during the restoration process to calculate an index of “feasibility" of each plan.
    - An index of “total recommendation” is computed of and a response is sent to On-Line Simulator with the result.
- The On-Line Simulator gets the Expert System response and emits the recommendation to the GUI Operator, including a full list of Very Important Clients who will be disconnected during the restoration process.
- At the same time, the On-Line Simulator launches a query to other external systems with historical information and operational failures such as the DMS or OMS, (it is possible to configure other systems), the result of this query is displayed as trend graphs and lists of failures of all equipments and parameters involved in the failure and restoration (voltages, currents, real and reactive power, etc.).
- Supported on the displayed information, the Operator according to his experience and criterion takes the best decision and follows it for the restoration strategy and selects it in NEPLAN to be guided in each of the operations to be executed.
- The NEPLAN analysis tool continues with the execution of the module "Strategy for optimal restoring" and shows the Operator the sequence of opening and closing switches to isolate and fix the failure, and also normalize the Distribution Network.
- In the process, it is possible to request metrics for the failure, e.g. un-resupplied loads, voltage and load profiles, technical losses, among others.
- After conclusion of the maneuvers for service restoration, the Expert System finishes execution and the On-Line Simulator continues on-line connected to SCADA information, acquired in the Distribution Network.

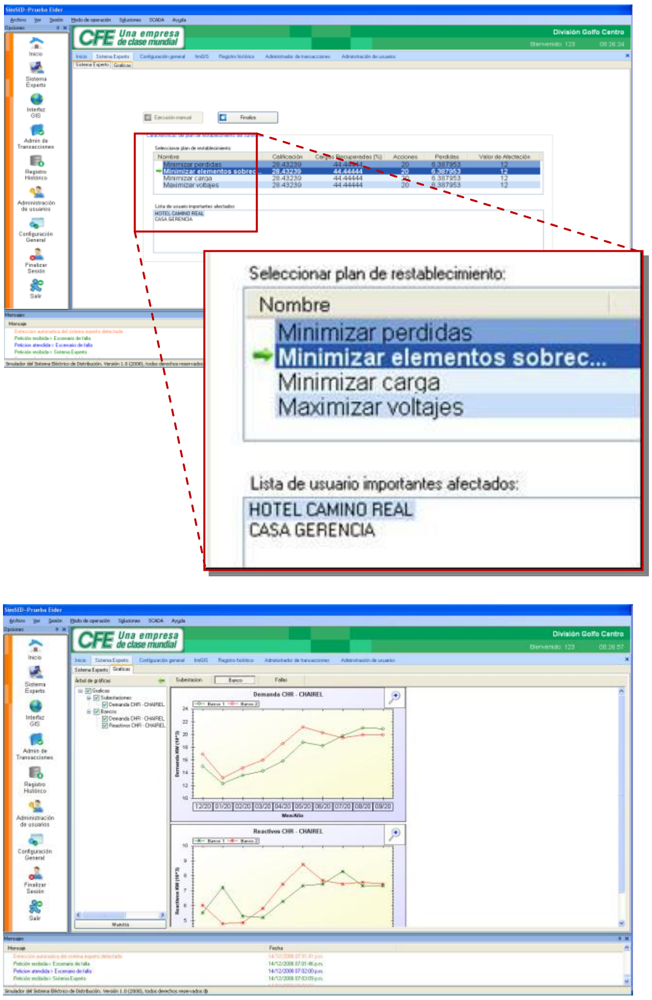

Fig. 4. On-Line Simulator –Example of GUI with results of the Expert System.

6 Results

The On-Line Simulator is installed at CFE into the Distribution Control Center at Tampico Zone and in Division Golfo Centro in the north of Mexico. Since its installation in December 2008, there have been measurements of its use and benefits, reaching the following conclusions:

- Nowadays, the On-Line Simulator is operating with the updated real power grid using simplified one-line diagrams which include current reconfigurations of the Distribution Network and substations.
- The On-Line Simulator has the real-time SCADA data and a reliable historical record.
- In case of failures in the Distribution Network, the On-Line Simulator:
    - Generates restoration strategies similar to the sequence that a skilled Operator applies to resolve the situation being presented.
    - Displays valuable information to the Operator. Up to now, Operators didn´t have a software tool or efficient means to access information to assess un-resupplied loads during failure repair, Very Important Clients being affected and the impact of the failure, as well as operational performance based on real measurements.
- The historical record allows a reliable analysis of maneuvers that are being carried out as well as planning new maneuvers based on real data measured by the SCADA system.
- With the historical record, previously executed maneuvers have been able to be evaluated, considering the current situation that is prevailing at the time of the maneuver, thus allowing to increase the level of certainty of success and minimize any possibility of maneuver error by the violation of physical and operational limits of the electrical equipment on the network.

