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Abstract
As the electric power industry advances toward the concept of a renewable energy-friendly smart grid, understanding the complications and challenges of wind and solar generation on transmission and distribution (T&D) operations becomes increasingly important. This report describes research on information display requirements for wind and solar power monitoring visualization tools.

Objective
The objective of this project was to investigate the state of current wind and solar visualization displays and forecasting tools. A goal for the work was to identify design guidelines and provide recommendations for effectively visualizing wind and solar power concerns in the control room.

Approach
This project team collected data from a site visit at a major ISO with a significant wind power profile and performed an extensive survey of documentation on current practices in wind and solar monitoring. Semi-structured interviews, observations, and detailed document analyses guided by specific design criteria were used to collect data on essential situation awareness factors related to wind and solar power monitoring. A survey distributed by e-mail was conducted to supplement the site visit data collection and document analysis.

Results
This project represents a detailed study of information display requirements for wind and solar power monitoring visualization tools. Data for the study were provided from a site visit at a major independent system operator (ISO) with a significant wind power profile, a voluntary survey distributed by e-mail, and an extensive survey of documentation on current practices in wind and solar monitoring. A total of 6 survey responses were collected from EPRI member companies and analyzed. Information requirements were identified for both wind and solar power monitoring displays.

Application, Value and Use
The requirements identified in this report will inform the power systems industry and software vendors to effect changes in the design of wind and solar power control room displays and forecasting applications.

EPRI Perspective
The results of this project will be presented in a workshop on December 10, 2009, which is open to the utility industry and software vendors.
Abstract
This report presents various visualization approaches to communicating conditions on the electric power system. The report first briefly reviews the history of how power system operators have tried to understand system conditions and formulate strategies for controlling it. The report then provides a survey of the current state of the art in visualization techniques. Although the survey identifies vendors and their products, the goal is to present examples of different ways of seeing the system rather than to promote any particular vendor's offerings. Finally, the report concludes by assessing the effectiveness of the various approaches and providing recommendations for developing a visualization strategy.

Objective
The electric power system is perhaps the most complicated dynamic control system currently in operation. It generates a quantity of data perhaps unrivaled by any other man-made system. To make sense of all the data, both to assess and to preserve the system's health, effective tools for organizing and visualizing the data and the complex relationships between them are necessary. This report will be valuable to utility engineers and operators because it identifies current system visualization techniques, assesses them in terms of visualization theory and human factors as well as operations practice, and provides recommendations for future deployment and investment. Since visualization tools will continue to evolve as the data needs of the system change, works such as this report that survey the state of the art in system visualization will continue to be important and helpful.

Approach
This work was informed by the authors' years of experience working with utility control engineers and operators as they use and search for visualization techniques appropriate to their systems. The authors also drew on their experience in building power system visualization tools and their previous research in the area of human factors in power systems. The content for the report came from site visits, interviews, market research, and Internet queries.

Results
This report informs the reader of current and emerging trends in power system visualization. Based on the authors' experience working with power system engineers and operators, as well as their research in the field of data visualization, the report provides a reasoned assessment of which approaches best convey system conditions. In light of this assessment, it recommends a strategy for future research and deployment in the area of power system visualization.

Application, Value and Use
As power system data sources and needs evolve, there will be an ongoing need to keep this document current to capture the more recent innovations. A periodic update to this document will help utility control rooms understand what tools are available so that they can match applications to their needs. It will also help point the way to future innovation in the field of system visualization so that engineers and operators may grow in their understanding and control of the power grid. Identifying current and future trends can also help fuel innovation among visualization tool vendors, because it can identify what is currently feasible and what may feasible in the near term.

EPRI Perspective
This report is unique in that it presents a vendor-neutral summary of current and emerging visualization techniques that, nevertheless, identifies the currently available tools that utilize those techniques. This approach will help power system personnel understand which techniques might address their needs and how they can implement those techniques in their control room.

