Real-Time Performance Management Tools for Wide-Area Operations in Competitive Electricity Markets

Carlos A. Martinez, *Member IEEE,* Joseph H. Eto, *Member IEEE*, Jim Dyer

Abstract—**Emerging competitive markets for electric power are changing traditional operational patterns, resulting in larger control areas, greater operational complexity, and new operations hierarchies. The Consortium for Electricity Technology Solutions (CERTS) is researching, developing, prototyping, and delivering real-time performance monitoring (RTPM) tools for wide-area operations in these competitive markets. This paper describes the applications, algorithms, hardware-software architectures, data flows, and visualization technologies associated with these tools. Some of the applications described are currently in use by system Reliability Coordinators. Other applications are being developed and or undergoing exploratory research. The paper describes some experiences with implementing these tools and the successful design and development processes employed in developing them.**

Index Terms —**ACE-Frequency Monitoring, CERTS, Dynamic Performance Monitoring, Grid-3P, Multi-View Geo-Graphic Visualization, Real Time Performance Management, Real Time Performance Monitoring Tools, Suppliers' Performance Monitoring. VAR Management.**

I. INTRODUCTION

As the U.S. electric power system weathers the transition from being centrally planned and controlled to being dependent on competitive market forces for its expansion and operation, system operators are suddenly faced with much greater challenges than in the past, including:

- Exponential growth in volume of transactions
- Larger areas to control
- New unregulated generation owners and power marketers
- Changing operational responsibilities
- Reliance on markets to match customers' loads and manage reliability, in contrast to the past approach of directly controlling generation and load
- Unpredictable system behavior

Paper presented at the Control Center Issues session from the 2003 IEEE general meeting on July 16 at Toronto, Canada.

C. A. Martinez is with the Electric Power Group (EPG), Pasadena CA 91101 USA (e-mail: martinez@ electricpowergroup.com).

J. H. Eto is with Lawrence Berkeley National Lab (LBNL), Berkeley CA 94720 USA (e-mail: jheto@lbl.gov).

J. Dyer is with the Electric Power Group (EPG), Pasadena CA 91101 USA (e-mail: dyer@electricpowergroup.com).

To address these radical changes in the system, operators have only the previous generation of operational tools that were designed for a centrally planned and controlled electricity grid, not for today's competitive trade, which is placing increased operational demands on operators. The increasing incidence of transmission congestion, price spikes, frequency abnormalities, voltage degradation, and managed and unmanaged outages makes clear that a real time performance management strategy supported by new real-time performance monitoring (RTPM) tools and technologies are needed to ensure grid reliability.

The U.S. Department of Energy (DOE) Transmission Reliability (TR) program develops technologies and policy options that promote market efficiency and enhance the reliability of the nation's electricity delivery system as it makes the transition to competitive power markets.[1] In the area of real-time grid reliability management, DOE contractors from the Consortium for Electric Reliability Technology Solutions (CERTS) are coordinating with leading independent system operators (ISOs) and the North American Electric Reliability Council (NERC) to research, develop, and demonstrate new tools to monitor the performance and manage the reliability of the grid and competitive markets in real time.

This paper describes CERTS work to date in the real-time performance management area, with the remaining sections organized as follows:

Section II describes CERTS organization and its research roadmap. It explains the need for these new RTPM tools and their place in the context of CERTS' research in real-time grid reliability management for competitive markets.

Section III outlines CERTS overall performance management strategy and where and how RTPM tools fit within that strategy. It also describes the relationship between the traditional supervisory control and data acquisition (SCADA) and energy management system (EMS), available in most system control centers, with the new tools' hardware/software architecture, input data requirements and

[1] The four principle research areas of the DOE Transmission Reliability program include: 1) Real-Time Grid Reliability Management; 2) Reliability and Markets; 3) Load as a Resource; and 4) Reliability Technology Issues and Needs Assessment. http://www.ercn.doe.gov/der/transmission/

overviews of data flows. This section also describes the general design approach and goals for defining the format and content of the multi-view geo-graphic visualization strategy used by the tools. This strategy was designed and evaluated using proven human-factors guides that have been effective in other control-intensive industries as nuclear plant operations.

Section IV focuses on four RTPM tools: the Area Control Error (ACE)-Frequency application, which has been successfully deployed, and the Suppliers' RTPM application, VAR Management and System Dynamics Monitoring, which are currently being field-tested. The first application was developed to allow the North American Electric Reliability Council (NERC) Reliability Coordinators to identify and quickly find the root cause of interconnection frequency abnormalities. The supplier's performance application was developed as a complement for the ACE-Frequency tool, to help Control-Area Dispatchers quickly identify non-compliant generators.