Fig. 5. On-Line Simulator installer at Distribution Control Center of Tampico Zone.

7 Performance

- In **normal operation**. The On-Line Simulator allows analysis of transformer licenses in 30 minutes including supporting documentation (this process normally can take up to two weeks, considering tools and manual procedures in Distribution Control Centers without the installed On-Line Simulator).
- In **contingency**. In case of failure or disturbance in the Distribution Network, the event is automatically detected in a maximum of 10 seconds (configurable time). From the failure location, the algorithm of the Expert System executes in 35 seconds and produces recommendations for restoration similar to those obtained by a skilled Operator with over 10 years experience in the Network under analysis. In 3 minutes, it shows the operational curves, historical failures and maintenance of items under failure and those who can assist in the restoration process.
- The integration of SCADA data into NEPLAN takes less than 1 second considering 1,000 measured values (analogical and status).

8 Benefits

- The Expert System acts as an Operator with experience in the current configuration and operation of the Distribution Network and supports the current Operator, in case of failures, with additional or complementary information for decision making at the moment of the failure.
- On the recommendation for restoration parameters or criteria are considered that are not normally easy to assess, such as losses and voltage profiles.
- On the recommendation for restoration, a possible combination of multiple failures simultaneously occurring is considered e.g. in the case of contingencies by natural disasters.
- The On-Line Simulator shows graphical trends of voltages, current and power so that the Operator assesses the profile of elements in failure as well as items for supporting restoration while failure is repaired.
- The On-Line Simulator automatically recovers historical and operational information which is shown in graphical trends, thus supporting decision making, as well as avoiding time waste for recovery and formatting.
- The graphical user interface (GUI) is designed considering usability criteria in order to minimize Operator interaction and it expeditiously displays results.
- For its architecture definition, the On-Line Simulator was developed with the philosophy of the Common Information Model (CIM)

established by standards IEC 61968 and IEC 61970, nowadays the model is integrated into the architecture and infrastructure for semantic interoperability of Distribution Management Systems (DMS) for CFE and it is being used for generation and validation of CIM/XML Profiles and CIM/XML Instances.

Fig. 6. On-Line Simulator installed in Monitoring and Analysis Center at Division Golfo Centro.

9 Application Context

The On-Line Simulator is currently in use in the CFE Monitoring and Analysis Center (CAM by its acronyms in Spanish) at Division Golfo Centro. Into the CAM, the regional analyst is able to use the On-Line Simulator in Regional or Zonal mode in order to support multi-Zonal operations, e.g. load transfer between different geographical regions (maintenance of the main substation transformer, multiple faults repair or feeder maintenance).

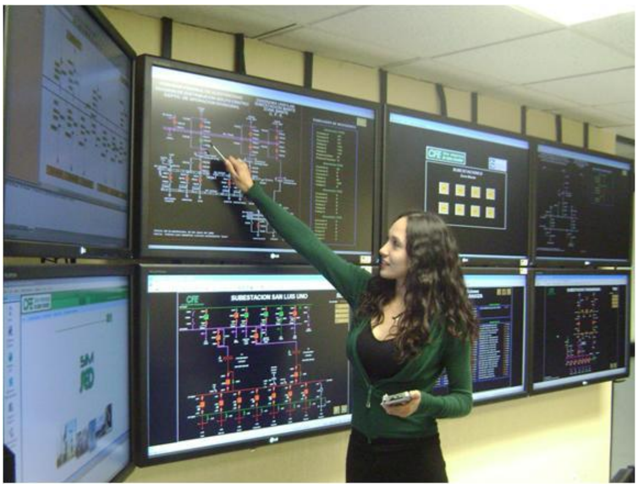

Fig. 7. Monitoring and Analysis Center for Regional Operators and analysts at Division Golfo Centro.

