Electricity Advisory Committee

MEMORANDUM

TO: **Honorable Patricia Hoffman, Assistant Secretary for Electricity Delivery and Energy Reliability, U.S. Department of Energy**

FROM: **Electricity Advisory Committee (EAC)**
Richard Cowart, Chair

DATE: **October 17, 2012**

RE: **Recommendations on Development of the Next Generation Grid Operating System (Energy Management System).**

The purpose of this memorandum is to respectfully recommend to the U.S. Department of Energy (DOE) a roadmap for the development of a next-generation grid operating system or energy management system (EMS). The nation's grid faces significant transformation in supply, demand, consumer expectations, and markets. Given the long lead time required to develop and implement fundamental changes in the way the grid is managed, it is imperative to anticipate and plan for this transformation. This memorandum provides the historical context for that grid operating system, identifies the shortcomings of today’s approach, and concludes with the EAC’s recommended roadmap for achieving the next generation EMS system, which is critical to future grid operations for our energy and economic future.

Historical EMS Perspective

One of the first challenges faced by both Edison and Westinghouse in the first direct current or alternating current power systems was to reliably control their operation, such that in any instant the total generation was balanced against the total load. This balancing is essential to good system operations. When not balanced, the system becomes unstable and can collapse. In the late 1800s, when the first of the Pearl Street Generators was placed in service, this balancing was relatively simple, achieved primarily through generator control systems.

As power systems evolved, they became larger, more complex, more interconnected, and more difficult to control. Balancing multiple generators with a network of loads throughout a city or across town and into the countryside could not be facilitated by

EAC
Electricity Advisory Committee
U.S. Department of Energy

generation control alone. A new interconnection control paradigm was needed, which had to go beyond balancing load and generation. The visualization and control over the state of the system became vital. By the mid-1950s, some of the first Supervisory Control and Data Acquisition (SCADA) systems were deployed in power delivery systems.

In 1962, a group of utilities located in the Midwest and South, met to prepare for the imminent closure of seven interconnections to form the largest synchronized system in the world. The committee formed to study this new interconnection recommended the creation of an informal operations organization for the future; which would promulgate “operating guides” for the reliable operation of interconnected systems. The North American Power Systems Interconnection Committee (NAPSIC) comprised what today are the Eastern Interconnection, the Western Interconnection, and the Texas Interconnection.

In 1965, a massive blackout in the northeastern United States and southeastern Ontario, Canada prompted the U.S. Congress to propose legislation — The Electric Power Reliability Act of 1967 — that would create a federal agency to regulate electric reliability. Responding to a petition by electric industry executives, the U.S. Federal Power Commission recommended instead the formation of “A council on power coordination made up of representatives from each of the nation’s Regional coordinating organizations to exchange and disseminate information on Regional coordinating practices to all of the Regional organizations, and to review, discuss, and assist in resolving matters affecting interregional coordination.”

On June 1, 1968, twelve Regional and area organizations signed an agreement forming the National Electric Reliability Council (NERC). Ten years later, NERC approved expanding its activities to include the development of planning guides for designing bulk electric systems to address changes in the industry resulting from the passage of the U.S. National Energy Act of 1978.

In 1980, NERC and NAPSIC merged, giving NERC a role in both the planning reliability and operating reliability of bulk electric systems.

In the late 1980s and 1990s, the Federal Energy Regulatory Commission (FERC) passed a series of orders that greatly expanded wholesale electricity markets (e.g., FERC Orders 888 and 889 in 1996). Accordingly, many of the US grid operating systems were modified to enable the connection to a highly increased number of market participants, increasing from a few dozen transactions to hundreds per day.

These developments, coupled with the major northeastern blackout of August 2003 and an overall industry recognition that more needed to be done to ensure a reliable electricity supply, led to the improvements in the grid control system. Although enhanced repeatedly, that computer-based control system, dating back to foundational computational elements developed in the 1970s, is the basic one in use today. The major improvements over the past decade or so expanded the system’s capability to balance supply and demand among many market participants, as well as multiple bulk power central generation resources, and exercise wide ranging control over numerous interconnected areas at high-voltage levels. In addition, the system today uses a much more sophisticated mathematical technique to estimate the condition of the system.