Section V describes CERTS' research and development process for the design and development of new RTPM tools. It also describes some of the development and dissemination experiences.

Section VI summarizes the paper's contents and CERTS' near-term efforts in real-time performance management and RTPM tools.

II. BACKGROUND

The right side of Figure 1 shows the partnership among CERTS' research providers, which include, industry, national laboratories, and universities. It was formed in 1999 to research, develop, and disseminate new methods, tools, and technologies to protect and enhance the reliability of the U.S. electric power system during the transition to a competitive electricity market structure. Figure 1 also shows CERTS is currently conducting research for the U.S. Department of Energy's Office of Transmission and Distribution and for the California Energy Commission's Public Interest Energy Research Program, under the guidance of and Industry Advisory Board whose members represent ISOs, RTOs and Regulators. The members of CERTS include the Electric Power Group, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory, Sandia National Laboratories, and the National Science Foundation's Power Systems Engineering Research Center.

CERTS' vision is to:

"Conduct needed public interest research on reliability technology solutions, tools, models, systems, and management processes required in competitive electric markets for improving reliability and market efficiency of the U.S. electric grid."

To help achieve its vision, CERTS is researching and prototyping a new generation of RTPM tools to maintain reliability within today's challenging environment, and it is one focus of CERTS' work in the area of real time grid reliability management. This research also supports DOE's efforts to promote market efficiency, enhance system reliability, and set the stage for the automatic, switchable electricity network of the future.

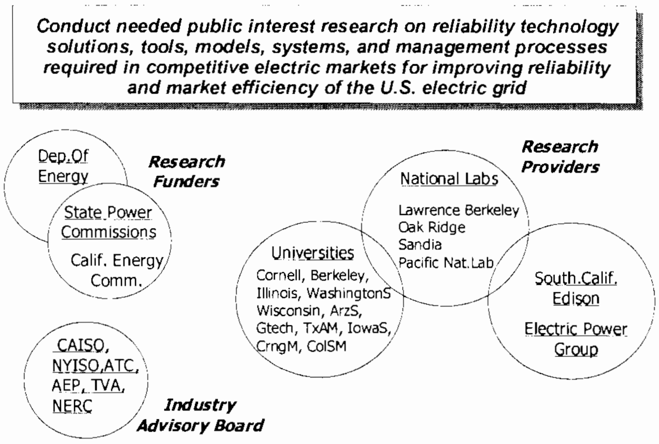

Fig. 1 Consortium for Electric Reliability Technology Solutions (CERTS)

Figure 2 shows CERTS real-time grid reliability management research roadmap with its four major areas (A-D) to improve grid reliability management; the tools described in this paper are part of research area A, Real-Time Performance Management. Although we do not specifically discuss in this paper all of the technologies required by the other three research areas listed on the figure, they are all contributors to the RTPM applications that, in the short term, are helping system operators maintain reliability and market efficiency.

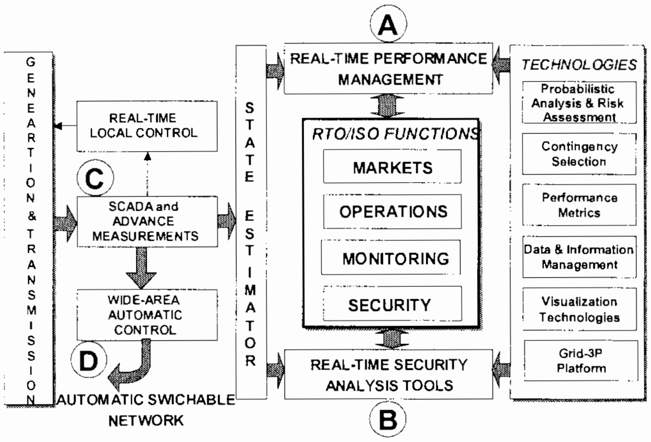

Fig. 2 CERTS' Grid Reliability Management Research Roadmap with Research Areas – A, B, C, and D

In the long term, CERTS' research in these four areas is intended to provide all of the technological components necessary to lead to a "smart" electricity grid that can automatically sense and respond to system emergencies.

III. REAL-TIME PERFORMANCE MANAGEMENT STRATEGY, ARCHITECTURES, DATA FLOW AND VISUALIZATION

Performance Management Strategy and Process

Figure 3 describes at the high level four major components of the CERTS performance management strategy. The strategy first calls for the definition of performance metrics, followed by a monitoring phase using RTPM tools that will compare actual performance with the metrics. The third stage consist of analysis to identify the root causes of non-compliance, and the final stage will assess if the strategy is effective in helping to improve reliability or if redefinition of a more appropriate metrics is required to make the strategy more effective.

