Reliability Monitoring:

The High-Tech Eye In the Sky

How reliability performance monitoring and standards compliance will be achieved in real time.

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The North American electric power grid has suffered several significant outages in recent years. These events and other incidents around the world spotlight the need for enforceable grid-reliability standards, wide-area visibility of the health of the power system, and real-time monitoring of grid-reliability performance to prevent blackouts. Effective reliability management requires real-time tools and technologies that can detect standards violations so that timely corrective or preventive actions can be taken.

The North American Electric Reliability Council (NERC), formed and managed by the power industry, has overseen North American electricity system reliability since 1967. But until recently, NERC had neither the authority to enforce compliance with reliability standards nor the tools to monitor reliability in real time.

NERC soon will have mandatory reliability management authority. As many readers may be aware, the Energy Policy Act of 2005 directed the Federal Energy Regulatory Commission (FERC) to confirm and regulate an Electricity Reliability Organization (ERO) to establish, monitor, and enforce compliance with mandatory reliability rules. This mandatory authority is an important element of reliability management. FERC certified NERC as the ERO in July 2006. NERC expects to begin performing ERO functions this month. Moreover, the Consortium for Electric Reliability Technology Solutions (CERTS), working for the U.S. Department of Energy (DOE) and with NERC, has, since 2000, been researching, developing, and demonstrating advanced software tools to monitor the electricity grid on a wide-area basis in real time. These tools track compliance with reliability rules and provide a visual assessment of the minute-to-minute health of the grid. The DOE-NERC-CERTS research effort is a positive example of government and industry collaboration to "keep the lights on."

Gaps in Reliability Technology and Research

Following blackouts on the West Coast in summer 1996, the energy secretary's Energy Advisory Board (SEAB) Task Force concluded "Reliability standards must be clear, transparent, nondiscriminatory, enforceable, and enforced. Compliance must be mandatory for all entities using the bulk-power system."

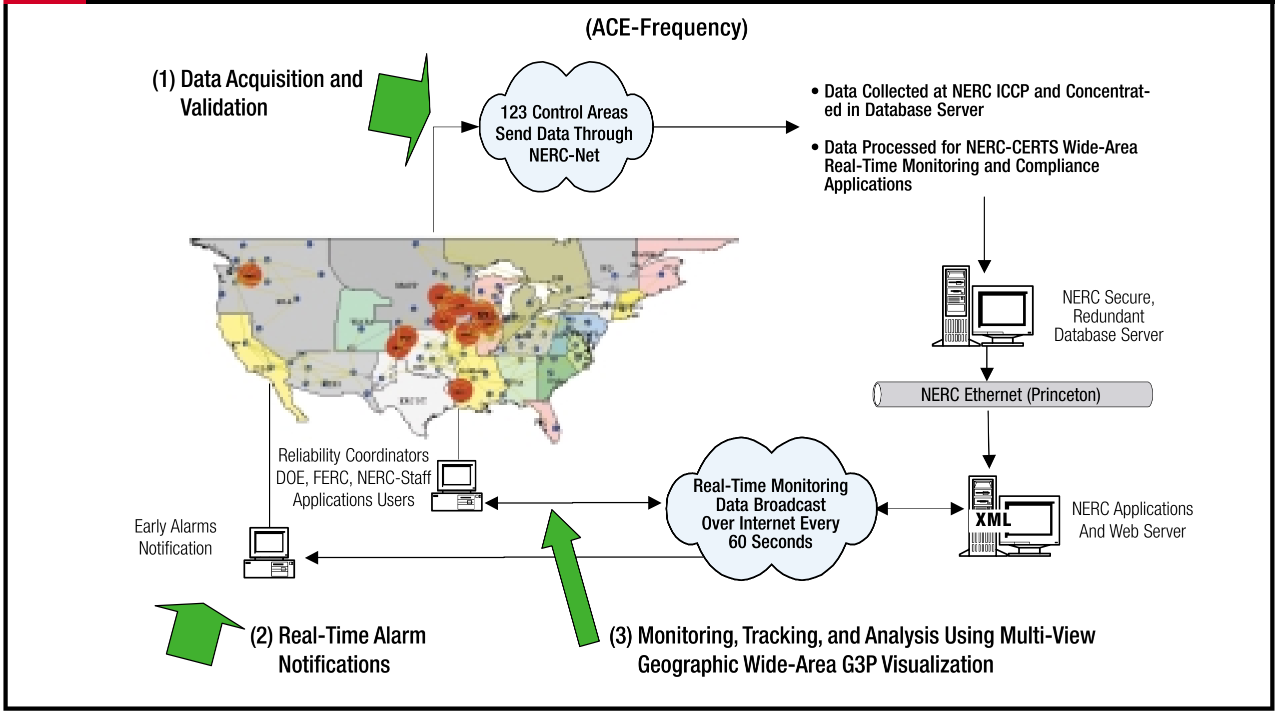
The SEAB report confirmed that electricity system reliability is an essential public good that, without legislation, would be under-provided by competitive markets. The report also recognized that, for the same reasons, public-good research on electricity reliability also would be under-provided—at precisely the time when it would be needed the most. Thus, the SEAB report concluded with a strong recommendation that DOE "monitor research on reliability technologies and assure that gaps do not develop." The formation of CERTS was a response to a congressional call for collaboration among universities, industry, and national laboratories to focus on public-good electricity reliability research and development needs.[1]