In this context, the Regional Operator or analyst has the ability to observe on-line the dynamic behavior for all the Zones in the Division in order to have a complete view for all the area, including the ability to model and simulate the hi voltage network and the detailed medium voltage network (Distribution Network) and including all the substations related.

The CAM includes the remote monitoring for Zonal SCADAs considering real time database replication, as well as, real time monitoring using DNP 3.0 protocol and a remote port server to convert the local serial port into an Ethernet serial port for legacy SCADAs installed and in operation. This monitoring is configured considering a secure communication between source and destiny. [12]

11 CIM Interoperability

Interoperability is the ability of two computers or systems of different types to work together and exchange data and processes.

The number of information exchange formats, the difficulty for integrating isolated systems inside each company, the variety of software and architecture platforms available, and the need for sharing information between different utilities, among others, has become an increasing problem. [15] [16]

To face this problem, the International Electrotechnical Council (IEC) developed the standards IEC 61970 and IEC 61968, which describe the components of an electric system, considering transmission, distribution and marketing, as the relationships between components. These two standards conform and define a model called "Common Information Model" (CIM) for electric systems. [15] [17]

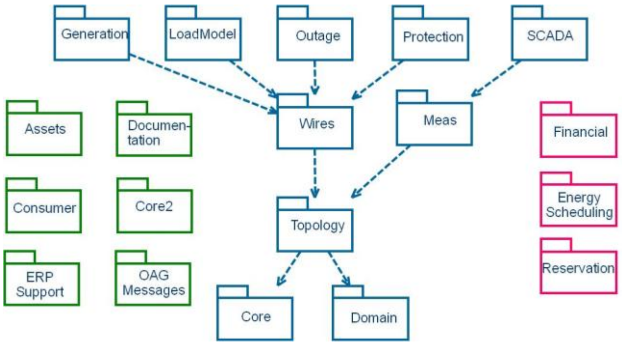

Fig. 8. CIM packages.

The CIM model is a standard information model for electric enterprises based on UML (Unified Modeling Language). Real world objects and their relationships are represented on this model, with the purpose of creating an information system that can be used between different applications for data exchange and management [17].

In order to adopt the CIM technology, features and abilities, CFE has defined the architecture for CIM Interoperability for systems supporting Operations for Distribution Networks in Mexico. [15]

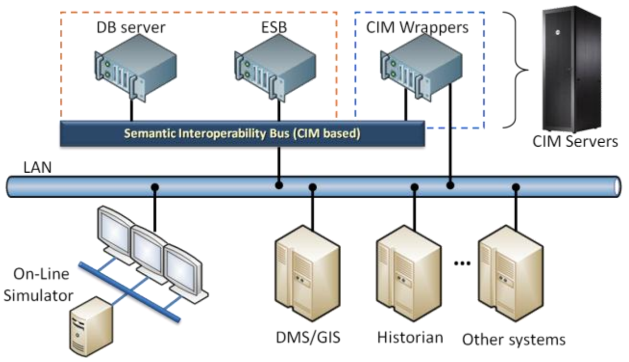

Fig. 9. Physical architecture for CIM Interoperability.

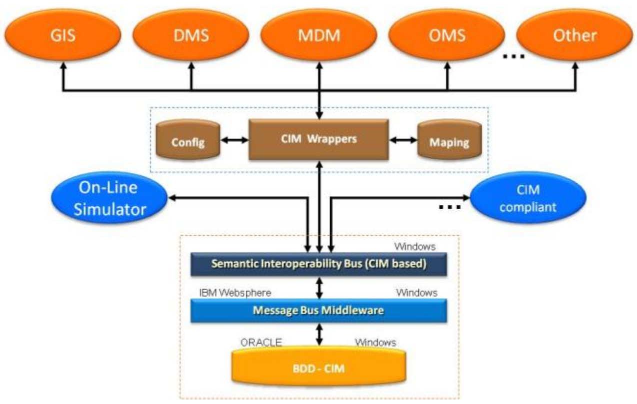

Fig. 10. Logical architecture for CIM Interoperability.

12 Application for Smart Grid

The Smart Grid is a system of systems, i.e. the architecture will be a composite of a large amount of architectures of systems and subsystems, allowing maximum flexibility during implementation, but also require a high capacity for integration of new systems with legacy systems.

The GridWise Architecture Council developed a conceptual reference model for identification of standards and protocols necessary to ensure interoperability, cybersecurity and define architectures for systems and subsystems in the Smart Grid.

