

# Simulation Environment for Development and Testing of Plug Compatible Power System Applications

CSIMG02

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## Abstract

The paper describes a simulation environment for research, development, integration, testing and deployment of plug compatible power applications. By using this environment the elapsed time from initial research to field deployment of new power applications can be dramatically reduced. The environment integrates the EPRI Operator Training Simulator with a Utility Software Development Framework. The Utility Software Development Framework uses the EPRI Common Information Model and the EPRI Application Program Interface for supporting the integration of plug compatible applications.

## Introduction

The research and development of applications software for large power systems have always been hampered by the availability of appropriate test systems. Although the proprietary nature of system data was an issue, the bigger problem was the ability of the researchers to handle large data sets. Thus in the 60s and 70s most university researchers could not handle power systems that were more than a few hundred buses, usually less, and the applications vendors were the only ones who had the data handling tools. This situation got better in the 80s with the ready availability of more powerful computers, commercial data base managers and some standardization of power network data formats. Thus it is quite possible today for any researcher anywhere in the world to download large realistic power network (power flow) data in a standard format to test their own algorithms or software.

However, the most commonly available data is still limited to power flow data in the bus-branch format. This is quite adequate for doing steady-state network analysis. Data for dynamic analysis is still not available in standard formats and nor is data for the details of substation configurations. Thus research work on dynamics or on substation based control still requires some ingenuity and ad hoc methods for testing. One of the areas where this has caused great difficulty is in the development of applications for control centers which requires data description at the substation breaker-bus level. Until now the only organizations that have had tools to handle breaker-bus level data formats are the EMS vendors and so were the only ones capable of doing research in state estimators, topology processors, on-line power flows and optimal power flows, etc. University researchers or consultants, if they had good ideas on such on-line applications, had to work closely with EMS vendors to develop them.

The purpose of this paper is to describe the changes already occurring to make such an environment, until now only available at EMS vendors, to be made available to all researchers. This would not only help individual researchers at universities and small companies but will also elevate the level of exposure that all power engineers can have to the specialized environment of control centers. Students at universities can now be exposed to the real time behavior of power systems as seen through the operator's eyes. Graduate students doing research in on-line applications can immediately try out their ideas on realistic power systems.

## Traditional Approach

The traditional approach to research, development, commercialization and deployment of new power applications for power system operations with proprietary systems is shown in Figure 1. The time scale is typical. The process is extremely long, highly serialized with significant hurdles and lapses between the different stages. Examples of successful products that have progressed through these stages include:

1. EPRI Operator Training Simulator. The research and development on long term power system models was performed by General Electric in the late 70s. The power system model software for the OTS was originally developed at Arizona State University in the early 1980s. [1], [2] This product was originally demonstrated at Philadelphia Electric by Control Data Corporation in the late 1980s and at Bonneville Power Administration by National Systems and Research in the early 1990s. It has been delivered by a number of suppliers including ABB, DSI, Incremental Systems, NSR, Siemens, Telegyr and Transdyn Controls.
2. EPRI Dynamic Security Analysis. The original research on direct stability methods was performed at System Control in the mid 1970s. This work was extended by Iowa State University in the early 1980s. This software has been demonstrated at Northern States Power by Siemens. EPRI plans are to integrate this package with the CIM in 2001 so it can be distributed more widely.

In the past, universities have lacked many of the tools that are very helpful to performing research on new applications for power system operations. These tools have generally been available to EMS vendors and include the following:

- Large scale operational models of real power systems including details of breakers, switches and measurement linkages.
- Real-time database management tools.
- Historical data recordings of actual power system operating conditions.
- Graphical user interface for display of substation and system overview diagrams.

The results of university research are often limited to prototype software, which is demonstrated on small power system models.

There are also significant barriers and costs to demonstrating new power applications on host utility systems. Firstly, it is difficult to find a host utility that is prepared to deal with the disruption to a mission critical operational system. When a host utility is found, a lot of the time, effort and expense is spent on software integration issues such as:

- Building real-time data-links to legacy systems.
- Converting legacy system databases
- Integrating application results with a legacy system user interface.

These complex software integration issues detract from the main objective of demonstrating and testing the new application. The problem is compounded by fact that the software developed for the demonstration may not be reused at other sites due to the special nature of the host utility system.

Once a developer has successfully demonstrated an application with a host utility there are still significant obstacles and delays to commercialization. In the past advanced EMS applications have typically been purchased when a utility purchases a complete new EMS. In a given year only a small percentage (around 4%) of installed energy management systems are candidates for being replaced. Four or five EMS vendors have shared the market for delivery of replacement Energy Management Systems. The supplier of a new application was therefore dependent upon these EMS vendors to propose its application. Even if such relationships could be established with one or two EMS vendors, an independent application supplier may be limited to capturing 1 or 2% of the market in a given year.