The DOE-NERC Collaboration

Shortly after the formation of CERTS, members participated in the energy secretary's Power Outage Study Team to investigate the blackouts and grid disturbances of the summer of 1999. During that investigation, one of the key events—extended periods of low frequency in the Eastern Interconnection followed by rolling blackouts—dramatically demonstrated the need for new wide-area tools to detect violations of reliability rules in real time.

During the July 1999 Eastern Interconnection low-frequency events, generation resources were inadequate to meet electricity demand, which jeopardized grid reliability and ultimately led to rolling blackouts in the middle South. NERC operating policies require that each operator balance generation with demand in its control area within 10 minutes, including dropping loads if necessary, to avoid a cascading event that could jeopardize the reliability of the entire interconnection. Members of the relevant NERC operating committees investigated the July 1999 events using established procedures, which required time-consuming manual investigations involving compilation

Fig. 1 Load-Generation Resource Adequacy Monitoring Architecture



Source: CERTS

and review of operating records and comparing scheduled transactions with actual flows.

Because of the time required for this manual review, it was not until five months later, December 1999, that the East Central Area Reliability Coordination Agreement issued a strongly worded reprimand to a Midwest utility, citing blatant disregard for reliability rules and threatening to revoke the utility's authority to operate as a control area. The investigation had found at least six hours during which the utility had failed to meet its obligations by more than 1,000 MW. Those actions had disturbed the interconnection's delicate supply-and-demand balance and created conditions that led to rolling blackouts affecting more than half a million customers in three states. Interestingly, the spot price of electricity in the Midwest during that period was routinely in the thousands of dollars per megawatt-hour, with a high of $5,000/MWh. By "leaning on the ties" and not meeting its obligations, the utility was avoiding millions of dollars per hour in spot-market purchases.

This event and its aftermath highlighted both the need for mandatory reliability rules and the need for new tools to replace manual review of records to monitor compliance with the rules. While Congress worked to pass legislation making the rules mandatory, DOE and NERC, through CERTS, began collaborating to develop and pilot new tools to monitor compliance in real time.