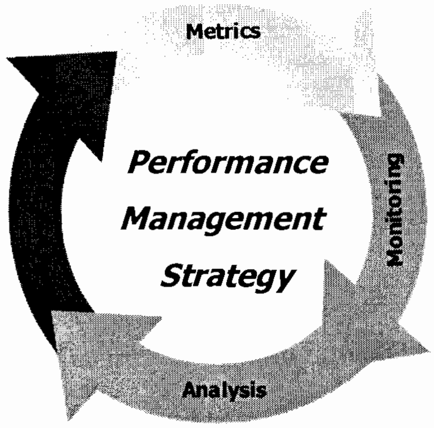

Fig. 3 CERTS Performance Management Strategy

Figure 4 describes in more detail the specific objectives for the metrics, monitoring, analysis and assessment stages of the performance management strategy, and also shows that the CERTS set of RTPM tools are serving the monitoring stage allowing system dispatchers and operators to monitor and track in real time performance metrics related to reliability parameters such as frequency, voltage and system dynamics.

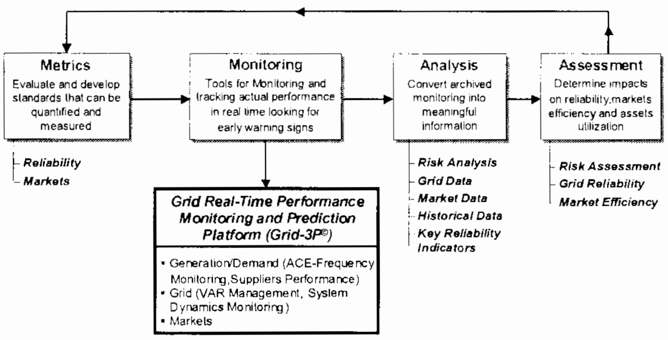

Fig. 4 CERTS Performance Management Strategy and Interface with RTPM tools

All of the RTPM tools described in this paper perform three key tasks:

- handling input data (traditional SCADA data complemented by phasor measurements) [1].
- executing functional calculations to assess the state of the grid and the risk that reliability may be compromised, and
- presenting output in a specially designed multi-view, geo-graphic visual display that enables operators to rapidly understand system conditions and take action to correct conditions that threaten system reliability

Figure 5 shows the general architecture and characteristics of CERTS' RTPM applications: Layer 1 is the database and data communications that collects data from hosts control and monitoring systems and supplies information used by the tools. Layer 2, the functional calculations are performed to determine the state of the grid (data optimization, forecasting, risk assessment, etc.), and includes the RTPM applications themselves, and Layer 3 is the geo-graphic, multi-view visualization that is produced for end users.

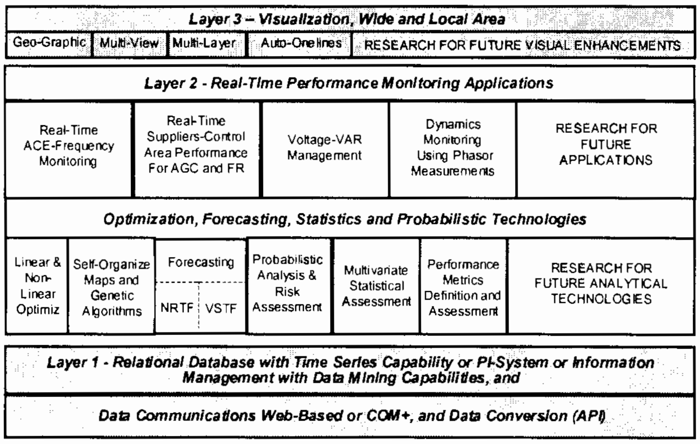

Fig. 5 Three Main Architectural Layers for RTPM Applications

Data Input – Layer 1

RTPM tools use the same data sources used by current SCADA, EMS, and PHASOR systems – i.e., These tools are not intended to replace SCADA, EMS, and PHASOR systems but instead to complement them by adding real-time performance monitoring capabilities. One challenge for RTPM tools is to efficiently collect data from numerous different asset owners, convert to a time series oriented arrangement, and group within information tables that facilitate integrated monitoring view for system operators.

Functional Calculations and RTPM Applications –Layer 2

Figure 5, Layer 2 lists some of the types of functional calculations that must be performed using the input data. Numerical algorithms exist for linear and non-linear optimization, near and very short-term forecasts, in addition to algorithms to determine the risk and probabilities for reaching collapse periods. These calculations feed into the RTPM applications that monitor key performance indicators of system reliability conditions or market efficiencies.