## EPRI Operator Training Simulator

The simulation environment has been developed by integrating the EPRI Operator Training Simulator with a Utility Software Development Framework.

The EPRI OTS is driven by a highly realistic long term dynamic model that simulates power system behavior under a wide range of abnormal conditions that includes thermal system overloads, voltage collapse, off nominal frequency, Ferranti voltage rise, system islands, large angle variations and cold load pickup. The simulator responds in real-time with

flows and voltages updated every few seconds. The user controls the simulator using a set of one-line diagram displays which can be laid out to mimic the displays that he/she may use as part of his/her EMS or SCADA system. The EPRI OTS is designed primarily to support training of power system operators. However, it also serves as a very valuable tool for testing new power applications. The OTS Power System Model provides a stream of real-time data and responds to the recommended or closed loop control actions of a new power application in a very similar manner to an actual power system. The OTS has the advantage that it can be used to run repeated tests under controlled conditions without endangering a real power system.

The EPRI OTS Power System Model (PSM) simulates the long-term dynamic behavior of the power system. Real and reactive power and voltages are simulated by a robust power flow that can handle wide bus voltage deviations. The power flow provides fast real time solutions so that the analog values are updated on displays quickly after any network changes, such as switching actions, are introduced. The models in the EPRI OTS can be broadly divided into the following categories: Powerplant models, System inertia and frequency model, Transmission network component models, Load models, Relay models, AGC and economic dispatch models

The network, generator and load models are referred to as the steady state solution models. The prime mover, system frequency, AGC and relay models are referred to as long term dynamic models. The inclusion of these models greatly expands the range of system conditions that can be simulated.

The power system model replaces the power system as seen from the control center. Detailed models and an advanced network topology processor make output from the power system model indistinguishable from the real power system. Advanced dynamic network solution methods provide simulated power system data as needed for power system control and for the operator's perception of real-time events.

The power system behavior is accurately depicted over a wide range of operating states; normal, emergency and restorative conditions. Models of the power system elements are based on accuracy in the voltage range of 0.85 to 1.15 per unit and the frequency range of 58.5 to 61.1 Hz.

Energy sources are modeled, including fossil, hydro, gas turbine, and nuclear units. Loads can

be modeled using a combination of constant current, voltage and frequency sensitive and load management components. Both power and reactive load components are modeled. Relays accurately portray the automatic switching in the network and can model cascading outages. Some relays operate rapidly during system transients and their effects on the network are depicted as open circuits.

## Utility Software Development Framework

The Utility Software Development Framework has the overall objective of supporting the research, development, integration and deployment of power applications by the extended EMS and DMS software development community where this community includes EMS and DMS vendors, Independent Software Developers, Electric Utilities, Systems Integrators, Consultants, Universities and Research Institutes.

The overall software architecture for the Utility Software Development Framework is shown in Figure 2. It is supported on major UNIX platforms including LINUX, Compaq UNIX, IBM AIX and Sun Solaris. It is also supported on Windows NT and Windows 2000.

The Utility Software Development Framework is based upon a component architecture where these components are integrated using a variety of middle-ware products. The components can be database components, user interface components, application components and middle-ware components. Any component can act as both a consumer and provider for data, events and methods. All components communicate with each other using the EPRI Application Program Interface (API). Components can provide and receive information using either an asynchronous publish/subscribe or synchronous request/response mechanisms. The EPRI API was originally developed by PowerData Corporation with EPRI sponsorship. It is now being used by EPRI contractors to interface EPRI applications to the EPRI Common Information Model. The EPRI API specification is openly published. It can therefore be used by anyone to interface any application to any data source.

The EPRI API is defined to meet the requirements that are encountered in building mission critical, high availability, real-time

Energy Management Systems and Distribution Management Systems.

The EPRI API encompasses:

- Operations for Common Data Access including create, read, update, delete and fine grained notification of data changes.
- Operations for Method Invocation. Methods can be invoked on applications (e.g. run program, stop program) as well as the individual objects that are modeled by an application (e.g. Trip Breaker).
- Operations for Event Notifications. Event Notifications can be generated by applications (e.g. program aborted) as well as the individual objects that are modeled by an application (e.g. Transformer Overload Detected).

The database components include the EPRI Common Information Model (CIM), PowerData and Oracle. Oracle is used for access to long term persistent data and PowerData is used for high performance access to real-time volatile data.