Early Success

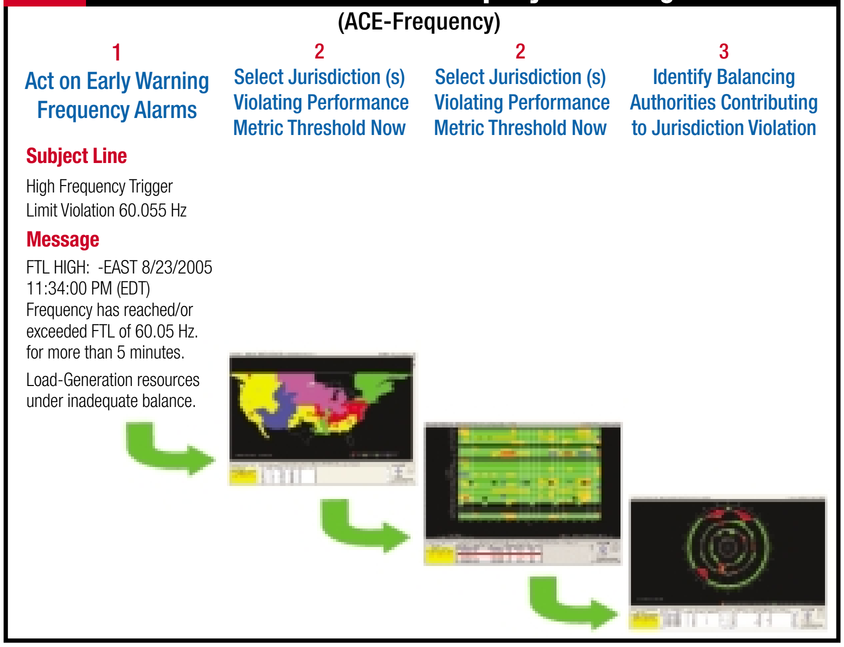
Development of a wide-area, real-time Area Control Error (ACE)-Frequency monitoring system was one of the first CERTS successes.[2] The new system provides reliability authorities with real-time situational awareness of grid frequency performance and the diagnostic tools to determine the nature and origin of problems. Use of the new system ensures that the review process, which in 1999 took five months, can now be accomplished in minutes.

CERTS, supported by NERC staff, developed the ACE-Frequency Monitoring System with funding from DOE and under the guidance of the NERC Resources Subcommittee, which oversees development of metrics and monitoring of compliance with NERC's resource adequacy rules. The ACE-Frequency system was field-tested in 2002 and today is in use by all 17 NERC reliability authorities and several control area operators.

The ACE-Frequency system utilizes real-time data from all NERC North America control areas. As shown in Fig. 1, data are updated by the control areas every four to six seconds and sent automatically via the NERC Wide-Area Network to a central server at NERC's headquarters in Princeton, N.J. The ACE-Frequency system reads and processes these data and converts them into meaningful monitoring metrics and wide-area, geographic visual displays that can be accessed, via a secure Internet connection, by NERC reliability coordinators, control area operators, and members of the NERC Resources Subcommittee.

The system automatically sends alarms in real time (in the form of electronic e-mails and pages) when interconnection frequency strays outside of normal limits, and when specific NERC-reliability performance metrics are violated. The alarms inform the reliability coordinators of load-generation resource inadequacies (ACE-Frequency imbalance) and provide summary information, which enables them to search systematically for root causes and to identify remedial actions. Fig. 2 provides a step-by-step illustration of how the ACE-Frequency system currently is used.

FIG. 2 Load-Generation Resource Adequacy Monitoring Utilization



Source: CERTS

Challenges in Reliability Compliance Monitoring

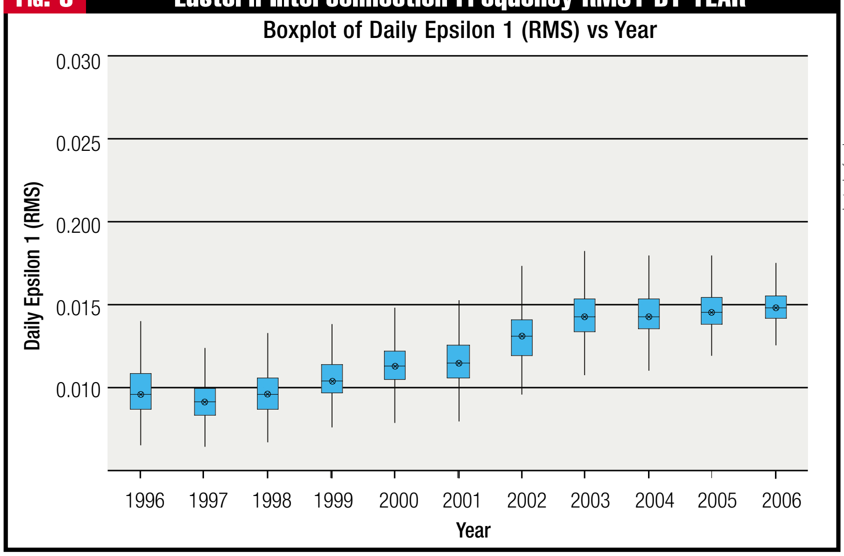
The early success of the ACE-Frequency collaboration suggests that there are both great potential and great challenges for further research on new technologies to improve grid reliability management and oversight. DOE's collaboration with NERC continues to evolve to meet these challenges.