The EMS provides the system operator with the necessary information to operate the grid from day to day, hour to hour, and minute to minute. In terms of system condition, the EMS (often referred to as real-time monitoring and control) provides near real-time information by using data coupled with input from sensors to estimate the condition of the grid 20 to 30 seconds after the fact.

Today's EMS has the ability to "fill in" or estimate data from missing sensory inputs. These systems are complex and use sophisticated applications software, have a large number of input/output (I/O) points, and a substantial number of remote terminal units to gather the data. The most prevalent types of intelligent electronic devices which communicate with the EMS are automated switches, protective relays, substation controllers, and phasor measurement units (PMUs).

EMS Critical Element to Grid Reliability

Blackouts are major catastrophic failures in large interconnected power systems. Predicting the occurrence of such phenomena is difficult at best. When they do occur, however, the socioeconomic impact is devastating. A cost estimate of the August 14, 2003 blackout prepared by the Anderson Economic Group (AEG) estimates the total cost to have been between $4.5 and $8.2 billion, with a mid-point of $6.4 billion.[1]

Some of the clear root causes for these catastrophic events are:

- a lack of reliable and synchronized real-time data
- a lack of time to take decisive and appropriate remedial action against unfolding events on the system
- a lack of properly automated and coordinated controls to take immediate and decisive action against system events in an effort to prevent cascading outages.[2]

The most recent major U.S. blackout, the Arizona-Southern California Outages on September 8, 2011, identified that the system failure stemmed primarily from weaknesses in two broad areas—operations planning and real-time situational awareness. Similarly, the August 14, 2003 Blackout Report[3] stated, "A principal cause of the August 14 blackout

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[1] The Economic Impacts of the August 2003 Blackout, Prepared by the Electricity Consumers Resource Council (ELCON) - February 9, 2004

[2] The anatomy of a power grid blackout - Root causes and dynamics of recent major blackouts - Pourbeik, P.; Kundur, P.S.; Taylor, C.W.; Power and Energy Magazine, IEEE Volume: 4 Issue: 5 Page(s): 22 - 29 Digital Object Identifier: 10.1109/MPAE.2006.1687814

[3] Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations, April 2004 - https://reports.energy.gov/BlackoutFinal-Web.pdf

was a lack of situational awareness, which was the result of inadequate reliability tools and backup capabilities." Since the EMS is the primary source of the information used by system operators to gather their real-time situational awareness, it is important to determine the deficiencies with these systems that contribute to blackouts.

Short Comings of Today's EMS

The future of grid operations will see smaller market intervals, more variable generation, demand and distributed resources (including integration with distribution management systems), and much more and frequent data on system state. Today's EMS technology was built in an era of the grid that had fewer variables and does not take advantage of advancements in visualization, computational, and communications technology. EMS architecture was built around the "SCADA" paradigm where the data base and operator interface are tied to the communications and measurement infrastructure instead of the power system equipment or application.

EMS architectures still have inherent single-threaded processes that cannot easily be distributed to multiple servers, and reliability/failover designs lag behind state of the art in the data center world.   In addition, the grid of the future will require more closed-loop (computer driven) and wider-area controls for voltage and power flow control than the more traditional open-loop (human intervention) and local-drivers for voltage and power flow controls.

What Contributes to Grid Visualization and Control Delays?

While there are many delays in the process, there are four primary sources:

1. Time delays in gathering the information from field devices
2. Computational methods used to process the data
3. Application processing time delays
4. Operator reaction time

Improving item 1 is solely at the discretion of the operating entity, and can be addressed by upgrades to the wide area communication system. Supported by DOE, the industry is installing phasor measurement units across the grid, which provide synchronized data on the state of the grid about 30 times per second. Therefore, this paper will not address item 1. Improving items 2 and 3 requires changes in the computer code and methods used by the EMS providers, and is necessary to take advantage of improvements that are being implemented in item 1. Within EMS, the industry must act to fully exploit the PMUs being installed across the grid. And item 4, the reaction time by operators, can be shortened with improvements in items 2 and 3, and the introduction of more closed-loop controls requiring less human intervention.

While the major EMS vendors have improved their products over the years with technology advancements, many of these products are still built upon *core components* that date back to the 1970s. The market for EMS systems is small, and replacement intervals tend to be on the order of a decade due to the complexity and cost of upgrading these systems. Given these limitations, the return on investment is low, which restricts investments in the technology by vendors.