The graphical user interface components include PowerVisuals Viewer, PowerVisuals Editor, PowerVisuals Autobuilder and PowerVisuals Data Engineer.

The middle-ware components can be assembled from one or more messaging systems that provided for remote data access, remote event notification and remote method invocation. The messaging systems can include a combination of Oracle Advanced Queuing and PowerData Events.

The EPRI Common Information Model provides specific knowledge of the power system. The entities, attributes and relationships for the EPRI Common Information Model (CIM) are defined in the EPRI Control Center Application Program Interface Guidelines. [3] The data dictionaries are openly published and accessible to all interested third party developers. When

implemented with PowerData, the EPRI Common Information Model is an on-line real time application that stores the real time scanned analog/status data, state estimator and power flow solutions, the parametric data needed to support the applications and a complete history of past operating conditions and models. The cornerstone of the EPRI CIM is the Conducting Equipment class. This includes include sub-classes such as reactors, capacitors, switches, loads, lines, busbars, transformers and generators. Relationships for equipment connectivity, groupings into substations, ownership and measurements are defined at the level of the conducting equipment class. These relationships are then inherited by all of the subclasses. The EPRI CIM can be used to support transmission and distribution applications. The model can be populated to include equipment from the substation, through the primary and secondary feeders all the way to the premise. In EMS, the typical number of loads and meters is in the range of several thousand. For DMS, the typical numbers of loads and meters is in the range of several millions. The same logical CIM applies, however, the performance and implementation issues are very different.

PowerData is a high performance real-time relational database management system developed by PowerData Corporation to support real time processes and large scale mathematical models.

PowerVisuals is a family of Net-enabled graphical user interface products that can be used for monitoring and controlling real-time event driven processes as well as maintaining and accessing their underlying databases.

PowerVisuals supports user defined displays types that are typically found in modern Energy Management, SCADA and process control systems including:

- System Overview Schematic diagrams
- Substation one-line diagrams
- Transmission line diagrams
- Repeat tabular (spreadsheet) displays.

PowerVisuals consists of two basic products:

- PowerVisuals Editor allows the existence and appearance of various pieces of information about the topological model to be controlled and changed.
- PowerVisuals Viewer manages commands, events, and data between users, and the applications. In Viewer mode, information on PowerVisuals displays updates dynamically as data in its supporting data bases changes. The result is a live graphical display that is updated in real time.

In addition, there are two related applications that work with PowerVisuals Editor:

- PowerVisuals Autobuilder is a program for building a first cut of a display from topological information that is stored in the EPRI Common Information Model.
- PowerVisuals Data Engineer is a program for updating the EPRI Common Information Model once PowerVisuals Editor has been used to build a power system schematic diagram.

### ***Generalized Model Importer and Exporter***

The Generalized CIM Importer can be used for importing EMS files into a CIM compliant database and the Generalized CIM Exporter can be used for exporting EMS files from a CIM compliant database. The Generalized CIM Importer and Generalized CIM Exporter can be configured using text files to handle the formats of a wide range of different EMS vendors. The specific configuration files are provide to handle importing an EPRI OTS file into the CIM and exporting an EPRI OTS file from the CIM.

### ***EPRI Topology Processor***

The Topology Processor is an on-line application responsible for establishing the database used by both real-time and study functions. The Topology Processor processes changes in the system configuration resulting from a change in the state of any switching device. The Topology Processor dynamically builds and maintains a CIM based bus oriented model of the power system for use by other applications.

The Topology Processor is totally generalized. The algorithm recursively searches and expands a sub-network until it reaches all the accessible nodes. A text configuration file is used to specify conducting equipment elements as either limiting or non-limiting. elements. By configuring which elements are limiting or non-limiting, the same Topology Processor can be used to:

- Determine the powerflow buses.
- Determine the breakers that must operate to clear a multi-terminal line.
- Determine an electrical island.
- Determine if an energized island might be grounded by a potential switching action.
- Determine if any loss of load will occur from a potential switching action.

### ***Historical Archiving***

A historical archiving facility allows the database to be reconstructed to any previous state in the database's recorded history. When archiving is enabled, each event in the database is recorded to a file storage area and ordered. Snapshots of the data can be taken at timed intervals or at intervals based on the number of events that have occurred. When an application opens the historical database and instructs the database to assume a specified time, the database is reconstructed from the snapshots and subsequent events as a "virtual copy" of the database.

### ***Fast Track Research and Development***

A targeted schedule for research, development, commercialization and deployment of a new power application using the EPRI OTS and the Utility Software Development Framework is shown in Figure 3.