The initial goal of the DOE-NERC collaboration was to prevent a recurrence of the summer 1999 low-frequency events described above. However, addressing that series of events led to identification of far more pervasive and widespread frequency issues in the Eastern Interconnection.

In Fig. 3, a box plot of daily epsilon, which is a measure of performance, shows that reliability control is deteriorating in the Eastern Interconnection. Underlying this problem is declining generator performance, specifically in response to frequency excursions (*see Figs. 4 and 5*). Left unchecked, this decline will pose a direct threat to the interconnection's future reliability.

To address this concern, CERTS supported the NERC Resources Sub-

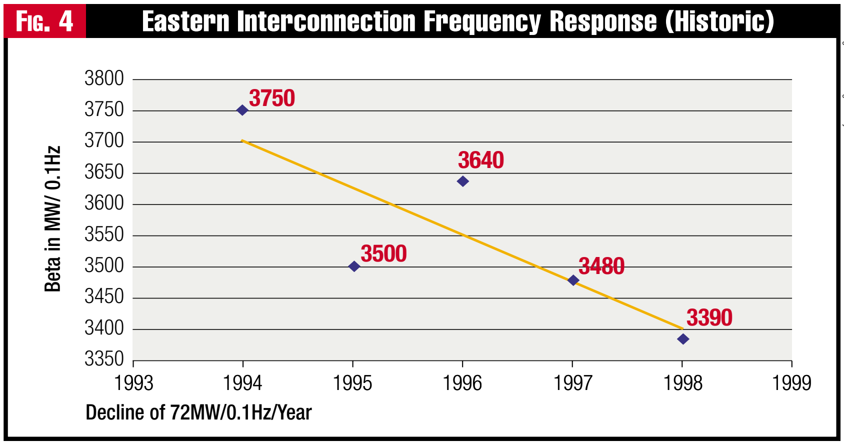
FIG. 3 Eastern Interconnection Frequency RMS1 BY YEAR



Data Through August, 2006

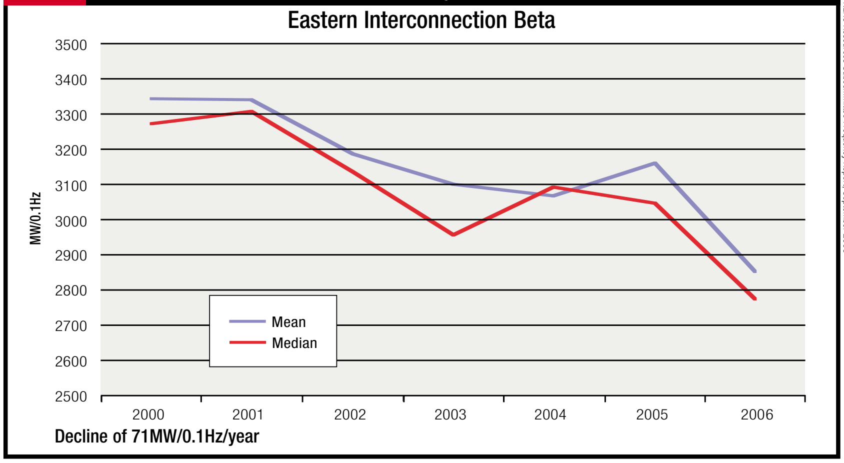
Source: NERC Resources Subcommittee Frequency Report, September 2006

FIG. 4 Eastern Interconnection Frequency Response (Historic)