End User Output Visualization - Layer 3

Figure 5, Layer 3 lists the characteristics of the local- and wide-area visual displays that present the information from layers 1-3. The geo-graphic, multi-layer, multi-view visualization strategy allows operators to quickly assess and act on system conditions. More details about this visualization infrastructure appear in the Visualization sub-section below.

RTPM applications turn raw data into actionable information so that operators can monitor electricity system operations in real time; the same information can be immediately available to engineering support management, and other personnel.

RTPM Tools Typical Data Flow

Figure 6 shows the typical data flow for CERTS' RTPM applications. The left side of Figure 6 shows the process begins with collection of the required SCADA, market, Phasor or information raw data by means of standard software or special programs developed for this purpose. The database is populated using both validated raw input data and data produced using sensitivity, distance from collapse points, remedial action, and risk and probabilistic algorithms. The right side of Figure 6 shows the client side of the architecture: the multi-view, geo-graphic visualization that is the output of each RTPM application.

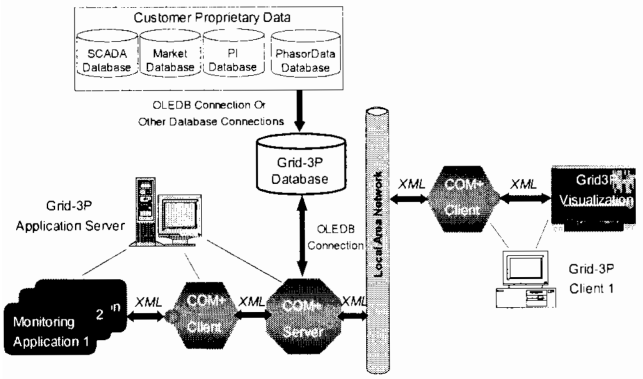

Fig. 6 Typical Data Flow for RTPM Applications

Multi-View, Geo-Graphic Visualization

A critical element of CERTS' tools is their graphic-geographic visualization approach and architecture, which has been carefully designed and implemented to permit system operators to quickly interpret and use data for monitoring and root cause identification purposes. To develop the visualization design for its RTPM tools, CERTS researched effective visual display strategies and developed seven goals that the visualization design should meet:

- improve operators' knowledge and understanding of wide-area system conditions at different operational levels
- be applicable to different monitoring applications
- apply relevant multi-view-layer design criteria
- minimize development and support by using configuration files and generic templates
- use pre-defined plotting functions
- have an adaptable data input reader
- allow functions to be added in for extended performance

The visual user interface selected to meet these goals is a multiple-view geo-graphic system. This type of system uses three or more distinct but coordinated geo-graphic views for real-time monitoring of a process. Human-factors experts have concluded that analysis of visual data is significantly improved if the viewer simultaneously reviews graphical images of different but related processed data. Experiments have shown that visualization techniques involving multiple coordinated windows result in improved user performance, user discovery of unforeseen relationships, and unification of the desktop.

Because multiple-view systems use sophisticated coordination mechanisms and layout, they are very challenging to design. Subtle interactions among the many dimensions of the design space complicate design decisions. Two fundamental design questions must be answered to determine a useful multi-view, geo-graphic visualization design:

- how many simultaneous views are required? and
- what information and graphs should be displayed in each view?

To answer the first question, CERTS' experts on real-time operations and human-factors for control rooms, developed the "Visual Information Wheel" shown in Figure 7, specifically created for the design and development of graphic user interfaces for real time performance monitoring tools.

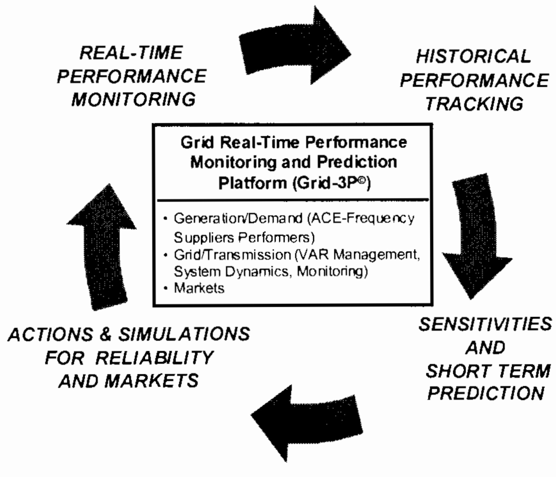

Fig. 7 "Visual Information Wheel" for Multiple-View Criteria Definition

Experts determined that each multi-view visual display in an RTPM application would have maximum of four main views, corresponding to the outer ring of four types of data shown in Figure 7: a **real-time monitoring view** to show the most current data, a **historical tracking view** to show the most recent historical data, a **prediction view** to show near-real-time prediction data, and a **remedial action** view to show a list of potential required actions or the ability to perform what-if-simulations.