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Abstract
Identify the weak sub-system and the requirement of reactive power reserves
The objective of this research project is to investigate and develop a methodology for identifying areas in power systems that are prone to voltage instability under particular operating conditions and contingencies. These areas, which are prone to instability due to their lack of reactive power reserves, are referred to as voltage control areas (VCAs). Once VCAs are identified, methods of determining their adequate reactive power reserve requirements to ensure secure system operation under all conditions are needed.

Platform Requirements
Windows™ XP

Newer Version of
1019370 - VCA Offline – BETA

Application, Value and Use

- Automatically identify weak sub-system
- Evaluate the performance of various power system designs or configurations with regards to susceptibility to voltage instability
- Assist in maximizing the efficient use of assets by determining the minimum amount and optimal location of required reactive reserves
Abstract
Voltage stability is an important concern in planning and operating electric power systems with increased power flow. System operators and planners have relied on computer simulation programs to study the voltage stability problem, as well as to monitor and control system voltage stability conditions. The simulation approach faces the challenges of modeling the dynamic characteristics of generators and loads precisely and, therefore, is not able to calculate voltage stability margin accurately in some circumstances. Having recognized the limitations of such voltage stability assessment (VSA) programs, EPRI developed the Measurement-based Voltage Stability Monitoring approach, which calculates voltage stability margins in real time using only measurement data at the boundary substations of a load center. This approach does not require modeling transmission system components and does not rely on the energy management system (EMS) state estimator; it can therefore avoid the potential problems of the online simulation-based VSA approach.

Besides describing the Measurement-based Voltage Stability Monitoring approach, this report documents the results of a validation study that used the Western Region of the Entergy system as a test case.

Objective
System operators currently rely on computer simulation programs to study voltage stability problems. However, the simulation-based voltage stability assessment approach has inherent limitations. The objective of this research is to use measurement-data at substation level to calculate voltage stability margins in real-time and send the margin information to the control center for operators to monitor and control system-wide voltage stability.

Approach
The Measurement-based Voltage Stability Monitoring and Control for Load Centers approach includes the following steps:
- Obtaining synchronized voltage and current measurements at all boundary buses of a load center
- Determining a fictitious boundary bus representing all boundary buses and calculating the equivalent voltage phasor, real power, and reactive power at this bus
- Estimating the external system’s Thevenin equivalent parameters
- Calculating power transfer limits at the interface of the load center using the Thevenin equivalent
- Calculating the voltage stability margin in terms of real power and reactive power

Results
The report introduces the background and the driver of this research and then thoroughly documents the detailed methodology of the innovative Measurement-based Voltage Stability Monitoring method. The developed method has been validated using the Western Region of the Entergy system as the test case. The validation study results show that the method has promise for enhancing the voltage security of transmission systems.

Application, Value and Use
The Measurement-based Voltage Stability Monitoring and Control for Load Centers method calculates the voltage stability of a load center in real-time. System operators can use the calculated voltage stability margin information to monitor system-wide voltage stability conditions. The calculated voltage stability margin can also be used as the control signal to trigger automatic control actions in order to prevent fast voltage collapse.

EPRI Perspective
As the interconnected transmission system is being operated closer to its limits, new risks emerge to a power system network due to voltage collapse. Utilities, transmission owners, and independent system operators (ISOs) or regional transmission organizations (RTOs) will be able to use this innovative method to monitor system voltage stability conditions and improve operator’s situational awareness in order to better detect voltage instability scenarios and eliminate unnecessary load shedding.

EPRI would like to work with the industry pioneers to demonstrate the Measurement-based Voltage Stability Monitoring and Control method.

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Abstract

Power system restoration is well recognized as one of the most important tasks for grid operations. Following a major power outage, operators in the control center work with the field crews to re-establish generation and transmission systems and then to pick up load and restore service. It is reported that the impact of a blackout increases with the duration of its restoration. Blackout events and aging transmission infrastructures in North America require that greater attention be paid to research and development in power system restoration and its associated decision support tools.

Objective

System reliability depends heavily on the efficiency of system restoration. Unfortunately, few decision support tools are available to system operators and restoration planners today. Restoration plans are developed off-line and then used as guidelines for dispatchers in an on-line environment. Operators need to adapt to the actual outage scenario and available resources and be able to develop a strategy based on their experience. EPRI has been working on developing a decision support tool for evaluating system restoration strategies. This tool will help establish specific restoration plans according to system conditions.