### ***Research and Development***

The EPRI OTS and the Utility Software Development Framework is available for power system researchers to use as a comprehensive environment for research, development, integration and testing of new power system applications. This provides the following advantages:

- Researchers can immediately focus their efforts on the core algorithms and computational engines. They are not distracted by the task of having to create their own software development and test environment.
- The source code is available for basic reusable components such as Topology Processor, Linear Power Flow and matrix manipulation for building new applications.
- The EPRI API provides documented interfaces and coding examples for interfacing existing applications.
- By following the coding examples that are provided with the Utility Software Development Framework researchers can build applications that are much closer to production quality.
- A set of power system test cases is available.
- The OTS allows applications to be tested under a full range of normal, emergency and restorative operating conditions with real-time data streams that respond to control actions.

### ***Demonstration with Utility Models***

The Utility Software Development Framework comes packaged with two models that can be used for testing new applications. The Generic Power and Light System includes 29 stations. This model is ideal for initial development and testing of new applications. The Western Area Power Administration Upper Great Plains (UGP) Model includes detailed models of substations in the WAPA UGP system, which encompasses North and South Dakota and parts of the surrounding states. The WAPA UGP system includes a control area in the Eastern U.S. system and a control area in the Western U.S. system. The WAPA UGP model therefore includes equivalents of the entire Western and Eastern U.S. Systems. The entire model includes approximately 850 generators, 4500 lines and 5800 switches. The WAPA UGP model is an excellent model for testing applications under high stress conditions.

In the United States and Canada, in order to support the data exchange needs of NERC Security Coordinators and the new RTOs, a growing number of power system models are now available in CIM compliant relational database. These Security Coordinators and RTOs are often willing to make their models available to researchers in a CIM format.

For international utilities that do not have a CIM, the Generalized Import Engine can be configured to import an existing proprietary EMS model into the CIM.

### ***Commercialization by Multiple Suppliers***

A number of major EMS suppliers are now willing to take EPRI CIM and EPRI API compliant applications and offer these to their existing and prospective customers. The feasibility of incrementally upgrading existing energy management systems has been increased by a combination of low cost standardized ICCP data links, low cost standardize database conversion utilities and automated packages for one-line display conversion and generation.

As a consequence, once an application, is integrated with the EPRI CIM and the EPRI API, it is in a form where it can be offered at competitive prices and competitive support costs to the entire market of utility customers world wide.

### **Conclusions**

The paper has described how the EPRI OTS and the Utility Software Development Framework can be used to enhance and accelerate research, development, integration, testing and deployment of new applications for power system operation and control. The EPRI OTS and Utility Software Development Framework is available to support power system researchers on world wide basis. The EPRI OTS and the Utility Software Development Framework can be a powerful tool attracting and retaining top engineers to work on power industry problems.

A growing number of third party applications are being developed to run with this environment including, Supervisory Control and Data Acquisition, State Estimator, Optimal Powerflow, Voltage Security Analysis, ATC, Topology Estimator, Unit Commitment, Load Forecast

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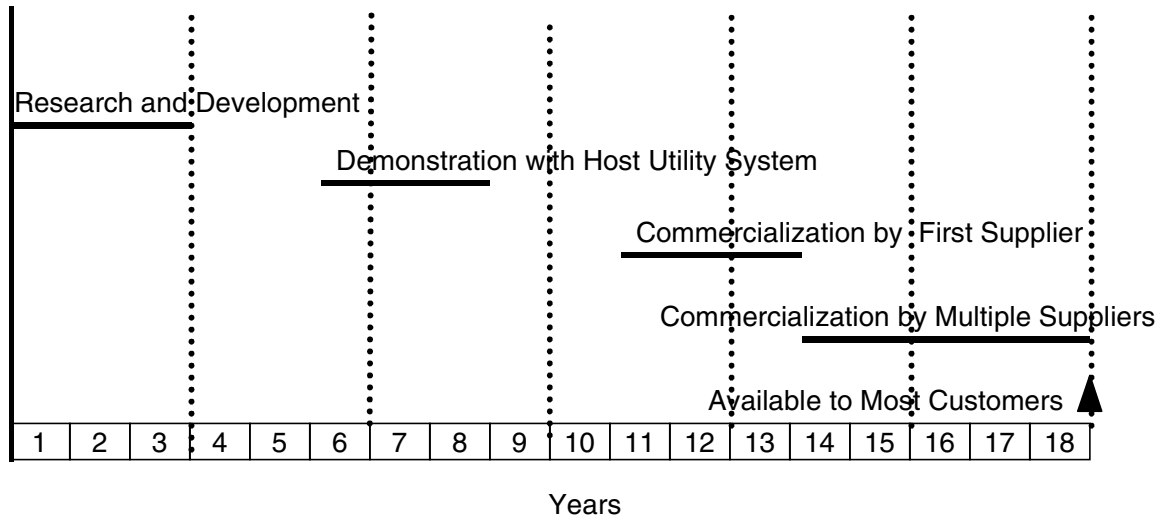