Figure 8 shows the decision table used by CERTS visual designers to answer the second question regarding what information should appear in each visual display.

Visual Content / Visual Horizon	***WHAT*** is Happening	***WHY*** it is Happening	***TREND*** Future Near Term	***ACTION*** *Corrective*
Real Time Monitoring (Now)	Abnormal Frequency Alarms	Control Areas Worst ACE	N/A	Control Area Dispatcher Communication
Historical Tracking (Most Recent)	10-Minute and 1-Hour Tracking	ACE-Frequency Correlation - Coplots	Forecast-Actual Comparison	Corrective Actions Archiving
Near Term Prediction (Next 1h-24h)	N/A	Near real time predictions for key parameters	Probabilistic Near Term Forecast	Pattern recognition approach - To be defined
Simulation and Replay	Automatic, Interactive Frequency Replay	Automatic, Interactive ACE-Frequency Replay	N/A	N/A

Fig. 8 Visualization Content Definition

Using the visual design goals, Visual Information Wheel, and visualization content definition above, CERTS' researchers created the visual format template shown in Figure 9 for RTPM applications.

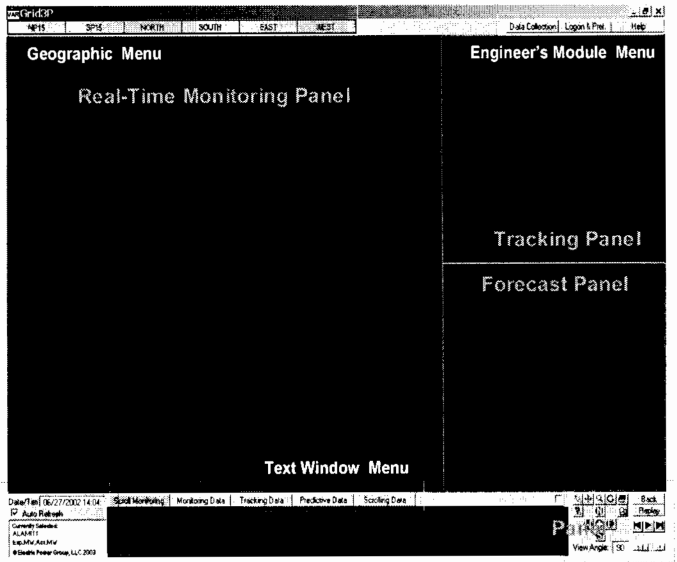

Fig. 9 CERTS RTPM Visualization Format

IV. REAL-TIME PERFORMANCE MONITORING APPLICATIONS

The first of CERTS' RTPM tools to be deployed was the ACE-Frequency Real-Time Monitoring System. The Suppliers' performance, the VAR Management and the system dynamics monitoring tools are currently being field-tested.

ACE-Frequency Real-Time Monitoring System

Reliability Coordinators throughout the nation are using the new CERTS ACE-Frequency Real-Time Monitoring System, developed for NERC.[2] The ACE-Frequency tool allows Reliability Coordinators to monitor compliance with NERC standards that ensure the reliable supply of electricity [2]. Prior to the introduction of this tool, it took many months to perform the data analysis necessary for determining the root cause of violations, so it was not possible to take corrective action in real time. The ACE-Frequency monitoring tool solves this problem by immediately detecting reliability threats and alerting Reliability Coordinators, so there is time to work with out-of-compliance control areas to correct problems and thus reduce the chances of unplanned events.

The ACE tool assesses the compliance of the 143 North American control areas with reliability standards, creating a real-time visual display of the state of the entire power grid based on data generated every minute by the control areas. NERC Reliability Coordinators are instantly notified of emerging frequency abnormalities within an interconnection and can then pinpoint the control areas causing the violations. Armed with this information, they can initiate appropriate corrective actions within minutes to prevent further degradation of system reliability – rather than months after the fact when action will almost certainly be too late to prevent blackouts.

The ACE-Frequency tool was released to all 23 NERC Reliability Coordinators and a few control areas in the fall of 2002. Four special training sessions were conducted in each region of the country in November and December 2002 hosted by the Midwest ISO (MISO), the New York ISO (NYISO), Southern Company, and CAISO. CERTS is already using feedback from Reliability Coordinators to enhance the application functional capability and user-interface visualization.