Approach

In this project, the project team studied current industry practices in power system restoration and then developed the computational concepts and tools necessary for evaluating system restoration strategies. Finally, the team performed simulations on different test systems to demonstrate the performance of the developed tool and compare different restoration strategies.

Results

The project team proposed and implemented a new concept, Generic Restoration Milestones (GRMs), along with a comprehensive methodology for power system restoration based on GRMs. The team developed a number of computational algorithms to implement GRMs. Those algorithms compose a decision support tool for evaluating system restoration strategies. The team demonstrated the proposed methodology and algorithms on three test systems with different characteristics.

Application, Value and Use

The decision support tool prototyped by this project can be used to evaluate different restoration strategy options. A specific restoration strategy can be established by a sequence of GRMs based on restoration guidelines and system conditions. Different GRM sequences lead to different strategy options. This tool helps evaluate different restoration strategy options to determine an effective strategy without violating security constraints. The report proposes a series of computer algorithms to implement GRMs. Some practical constraints are incorporated in these algorithms, which system planners can use to evaluate the existing restoration plan and develop alternative plans.

EPRI Perspective

It is important to develop a decision support tool to assist system planners in system restoration planning and, ultimately, assist system operators in an online restoration environment. This project demonstrates the capability and great potential of the prototyped decision support tool for evaluating system restoration strategies. Based on this tool, online decision support software tools could be developed for system operators to save system restoration time and improve transmission system reliability. This tool can also be integrated with Operator Training Simulators (OTS) to help participants in system restoration training gain knowledge and experience in safe and effective power system restoration procedures. It is believed that the proposed methodology represents a major step toward modernization of power system restoration, which is mainly manual at present.
Abstract
Controlled system separation is considered the final line of defense to save a power transmission system against a catastrophic blackout under severe disturbances—for example, cascading failures. In a controlled manner, the system is separated into sustainable electrical islands, which can be resynchronized later to restore the system. This technical report gives an overview of controlled system separation and then proposes a practical controlled system separation scheme utilizing phasor measurement units (PMUs).

Objective
For a particular power system, the development of a controlled separation scheme is a complicated planning problem. Existing policies and nontechnical concerns also play important roles in designing the scheme. The three key problems of where, when, and how to separate need to be prioritized and interpreted according to system characteristics. This multiyear project aims at:

• Increasing members’ knowledge about mitigation of cascading failures to prevent blackouts
• Introducing potential technologies and suggesting feasible R&D directions in controlled system separation
• Documenting industry practices and R&D needs related to system separation
• Performing research and development in practical separation schemes and implementation frameworks

Approach
Based on in-depth analysis of technical issues relevant to controlled system separation, the EPRI project team conducted a wide review of state-of-the-art technologies and industry practices. Then, research was conducted to develop a practical controlled system separation scheme. A number of innovative techniques were proposed as well, to perform specific tasks of the scheme. The scheme was then examined on a test power system through the use of simulation studies.

Results
The report first introduces the concept of controlled system separation, discusses its importance in mitigating cascading failures to prevent a blackout, and summarizes related technical issues, methodologies, industry practices, and R&D needs. Then, a controlled system separation scheme is proposed to adaptively form optimized islands with the aid of real-time PMU measurements.

The scheme suggests a practical implementation framework for controlled system separation, comprising three stages: Offline Analysis, Online Monitoring, and Real-Time Control. Under that framework, the decision-making process of controlled system separation can focus on solving three key problems:

• Where to separate
• When to separate
• How to separate

The problems can further be strategically decoupled into different time frames. Such a time-staged strategy effectively simplifies the problems and helps efficiently organize computational resources to enable on-line implementation of the proposed scheme. The scheme leverages existing and newly proposed techniques. The techniques adopted in its different stages can also benefit power system engineers in power system analysis, operations, and planning.

Application, Value and Use
This report provides members with an overview of controlled system separation, and also proposes a new controlled system separation scheme as a basis for members to develop separation schemes meeting their specific requirements.