Figure 1: Traditional Research, Development and Commercialization Schedule

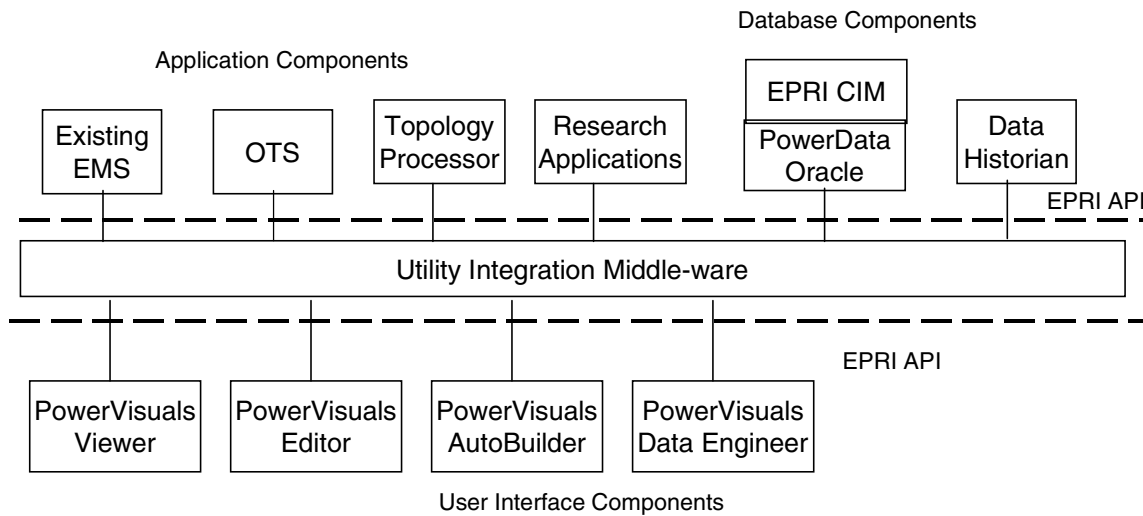


Figure 2: Software Architecture for Utility Software Development Framework

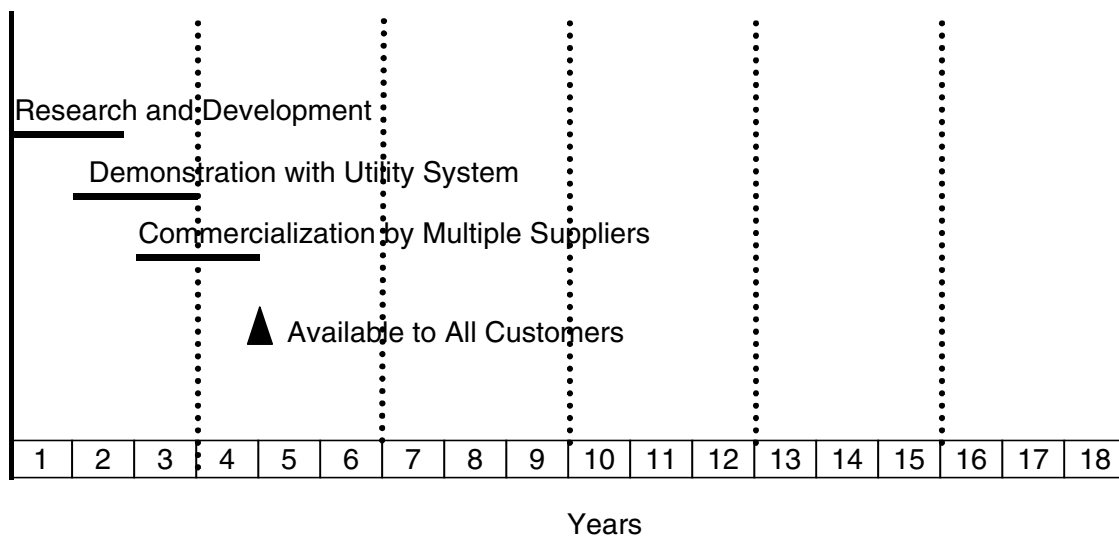


Figure 3: Fast Track Research, Development and Commercialization Schedule