In combination with the Supplier's Real-Time Performance Monitoring application described in the next section below, the ACE-Frequency tool could help prevent recurrence of

[2] Reliability Coordinators perform a specialized function, created under the auspices of NERC, monitoring and overseeing reliability management among multiple control areas. There are 23 Reliability Coordinators throughout the Western and Eastern Interconnections.

conditions such as those that led to rolling blackouts in the southeast during the hot summer of 1999.[3]

The top right-hand portion of Figure 10 shows the three major functional components of the ACE-Frequency monitoring application: data collection from the 143 control areas (A), automatic frequency notification and alarms (B), and functional and visual capabilities that allow users to quickly identify the root cause of interconnection frequency abnormalities (C).

Suppliers' and Control Area RTPM for Automatic Generation Control (AGC) and Frequency Response (FR) Services

The Suppliers' performance monitoring application allows system operators, once they are notified by Reliability Coordinators of frequency abnormalities in the system, to rapidly and accurately pinpoint the individual suppliers response to AGC and Frequency Response and quickly identify those that are deviating from their operating commitments and causing the abnormalities [3]. System Operators can immediately notify non-compliant suppliers and initiate remedial action to preserve system reliability and maintain market efficiency.

The bottom right-hand portion of Figure 10 shows the components of the Suppliers' performance monitoring application: the collection of suppliers' performance data (D), and graphic indicators for current conditions, historical tracking, near real-time predictions and also indicators for preventing actions taken by dispatchers. (E)

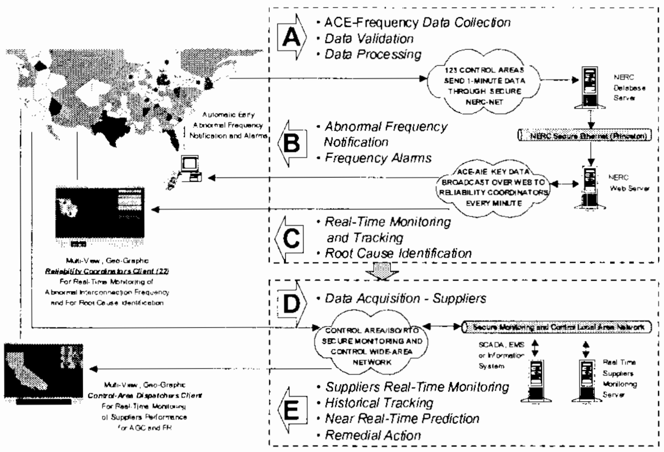

Fig. 10 Integrated ACE-Frequency and Suppliers' Real-Time Performance Monitoring Applications

[3] In 1999, the DOE Power Outage Study Team investigated rolling blackouts during the summer of 1999 in response to dangerously low frequencies on the Eastern Interconnection. Several months after the event, NERC determined the control area cause "leaning" on the system, which went undetected in real time; this protracted low frequency threatened the reliability of the entire Interconnection.

Maximum benefit can be obtained if the ACE-Frequency and Suppliers' applications are used together to maintain system reliability. These two tools together address the emerging new hierarchy of real-time grid reliability management. The ACE-Frequency Real-Time Monitoring System operates at the highest level of this hierarchy – the entire Interconnection and the underlying control areas. The Control Area and Suppliers' Performance for AGC and Frequency Response Services tool operates at the next level down within the hierarchy – the control area and the underlying generators within the control area. Integration of these two tools is the first step toward a fully integrated portfolio of RTPM applications that work together so that all levels of the system operational hierarchy can work together, to prevent reliability problems.

The CERTS Suppliers' tool is planned for delivery to CAISO system operators for summer 2003 operations. CERTs is in discussions with the Pennsylvania-New Jersey-Maryland RTO (PJM), and MISO, regarding them actining as additional hosts for the application.

VAR-Voltage Management Tool

The CERTS VAR-Voltage Management Tool can mine, analyze, and present existing SCADA operational data visually, both geographically and dynamically [4], simplifying the process of assessing a key aspect of system health and thereby enabling more effective and reliable management of operating margins.

During and immediately after a significant grid disturbance, operators must maintain system reliability by managing voltages and reactive reserves, which vary according to local conditions. In layperson's terms, the VAR-Voltage Management Tool replaces difficult-to-read and time-consuming tables of voltages at each monitoring point within the system with a visual, bird's-eye view of the overall health of the grid. The tool uses sensitivity calculations to determine how close the system is to voltage collapse and what remedial actions must be taken. This information is presented in geographic-visual displays.