EPRI Perspective
A major RD&D goal in transmission system protection is to avoid cascading failures by using improved special protection schemes. Existing separation schemes that fix separation points at predetermined locations can be replaced by a more “intelligent” separation scheme in which separation points are adaptively optimized according to actual system conditions. PMU-based wide area measurement systems (WAMs), now in development, can gather and process the information needed for controlled system separation. EPRI plans to develop a PMU-based separation scheme that integrates appropriate and practical technologies to address key separation problems.
Abstract
This report is a technical update of recent results of EPRI base funded research work related to on-line model validation and derivation for power plants, conducted under Program 40.001 Load and Generator Modeling. The work is follow-on work from the EPRI R&D program that was published earlier this year in the report Automated Model Validation for Power Plants Using On-line Disturbance Monitoring, EPRI report 1016000 (2009).

Objective
Historically, it is well understood that the turbine-governor portion of the power plant model is perhaps the most simplistic. This study was conducted to see if some simple modifications to the turbine-governor model for large steam-turbine governors could help to improve the ability to simulate the response of coordinate boiler-turbine units to system disturbances. The project also looked at some other issues such as model validation using recorded responses to unbalanced faults.

Approach
The approach taken was to investigate the potential for fitting boiler-turbine models for large steam-turbine generator response to system disturbances in the MATLAB® environment, using the algorithms developed in the EPRI PPPD tool—see Power Plant Parameter Derivation (PPPD) Software User's Manual: Version 2.0, EPRI report 1017803 (2009).

Results
The technical update outlines the latest lessons learned from the on-line disturbance based model validation technique developed by EPRI.

Application, Value and Use
This report updates work on model validation using data captured by event recorders, such as digital fault recorders (DFRs), in the power plant during systemwide disturbances. These data are used to validate and fine-tune the power plant model. The benefits are that there is no need to schedule time for testing the unit, the unit need not be maneuvered or taken off-line, and there is no additional risk of damage to the unit. Another key benefit is that the unit's response to actual events is seen. However, for this process to work, good baseline data on the applicable models for the power plant are required, hence the need for some form of staged testing or model validation upon plant commissioning.

EPRI Perspective
EPRI's involvement in synchronous machine parameter testing goes back to the 1980s and 90s with the advent of stand still frequency response-based parameter estimation techniques and the PIDAS project. This report is part of an ongoing effort by EPRI to investigate not only state of the art in power plant model parameter derivation, but also to keep such efforts focused on meeting the needs of the industry as dictated by reliability standards while at the same time keeping the approach to such work as simple, practical, and effective as possible.
Abstract
The tool allows the user to find optimum values of parameters for two load model structures developed as part of the load modeling project using system disturbance data.

Description
It is important to represent the dynamic behavior of system load for system planning studies and analysis. Developing load models is a challenging task due to the varying nature of loads and uncertainty in the load information. The Load Model Data Processing and Parameter Derivation (LMDPPD) Version 2.1 software tool is a simulation program that can be used for parameter estimation of the 1-machine and 2-machine load model structures developed as part of EPRI’s load modeling efforts over the past several years. These two load models represent the aggregate response of the loads connected to the system under consideration. This software provides a tool for estimating the load model parameters using system disturbance data. This tool can estimate parameters and load composition for the following two load model structures:

- 1-machine structure comprising of a static load model and an induction motor model to represent static and dynamic load characteristics respectively in the captured response
- 2-machine structure comprising of a static load model and two induction motor models to represent dynamic loads in the captured response. The two induction motors allow representing large motors (for example fan motors, 3-phase industrial motors etc.) and small motors (e.g. residential air conditioners) separately.

Platform Requirements
Windows XP Professional Version 2002 (Service Pack 3)

Newer Version of
1017802 - Load Model Data Processing and Parameter Derivation (LMDPPD) Version 2.0

Application, Value and Use
- Readily estimates the load model parameters and significantly reduces trial and error
- Input data for the software can be collected using commercially available data acquisition devices like power quality monitors and DFRs
- The parameters obtained can be readily used in standard load models available in Siemens PTI PSS/E™ and GE PSLF™.
Abstract
The tool allows the user to validate and fit model parameters to standard, dynamic models of synchronous generators, their excitation systems, and turbine-governors, using either measured on-line disturbance data or measured data from staged field testing.