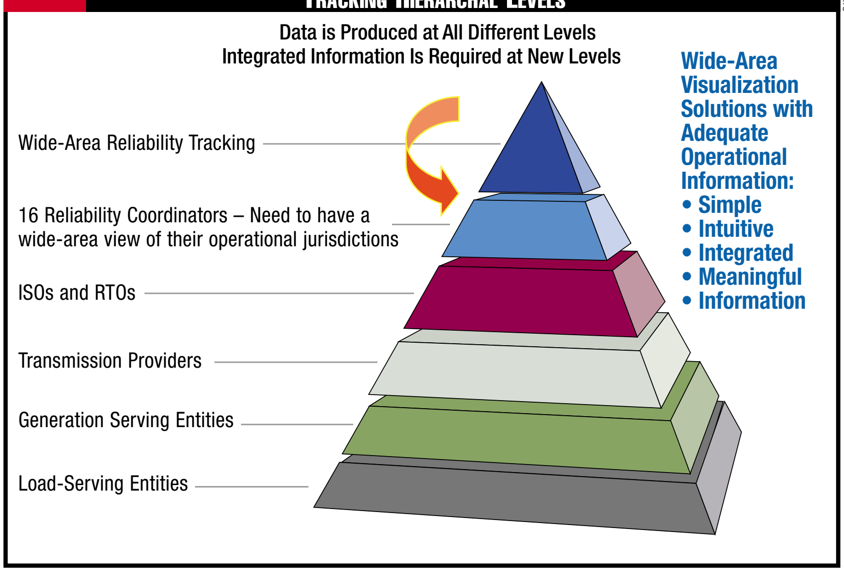
Source: Ingleson and Nagle Study

FIG. 5 EASTERN INTERCONNECTION FREQUENCY RESPONSE (RECENT)



Source: NERC Resources Subcommittee Frequency Report, September 2006

FIG. 6 POWER INDUSTRY OPERATIONAL, MONITORING AND TRACKING HIERARCHAL LEVELS



Source: CERTS

committee in research and development of new reliability metrics. CERTS continues to support NERC Standard Drafting Teams, including the Balance Resources and Demand Standard drafting team, in validating and field-testing the new reliability metric, called the Balancing Resources and Demand (BRD) performance metric with a threshold for each balancing authority called the Balancing Authority ACE Limit, or BAAL. The shortcomings of the old, long-standing Control Performance Standard 2 (CPS2) metric, are addressed by the BRD metric. In the past, the CPS2 often led to unneeded and sometimes uneconomic control actions, which under some conditions could further degrade interconnection frequency.

The new BRD metric addresses these shortcomings by linking a control area's ACE compliance with the impact of this compliance on interconnection frequency, including explicit consideration of risk, in establishing acceptable frequency limits. The drafting team will complete a field test of the new metric with selected utilities serving almost half of the Eastern Interconnection in the fall of 2006. A recommendation to adopt a revised standard is expected to follow.

Implementing Recommendations From the 2003 Blackout Investigation

The U.S.-Canada final report on the Aug. 14, 2003, Eastern Interconnection blackout contains 46 recommendations. The following five are related to coordination and improvement of wide-area monitoring and are the current targets of DOE-sponsored research on technology solutions:

- Develop reliability related tools and technologies;
- Adopt better real-time tools for operators and reliability coordinators;
- Strengthen reactive power and voltage practices;
- Improve quality of system modeling data and data exchange practices; and
- Utilize time-synchronized data recorders.

A key objective of the research effort is to create common wide-area monitoring functions and visuals that facilitate operational communications between the different stakeholder levels responsible for operating and managing the power grid. New operational requirements for large control areas and reliability authorities are making traditional monitoring systems obsolete and user interfaces ineffective. Fig. 6 shows that, as a result of industry restructuring, raw operational data now are being generated at each of five different organizational or operational levels within the industry. Traditional utility monitoring systems—Supervisory Control and Data Acquisition (SCADA) and Energy Management Systems (EMS)—were developed to monitor reliability performance for a single control area and its immediately adjacent neighbor.