The CERTS VAR-Voltage Management Tool might have been instrumental in preventing the widespread power outages that crippled the west coast in 1996 by alerting operators to dangerously low reactive reserve margins at critical locations. Damage from that outage was estimated at $2 billion, and the loss of power affected millions of customers.

System Dynamics Monitoring

The original network of phasor measurement technologies was installed in the west during the mid-1990s, supported by a joint project of DOE, the Bonneville Power Administration (BPA), WAPA, and the Electric Power Research Institute (EPRI). The cost of that demonstration project was paid in full when information recorded by the phasor devices was instrumental in determining the causes of the August 1996 west coast blackout. The data confirmed that the models used by operators to determine safe operating limits were in serious error.

CERTS has worked with CAISO to deliver three post-disturbance assessment applications based on phasor measurements [5]. These applications are currently being used by CAISO operating engineers to support off-line studies of grid disturbances. The tools are being used in the calibration of system models for developing real-time operations guidelines in coordination with WECC.

In addition, phasor data currently being collected by BPA, SCE, and Pacific Gas and Electric Company (PG&E) are being transferred to a CAISO phasor data concentrator using the WECC wide-area network. These data will be used to support new, prototype, real-time monitoring displays that CERTS is building for CAISO system operators.

Though this project, CAISO is pioneering the first-ever, real-time application of phasor technology. The objective of the new displays is to provide grid operators with real-time synchronized phasor data that offer an accurate picture of the actual health of the grid. This information will allow operators to verify that the system remains within the boundaries of safe operation as determined by off-line planning studies; the information will also permit operators to determine whether the operating guidelines established in these studies remain valid. Ultimately, real-time data provided by phasor and other monitoring technologies will support creation of an automatic, switchable grid that can sense and respond automatically to warning signs of emergencies.

DOE is working with MISO, NYISO, the Tennessee Valley Authority (TVA), American Electric Power (AEP), PJM, National Grid, and NERC to arrange a large-scale demonstration of the region-wide sharing of real-time information from phasor measurement technologies. There is growing recognition of the need for phasor technologies to support reliable transfers of power across the Eastern Interconnection as system operators are increasingly encountering voltage and stability problems resulting from the magnitude of power shipments and the distances over which power is being shipped.

V. DEVELOPMENT AND DISSEMINATION EXPERIENCES

CERTS has established the RTPM application, research, and development process, shown in Figure 11. The following subsection will describe each of the four steps of the development process together with CERTS experiences during the execution of each step for each of the four RTPM applications.

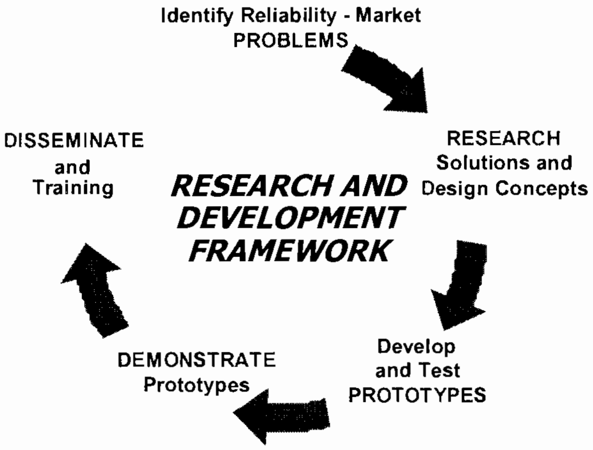

Fig. 11 CERTS Research and Development Process

Identify Reliability Problems

CERTS identifies reliability problems to address based on twice-yearly input from its Industry Advisory Board regarding new operational and technology challenges faced by board members in their organizations. Items identified by board members are discussed with operations managers and system operators, and coordination meetings are held with DOE, NERC, the Federal Energy Regulatory Commission (FERC) and CEC to fine-tune CERTS' list of research projects, and to be certain that problems are addressing real reliability or market challenges or problems.

Research Solutions and Design Concepts

Individual projects from the master list created in step 1 are allocated to each of CERTS' four major research areas and assigned to research groups with expertise in the relevant areas. CERTS research groups review the technical literature and collaborate to identify and define the most promising technology approach to address the problem.

Develop and Test Prototypes

Once a clear functional specification is created, teams of CERTS researchers work with independent expert vendors to devise the most appropriate design specification. This document becomes the guide for prototype deployment and field and factory tests.