Description
The Power Plant Parameter Derivation (PPPD) software tool is a simulation program that can be used for validation and parameter estimation of models for synchronous generators and their controls. This is a critical task and is currently mandated in the Western Electricity Coordinating Council (WECC) and soon to be mandated across the United States by the North American Electric Reliability Corporation (NERC). Based on WECC and imminent NERC standards, power plant models (for generators, their excitation systems, and turbine-governors) need to be validated periodically. This software tool offers a streamlined method for performing such model validation using one of two sources of data:

1. Data collected and measured from staged (typically, off-line) testing of the unit in the field
2. Digitally recorded ambient data from the unit while on-line, showing its response to naturally occurring system events (such as remote faults, loss of generation elsewhere on the system, and small frequency or voltage dips)

The second method is typically the more effective and simpler way to achieve such model validation and saves significant costs by averting the need for staged field testing for revalidation of existing baseline models. (For training contact: P. Pourbeik; ppourbeik@epri.com; ph: 919 806 8126).

Software Requirements
Microsoft Windows XP Professional Version 2002 (Service Pack 3)

Application Value and Use
- Significantly reduces engineering time needed for model validation
- Exports validated models in easy to use format for planners
- Can be used to validated models from on-line recorded unit response to disturbances (e.g. from DFRs), thus avoiding the need for staged testing.
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**Abstract**

Major blackouts are usually the outcome of uncontrolled cascades of line and generator outages. Analyses of the 2003 Northeast Blackout—and of every major blackout since implementation of the Federal Energy Regulatory Commission (FERC) Open Access Orders 888 and 889 in 1996—have concluded that system operators likely could have mitigated the extent and damage of the blackout. However, such mitigation could occur only if operators had access to real-time software tools that identified the impending crisis and provided the data needed to make timely, informed decisions. System planners and operators clearly need tools to predict, and, if possible, prevent potential cascading outages. This project provides a functional specification for analyzing cascading outages as a part of a reliability assessment. The specification will also serve as the basis for developing and testing new software tools for cascading outages analysis.

**Objective**

The large volume of computations as well as massive amounts of output data produced made cascading outages analysis impractical in the past. Another issue that contributed to the difficulties of performing a comprehensive analysis of cascading outages is the lack of NERC standards that address this issue. Since NERC Standard TPL-001-1 includes assessment of system performance following planning events and extreme events, development of a systematic approach to cascading outages analysis becomes critical to utilities and independent system operators (ISOs). The objective of this project was to develop a specification that would permit power system operators and planners to effectively assess power system performance following cascading outages.

**Approach**

The approach taken in preparing this specification addressed the following issues:

- Providing a comprehensive framework for cascading outages analysis
- Increasing the awareness of power system planning and operations engineers as to current industry practices for performing cascading outages analysis

**Results**

The forthcoming North American Electric Reliability Corporation (NERC) Standard TPL-001-1 includes assessment of system performance following planning events and extreme events. While extreme events are more severe and have a lower probability of occurrence than planning events, one of the major concerns with extreme events is the possibility of cascading outages. The specification described in this report provides a comprehensive approach to the analysis of cascading outages from both steady-state and transient perspectives. It incorporates requirements for performing the analysis in planning, operations, and real-time environments and includes requirements for the type of output that should be produced as a result of the analysis.

**Application, Value and Use**

The present functional specification offers a scope of work as well as input/output requirements for performing a comprehensive, systematic assessment of cascading outages. It also provides for determining optimal remedial actions to ensure reliable operation of the transmission system if a cascading outage takes place.