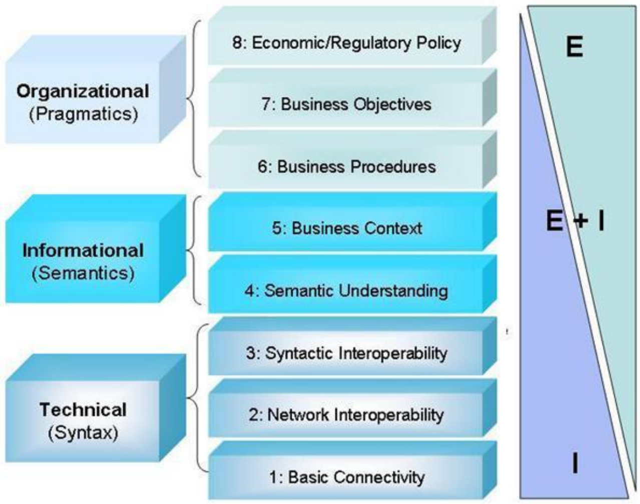

Fig. 11. GridWise Architecture Council - Interoperability Framework Categories.

"The framework pertains to an electricity plus information (E+I) infrastructure. At the organizational layers, the pragmatic drivers revolve around the management of electricity. At the technical layers, the communications networking and syntax issues are information technology oriented. In the middle, we transform information technology into knowledge that supports the organization aspects of the electricity related business." [13]

In the Smart Grid context, the On-Line Simulator is the first one system fully compliant with the CIM interoperability architecture defined and is being used for obtain the Semantic Model (CIM based) of the Electrical Model, Topological Model and Physical Model for Distribution Networks. [15]

Fig. 12. Example of the Semantic Model (CIM based) for the On-Line Simulator.

The Semantic Model developed has been validated using some software tools recommended by CIM Users Group (CIMug).

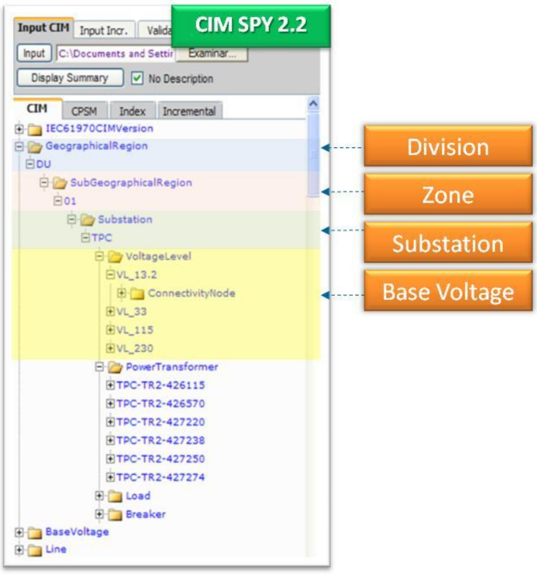

Fig. 13. Validation of the Semantic Model (CIM based) for the On-Line Simulator using CIM Spy.

Currently, the Semantic Model includes the next main equipments and electrical infrastructure:

- HV and MV Lines.
- Nodes.
- Transformers.
- Physical Estructures.
- Measurements (from SCADA).
- Switches and Reclosers.

Considering this feature, the On-Line Simulator is able to export the entire distribution network to a CIM/XML instance file in order to use the information into other system considering the semantic meaning. In the inverse procedure, the On-Line Simulator is able to import the entire distribution network from a CIM/XML instance file and execute the engineering functions for distribution networks.

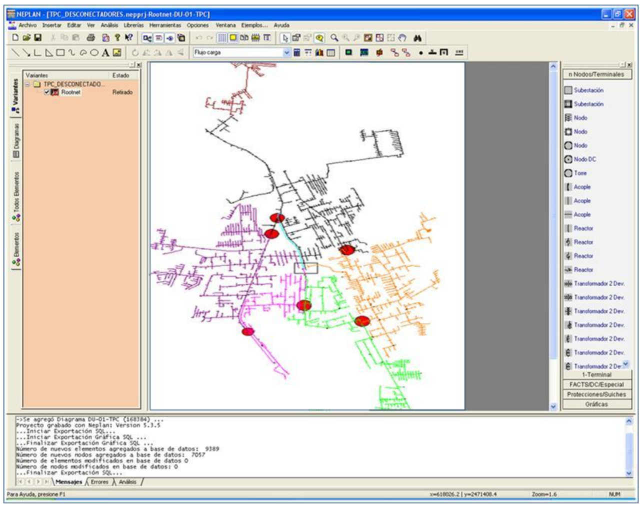

Fig. 14. Distribution network exported using CIM/XML instance.