Demonstrate Prototypes

Once a successful proof-of-concept prototype is complete, a host is selected to deploy the prototype using real-time data in an operational environment. The CERTS team works with the host to determine what changes are required in the prototype so that it can integrate in a non-disruptive way with the host's systems. After the prototype is installed and tested to everyone's satisfaction, it remains at the host site for four to six months so that dispatchers can use and experiment with it.

Dissemination

If prototype testing and utilization by hosts proves successful, CERTS enters into a dissemination phase, starting with direct demonstrations or partnership with other hosts or independent vendors to tailor the prototype to their requirements and to assist them in understanding the application's functional capabilities and integration issues.

CERTS experience with the above process has demonstrated its effectiveness to: a) focus resources into technology solutions for high priority problems, b) productive utilization of CERTS resources by using the appropriate expertise for the appropriate development stage, c) reduce cycle development process, d) involvement of end-users from the start to the end of the process, and e) creation and utilization of generic technical templates used for several RTPM applications.

VI. SUMMARY AND FUTURE WORK

Competitive markets and restructuring in the electricity industry are increasing the need for RTPM tools that can rapidly detect and help correct conditions that threaten the reliable operation of the electricity grid and the efficiency of the markets. CERTS has developed real-time monitoring tools using a multi-view, geo-graphic visualization approach, which permits operators to quickly interpret system operation data and institute corrective action. These tools replace data that were previously available only in text format and required considerable time to evaluate, so understanding of the causes of an outage or other system problem could only be reached after the fact.

CERTS' experience with these tools demonstrates that they can be effectively integrated into system operations. In particular, CERTS' successful launch of applications for ACE monitoring has shown that dispatchers can incorporate additional performance-monitoring responsibilities and use of corresponding tools into the normal minute-by-minute operation of the power system.

CERTS' successful deployment of its first performance monitoring applications has also shown the value of close coordination with system operators and operations management and created opportunity for feedback from end users during the design, development, and demonstration process.

ACKNOWLEDGMENTS

This work was funded by the Assistant Secretary for Energy Efficiency and Renewable Energy of the U.S. Department of Energy, Distributed Energy and Electricity Reliability Program, Transmission Reliability, under Contract No. DE-AC03-76SF00098 with direction provided by Philip Overholt and by the California Energy Commission, Public Interest Energy Research Program, under Work for Others Contract No. BG 99-396 (00) with direction provided by Don Kondoleon. We also wish to acknowledge the support of Bob Cummings and Paul Baratelli, North American Electric Reliability Council (NERC), NERC Resources Subcommittee and Reliability Coordinators, and California Independent System Operator Operations, Reliability Coordinators, and Information Technology Departments, including David Hawkins and Lisa Szot.

REFERENCES

[1] Eto J., C. Martinez, and V. Budhraja. 2001. "Grid Reliability Management Tools." *Proceedings, IEEE Power Engineering Society Winter Meeting. January 28-31, 2001* .

[2] Martinez, C., J. Dyer. 2001. *Reliability Compliance Monitoring System for Area Control and Area Interchange Errors*. Electric Power Group, Pasadena CA. http://certs.lbl.gov

[3] Martinez, C., J. Dyer, and M. Skowronski. 2003. *Supplier and Control Area Performance Monitoring System: Utilization of Grid-3P for Automatic Generation Control (AGC), Frequency Response Reserves (FRR) and Ancillary Services (AS) Regulation*. Electric Power Group, Pasadena CA. http://certs.lbl.gov

[4] Martinez, C., J. Dyer, and M. Skowronski. 2003. *Real-Time Voltage Monitoring and VAR Management System*© Electric Power Group, Pasadena CA. http://certs.lbl.gov

[5] Consortium for Electricity Reliability Technology Solutions (CERTS). 2001. *Synchronized Phasor Measurements Applications User Guide*. Electric Power Group, Pasadena CA. http://certs.lbl.gov

[6] M. Q. Wang Baldonado, A. Woodruff, and A. Kuchinsky, "Guidelines for Using Multiple Views in Information Visualization," submitted to ACM Conference on Human Factors in Computing (CHI'2000).

[7] C. North, N. Conklin, K. Indukuri, V. Saini, "Visualization Schemas and a Web-based Architecture for Custom Multiple-View Visualization of Multiple-Table Databases," Available: http://infovis.cs.vt.edu

[8] V. S. Budhraja, "Harmonizing Electricity Markets with the Physics of Electricity," *The Electricity Journal*, pp. 51-58, April 2003.

[9] V. S. Budhraja, "California's Electricity Crisis," *IEEE Power Engineering Review*, vol.22, no. 8, pp. 6-7,14, August 2002.