**EPRI Perspective**

As the interconnected transmission system is being operated closer to its limits, new risks emerge to a power system network due to cascading outages. Utilities and ISOs have not performed comprehensive analysis of cascading outages in the past. In fact, only a limited number of contingencies are usually tested for their vulnerability to cascading events in the planning environment. Such analysis has also not been performed in operations and real-time environments. Recent EPRI-sponsored research and extensive industry efforts encourage the inclusion of cascading outages analysis in the planning, operations, and real-time environments of utilities and ISOs.
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**Abstract**

Developments in the electric power industry have accentuated the need to resolve problems caused by certain limitations inherent to ac transmission, including inadvertent (parallel and loop) flows, stability and voltage constraints limiting total transfer capability (TTC), the propagation of disturbances capable of producing system separations and cascading outages, limited power densities on rights-of-way, and difficulties in achieving coordinated transmission planning. Segmenting a grid by breaking it into sectors that are interconnected only through high-voltage dc (HVDC) ties and are operated asynchronously from each other provides a new approach to resolving these problems. This report is a technical assessment of the reliability benefit of segmenting a portion of the Eastern Interconnection (EI). The assessment investigates segmentation by inserting back-to-back (BTB) voltage sourced converters in the ac ties between several candidate sectors. It concludes that segmentation has the potential to prevent cascading blackouts and to substantially increase TTC between the sectors.

**Objective**

The dilemma facing segmentation is the combination of high costs and high benefits. The objective of this report is to demonstrate a method for quantifying these costs and benefits. Through a stylized example on the EI, the goal is to show that the high benefits of avoiding cascading outages and increasing TTC have the potential to overcome high installation costs, providing a basis for detailed studies of actual projects.

**Approach**

The study region includes five distinct sectors: New York, the New England states, the Canadian Province of Ontario, and the northern parts of the Midwest Independent System Operator (MISO) and Pennsylvania-New Jersey-Maryland Interconnection (PJM). The study used estimates of historic and potential tie capabilities extracted from system models provided by MISO, as well as regional stability and thermal transfer limits known to the authors and available from various area and regional studies. The study documents a proxy valuation approach for deriving costs of ac tie capability increases. Projections of new ac line costs for various projects of comparable voltage level formed the proxy. The best-known estimations in the literature provided the basis for determining the value of mitigating cascading blackouts with BTB converters installed in the ac ties. The combination of reduction in BTB converter costs due to the value of improved reliability was then compared with the cost of comparable ac tie capability increases.

**Results**

Conversion of ac ties to dc in order to segment a portion of the EI could be cost effective. The cost of installing and operating HVDC ties could be offset by the benefits, which include vastly reducing the likelihood of large-scale regional blackouts such as the 2003 Northeast Blackout along with substantial increases in inter-sector TTC. This report addresses the following key topics:

- Segmentation boundary selection and operational considerations
- Selection of segmentation boundaries
- Cost of basic segmentation
- Potential total transfer capability gains
- Additional TTC from segmentation
- HVDC alternatives to segmentation
- Assessing the value of TTC gains
- Reliability benefit of segmentation
- Comparison of basic segmentation costs and benefits

**Application, Value and Use**

This report provides important insight into the potential costs and benefits of segmenting large ac interconnections. Grid planners and managers will be better positioned to consider segmentation as an important technology for increasing the value and capability of their transmission assets without the need for new rights-of-way.

**EPRI Perspective**

This report describes a preliminary method for partially assessing the cost effectiveness of segmentation, providing a platform for more aggressive and detailed investigations of segmentation opportunities. Additionally, the dissemination of information about the intricacies of segmentation allows electric utility planners to consider this option and encourages new creative analysis.
Abstract
EPRI is sponsoring development of a first edition of the EPRI Power Electronics-Based Transmission Controllers Reference Book. This report is the most recent draft of a chapter for the “Gold Book,” an authoritative guide for utilities and others who install and maintain power electronics equipment to increase power transfer capability.

Newer Version of
1013993 - Power Electronics-Based Transmission Controllers Reference Book, ("The Gold Book")

Background
The reference book will provide a broad overview on power electronics-based controllers—with information on historical perspectives, basic design considerations, factory testing, site installations, commissioning, operating performance, operation and maintenance, and future trends. The book will assist users in planning, developing, installing, and using this technology to enhance the controllability and increase the power transfer capability of transmission systems.