The limitations of the legacy *core components* prevent the vendors from implementing many of the recent advances in computational mathematics (how the computer actually performs math) and advances in analytic methods (how the power system equations get solved). The combination of these two advancements can go a long way to reducing the calculation time and therefore reducing the 20-30 second delay to single digit seconds, and possibly even faster to fractions of a second. However even these improvements will not be sufficient to mitigate the broad changes currently underway within the grid.

The power grid is evolving at an exponential pace into a highly interconnected, complex, and interactive network of power systems, telecommunications, Internet, and electronic commerce applications. Virtually every element of the power system will incorporate sensors, communications, and computational ability. No longer will society depend primarily on central station power and what is essentially the one-way flow of information and electrons on the grid, if the use of distributed generation, distributed energy storage, and demand response applications proliferate as expected.

At the same time, the move towards more competitive electricity markets requires a much more sophisticated infrastructure to support a myriad of informational, financial, and physical transactions between the members of the electricity value chain that supplement or replace the vertically integrated utility. Additional changes include: Variable Generation, Demand Response, Electric Vehicles, Electric Storage, Smart Meters, Distributed Generation, PMUs, and Communications. The development and installation of new EMS systems will both facilitate and help system operators manage these complexities.

The EMS Market Lacks R&D Funding

As stated before, the EMS Market is highly competitive, with fairly slim R&D budgets. Most EMS vendors have gone through “boom and bust” cycles due to the uncertainty of revenues in the industry, particularly as the utility industry has consolidated. Following the 1965 Northeast blackout, in which millions lost power for several days, there was a surge of interest and investment in R&D for transmission planning and system operations, as well as basic infrastructure. At the same time, there was a surge in investment in higher transmission voltages and larger central generation plants.

Given their critical mass, in the 1970s large utilities such as Bonneville Power Administration (BPA), American Electric Power (AEP), as well as the newly formed Electric Power Research Institute (EPRI) and U.S. government agencies invested in R&D in the mathematics and software for planning and operations, and this in turn spurred private investment by the utility suppliers and new entrants from Silicon Valley and the aerospace/IT sector. This resulted in the rapid development of new tools for transmission planning and operations, as well as their gradual adoption by the industry over the period 1970 – 1985. On an inflation adjusted basis, the North American EMS market was several times larger than its current size during this period, and supported a healthy level of industry R&D.

Recent utility consolidation and a lack of demand for ongoing EMS development for the past few decades have stalled the development of new mathematics and software.

Establishing Grid Situational Awareness and Reliable Operations

Several organizations have work underway that relates to EMS system improvements:

- Recommendation 13 of the August 14, 2003 Blackout Report[4] suggested that the "DOE should expand its research programs on reliability-related tools and technologies" and the DOE has continued to support the North American Synchrophasor Initiative through it normal funding sources and through the Smart Grid Investment Grant program, where 850 networked phasor measurement units will be installed. These will provide power system data 30-to-120 times per second, which is more than 100 times faster than current technologies. However the ability of the EMS to truly capitalize on this information requires a complete redesign of the *core components*.

- The International Council on Large Electric Systems (CIGRE) has published a set of information technology (IT) requirements that will be useful in outlining some of the communications and IT needs. CIGRE has outlined the real-time and near-real-time systems which will be part of future developments (CIGRE 2011). Also brochure 452 "EMS for the 21st Century System Requirements" Working Group D2.24 has relevant EMS design information.

- The International Electrotechnical Commission (IEC) has a working group, TC-57, coincidentally working on standards which build off of several existing IEC Standards. Several of these standards used foundational work including: IEC 61970 – Common Information Model (CIM); IEC 60870-TASE.2 – Inter Control Center Protocols (ICCP); and IEC 61850 – Communications Networks and Systems in Substations.

- The IRC (ISO/RTO Council) in North America has recently established an Enterprise Architecture Standardization (EAS) standard with an objective of reducing the IT costs of ISOs and RTOs.

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[4] Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations April, 2004 prepared by: U.S.-Canada Power System Outage Task Force

- The Electric Power Research Institute (EPRI) has embarked on formulating the broad requirements on the next generation EMS, which they call Grid 3.0.

- The North American Electric Reliability Corporation issued a report in October 2010, "Real-Time Application of Synchrophasors for Improving Reliability,"[5] which reviewed the many ways that synchrophasor technology can be used to support real-time and off-line activities to enhance the reliable operations of the bulk power system.