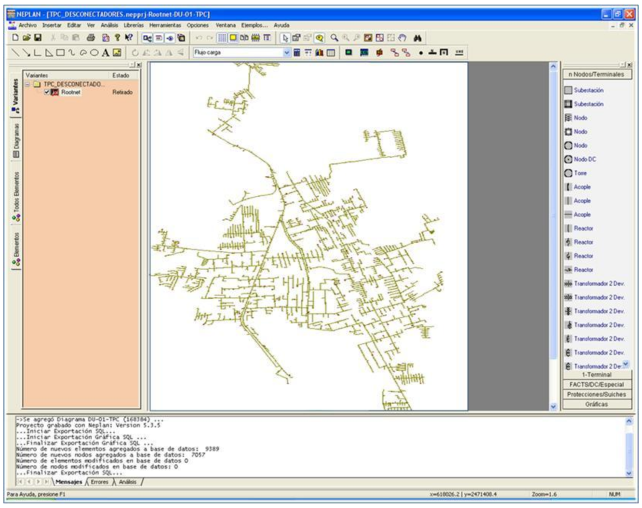

Fig. 15. Distribution network imported using CIM/XML instance.

The differences between the circuits of the figures 14 and 15 are because some features of the graphical representation are not exported to the CIM/XML instance.

13 Conclusion

The On-Line Simulator is currently supporting the development of substantive activities of the Operators of Distribution Network in the Control Center in which they settled, and it is also supporting the process of analysis and suggestions for improvements, for example, to support a reconfiguration in order to minimize losses and improve reliability.

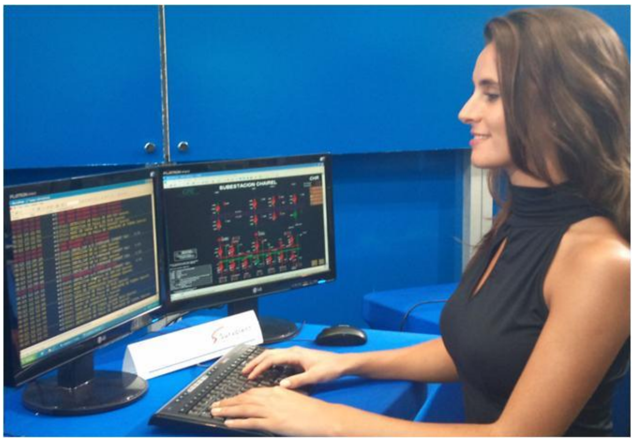

Fig. 16. SCADA Operator using the Tampico Distribution Network.

The On-Line Simulator integrates many technologies and products that are proven to be a joint solution for improving operational objectives of the Distribution Network.

The On-Line Simulator is evolving in order to fulfill requirements of the new architecture defined for CIM interoperability into the Smart Grid concept and will be used for validation of CIM/XML profiles and instances.

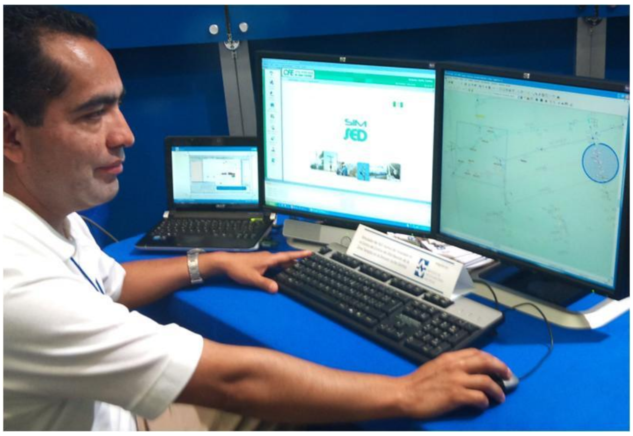

Fig. 17. Analyst using the On-Line Simulator of the Tampico Zone.

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