Objective
To assist utilities in planning, developing, installing, and using power electronics-based controllers

Approach
Work on the new reference book began in 2005 and will continue through 2010. This 2009 report incorporates work completed through December 2009 and is intended to provide the preliminary foundation and guidance for further development of the reference book.
Two new chapters were added in 2009:
Chapter 5: Grid Shunt Reactive Power Compensation
Chapter 14: Impact of Flexible AC Transmission System Devices on Power System Protection

Results
The draft reference book now includes ten completed draft chapters—over 600 pages of text—and 6 detailed chapter outlines. Together, these chapter drafts and outlines establish the basic organization and structure of the reference book. Project advisors and contributing authors will find this material useful in planning and developing additional content.
Each chapter is intended to be largely self-sufficient, containing all the necessary information needed for understanding the subject matter. The information will be tailored to enable potential users to understand the essential principles and issues involved, with credible comparisons, sufficient practical data, and accumulated installation experience to help them in the evaluation, potential acquisition, and use of the right transmission controller for their specific applications.

EPRI Perspective
The new EPRI Power Electronics-Based Transmission Controllers Reference Book is being developed in the tradition of the landmark series of EPRI power delivery reference books. Most notable of these volumes was the EPRI Transmission Line Reference Book: 345 kV and Above. First published in 1975 with a red cover, the book became commonly known in the industry as the "EPRI Red Book." To continue this tradition, the new reference on power electronics-based controllers will be printed with a gold cover and be referred to as the "Gold Book."
Abstract
This report addresses the communications and computing foundations necessary to achieve the smart transmission grid: one capable of anticipating problems and automatically reconfiguring itself after an event. Wide-Area Measurement System (WAMS) is a new technology that enables major advances in power system operation, protection, and maintenance. Key building blocks of WAMS are synchronized phasor measurement units (PMUs), or synchrophasors. When linked together, they can provide a precise and comprehensive view of the state of the grid. But current PMUs lack the necessary security, remote configuration, and other features capable of providing the requisite broad dissemination of data. This report surveys and documents the advanced features essential to the next-generation PMU, which will allow utilities to improve power system reliability, optimize asset utilization, and realize cost-savings.

Objective
The North American Synchro-Phasor Initiative (NASPI) is a recent major effort by the U.S. electric power industry to improve power system reliability through wide-area measurement, monitoring, and control. NASPI is working to advance the deployment and use of networked phasor measurement devices and phasor data-sharing. Important benefits of phasor technology include integration of renewable and intermittent resources, automated transmission and demand-response controls, forensic analysis of grid disturbances, and increased transmission throughput. NASPI-created measurement systems meet two important requirements: they are time-synchronized to support wide-area visibility, and they provide high-speed data that enables quick response to changing conditions. PMUs meet these criteria. EPRI’s next-generation PMU project will provide improved data management, enhanced security, and more cost-effective maintenance of this technology.

Approach
The objective of the PMU research project is to gather industry input and develop the functional requirements for the next generation of this technology. In order to effectively identify the features of the next-generation PMU, it is necessary to understand the shortcomings of the existing devices. In March 2009, the project team developed a survey and sent it to all participating member utilities to gather their insights on the units installed at their plants. The survey requested that participants provide input on the following issues: remote control function, communication protocol, data management, and security. Respondents were also encouraged to identify any other pressing issues regarding existing PMUs. Three companies provided responses to the survey. Project advisors used the compiled results as a basis for detailed discussions, which were facilitated through a series of web-casts held every three weeks over a period of five months. The project team will use these survey responses and discussions to develop the functional specifications for the next-generation PMU.

Results
Responses to EPRI's PMU survey included the following topic areas: data management, security, maintenance, visualization, design, asset management, remote control function, communication protocol, and "other." The project team used these responses to identify and categorize critical features for next-generation PMUs. Key examples: Design new PMUs with programmable triggers to mark data sets, thus making them more easy to identify and retrieve. Increase data storage capability. Enhance device-level security. Develop stand-alone PMUs with built-in phasor gateway features. Improve calibration and device diagnostics. Design plug-in cards to allow easy field upgrades of older units. Develop visualization tools to analyze the system and assist operator troubleshooting. Provide remote control of PMUs in compliance with cyber-security requirements. Address data-quality issues involving time stamps, measurement values, and transformer phase errors. Develop time-synchronized topology information to help operators determine causes of outages in time to prevent more serious conditions.