Since situational awareness is key to safe and reliable operation of the grid, it is natural to ask what can be done to enhance this feature for grid operators.

- First and foremost, reducing the delay in providing operators with real-time data is essential. Ideally this should be at the second or sub-second level.

- Second, providing a suite of modular applications and tools to guide grid operators to operate the grid safely and reliably. These tools need to provide significant simplifications in the interpretations of the results for the operators along with sufficient time to take necessary actions are essential.

- Last, as the grid continues to evolve and become more complex, additional automated controls will be critical to maintain stability, reduce oscillations and maintain safe operating margins.

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[5] http://www.nerc.com/docs/oc/rapirtf/RAPIR%20final%20101710.pdf

Electricity Advisory Committee (EAC) Recommendations

Given the broad societal dependence on reliable electricity as well as the interdependence between the electric sector and other sectors such as oil and gas, telecommunication and transportation, the EAC recommends that the DOE isolate R&D funds and take the following steps in a cost-effective manner to develop the next generation grid operating system:

1.) Convene a technical conference or webinars with key industry stakeholders to develop the vision and roadmap for the next generation EMS. The starting point for these conferences is a draft vision and roadmap to be developed by DOE's Grid Technology Team.

2.) Assemble a team of computational mathematicians and power systems engineers to assess the available technologies and identify those suitable to dramatically enhance the EMS system capability in a cost effective manner. Specifically, identify technologies that enhance computational and analytic capability that can support real-time situational awareness at the second or sub-second level, and identify technologies that enable real-time analysis of exploratory load flows that represent potential near-future states, including contingency analysis and solutions for potential limit violations.

3.) Determine how to integrate new, synchronized, voluminous, detailed and robust real time information such as from phasor measurement units (PMUs) within the next generation EMS for model verification, visualization of system conditions, identification of problem conditions, and other applications. Multiple sources of data should be integrated from applications such as digital fault recorder data and disturbance characterization, while also enabling the move from State Estimation to a State Measurement mindset. Leverage existing foundational elements such as Common Information Model concepts for integration with Geospatial Information Systems and other applications that require significant information exchange.

4.) Develop EMS performance specifications for implementation of EMS improvements to further mitigate the likelihood of blackouts resulting from lack of situational awareness or lack of analytical tools and models to address our grid future. Identify and establish a path forward that accommodates enhanced automated control actions to support grid stability, reduce oscillations and maintain safe operating margins. Specifications should include:

- Flexibility required to accommodate a wide variety of new and emerging technologies such as distributed generation, variable generation resources, demand response, growing number of non-utility sources of data and control systems in its operations, nodal distribution markets, micro-grids and other changes in distribution topology and local control, voltage optimization, reactive power management, enhanced automated control for grid stability to reduce oscillations in areas of modeling, simulation, visualization, operation and control.

- Consideration of the human factor involved inside control centers. Any new EMS designs should provide grid operators with common, understandable real-time displays to enhance grid visualization, which can be shared among operators of neighboring systems.

- Enhanced and common modeling of the grid, including special protection systems, remedial action schemes, safety nets, automatic separation schemes, and other relay schemes in order to give operators a complete understanding of how the power system components will perform following contingencies.

- Integration and coordination with SCADA-based Distribution Management Systems (DMS). Information exchange between transmission and distribution control entities becomes crucial for both situational awareness and control. Once the data integration is achieved, application coordination will provide a high level of efficiency.

5.) Ensure the development of the next generation EMS conforms to applicable reliability and cybersecurity standards, and includes provisions for the changes needed for cybersecurity over time.

6.) Establish a broad collaborative organization to execute these recommendations that includes DOE, LBNL, Oakridge National Laboratory, NERC, EMS vendors, EPRI, relevant academic experts and industry technology leaders. This collaborative would also be responsible to keep all stakeholders, including state and federal regulators, informed of progress. The DOE should consider providing the appropriate funding to ensure the development of foundational technology that can be released to the industry in an ‘open-source’ manner. The DOE should also consider the merits of establishing a proof of concept center or centers at National Laboratories accessible to stakeholders to test and provide feedback for the next generation EMS prototype.

7.) Engage intelligence outside the industry as well to ensure the proper and elegant solution is developed. These can include companies (and elements within) not engaged with the energy industry such as IBM, Google, CISCO, and Oracle.

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