Today, reliability monitoring jurisdictions consisting of 10 to 30 control areas are increasingly common. Relying on traditional tabular displays » to perform this monitoring is time consuming, cumbersome, and risky. As seen first with the ACE-Frequency system, a common feature of all CERTS monitoring tools is a multi-view, geographic visualization approach and display architecture, which enables system operators to quickly interpret and use real-time data for monitoring and for identification of root causes. Human-factors experts have concluded that analysis of visual data is significantly improved if the viewer simultaneously reviews graphical images of different, yet closely related, processed data.

Currently, CERTS is researching and prototyping new wide-area real time performance monitoring tools for:

- Wide-Area Real Time Situational Awareness for Load-Generation Adequacy;
- Wide-Area Real Time Monitoring for Load-Transmission Adequacy; and
- Wide-Area Real Time Situational Awareness for Load-Transmission Adequacy.

Some of the Situational Awareness for Resource Adequacy (SARA) tools are being field-tested with the expectation that they will be integrated by NERC and made operational before the summer of 2007.

Looking forward, CERTS is researching and prototyping wide-area monitoring applications using time-synchronized phasor measurements from the DOE Eastern Interconnection Phasor Project.[3] For monitoring wide-area, real-time resources adequacy, the SCADA measurements required are taken at intervals ranging from 5 seconds to 5 minutes. However, lack of time synchronization among different SCADA systems is becoming a serious source of data errors in wide-area monitoring. Better data resolution and time synchronization can be achieved with phasor measurements » and other advanced monitoring technologies.

In conclusion, DOE and NERC and other advanced monitoring technologies have been conducting a collaborative program to research, develop, prototype and demonstrate advanced software tools to monitor on a wide-area basis and in real time compliance with reliability rules, in preparation for confirmation of NERC as the ERO with mandatory reliability authority for the North America's electricity grid. The origins, process, and early results from this collaboration document the industry's growing need for mandatory reliability rules and provide a positive example of government and industry working together to "keep the lights on." ◼

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Endnotes

1. The founding members of CERTS include four national laboratories (Lawrence Berkeley, Oak Ridge, Pacific Northwest, and Sandia), a National Science Foundation Industry/University Research Center consisting of 13 major universities, called the Power Systems Engineering Research Center and the Electric Power Group. See *http://certs.lbl.gov*.
2. Area Control Error (ACE) is a real-time control measure that measures the balance between load and generation for each control area. An ACE of 0 MW is the control target for each control area. Achieving this target means that the control area is contributing proportionately toward maintaining the frequency of the interconnection at a reliable 60 Hz.
3. For more information on the Eastern Interconnection Phasor Project see *http://certs.lbl.gov/certs-eipp.html*.

CAIR

(Cont. from p. 50)

Endnotes

1. U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook 2006 With Projections to 2030*, p. 28.
2. Among the states east of the Mississippi River, plants in Georgia will be regulated only under the CAIR PM2.5 rule, plants in New Jersey, Delaware, Connecticut and Massachusetts will be regulated only under the CAIR Ozone rule, and plants in Rhode Island, Vermont, New Hampshire, and Maine will not be regulated under either of the CAIR rules. The plants in the rest of the states east of the Mississippi River will be regulated under both CAIR rules. Plants in six states west of the Mississippi River will be regulated under either or both of the CAIR rules—those in Arkansas will be regulated only under the CAIR Ozone rule, those in Minnesota and Texas will be regulated only under the CAIR PM2.5 rule, and plants in Iowa, Missouri, and Louisiana will be regulated under both of the CAIR NOx rules.
3. In some cases, states and federal settlements limit the extent to which NBP allowances can be used by generators, which we reflect in our analysis.
4. We assumed the state holdbacks under CAIR Ozone and CAIR PM2.5 would be the same as those under the NBP.
5. The 301,700 MW is the sum of the 284,500 and the 17,200 from Table 2.
6. The 323,600 MW is the sum of the 284,500 and the 39,100 from Table 2.
7. The 399,500 MW is the sum of the 284,500 and the 115,000 from Table 2.
8. The CAIR provisions for sulfur dioxide control and the Clean Air Mercury Rule (CAMR) are assumed to be in place throughout the analysis.

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