Application, Value and Use
NASPI's ultimate objective is to decentralize, expand, and standardize the current North American synchrophasor infrastructure through creation of a data-communications network called NASPInet. NASPInet will be composed of phasor gateways that will link PMUs to the network and a data bus that will carry data between the gateways. NASPI also promotes the creation of new monitoring and analysis tools to help operators manage transmission system stresses. Next-generation PMUs may be able to collect precursor signals of an impending cascading outage and gather data to improve resynchronization during power system restoration.

EPRI Perspective
Although the current generation of PMUs function quite well, enhancing power system reliability will require continuous improvements in the features of this technology—particularly in the areas of communications protocol, data management, and security. This report, which is based on the input of a relatively limited set of users, is just one step in that ongoing process. The federal stimulus program will result in the installation of more PMUs, generating additional ideas for innovative features and uses. Through NASPInet, NASPI will define the phasor gateways and data bus that will carry data between the gateways. NASPI also promotes the creation of new monitoring and analysis tools to help operators manage transmission system stresses. Next-generation PMUs may be able to collect precursor signals of an impending cascading outage and gather data to improve resynchronization during power system restoration. Finally, enhancing PMU security features will be a continuously evolving requirement. In this ongoing research effort, EPRI will play a crucial role between the vendors who provide the hardware and software products and the utility consumers of PMU technology.
Abstract
The Engineering Study Toolbox (EST) Version 1.0 is a toolbox that automates PSS/E execution using Python script.

Description
EST 1.0 is a toolbox that automates PSS/E execution using Python script. It facilities the analysis of various system conditions, contingencies and power interfaces. It also provides voltage stability analysis that can automatically produce PV curves for different network configurations.

Platform Requirements
Windows™ 2000, XP and Vista

Application, Value and Use
- Can set up and analyze a large number of scenarios efficiently and quickly.
- Can provide detailed information regarding critical contingencies, voltage security violations, and locations.
- Can reinforce the performance and expand applications of conventional PSS/E tool in a deregulated environment.
**Abstract**

As the penetration and size of renewable generation resources increase, the industry must expand transmission infrastructure to accommodate increasing renewable resource output. Conventional transmission expansion planning requires sufficient transmission capacities to transfer the full name plate capacity of all power plants to load centers at the same time. However, renewable resources, such as wind and solar, have highly variable output and are spatially diversified. Thus, transmission expansion planning with variable resources should evaluate the resources’ spatial diversity and the statistical expectation of their simultaneous maximum output levels. This technical update introduces a Monte Carlo simulation-based probabilistic approach to investigate the utility-scale renewable generation integration problem at the planning stage.

**Objective**

The deterministic approach cannot capture the full spectrum of the renewable generation variability and uncertainties, which likely cause more server overloading and congestion problems. Probabilistic approach-based studies give system planning engineers a better feel for future system conditions and will provide more confidence in making judgments concerning investment. Planning engineers at transmission companies, ISO, RTO, regional planning entities, regulatory bodies, and independent investors of merchant transmission projects should be interested in this technical update.

**Approach**

The project team reviewed the presented approaches and discussed their advantages and drawbacks to help identify existing or potential new approaches and criteria for probabilistic or risk-based approach applications. This technical update introduces a Monte Carlo simulation-based probability approach to investigate the utility-scale renewable generation integration problem at the planning stage. The technical update also addresses the issue of performing statistical analysis for renewable generation.

**Results**

This technical update introduces the Monte Carlo simulation-based probability approach to investigate the relationship between transmission flow and the variability and uncertainties of renewable generation, with the considerations of probability distributions of wind and solar generations as well as the correlations among all uncertain variables.

**Application, Value and Use**

This technical update may also serve as the basis for developing new software tools for applying probabilistic approaches to address wind integration issues in transmission planning. Ultimately, it will help:

- Enable greater utilization of current renewable resources and increase potential for greater efficiencies;
- Optimize the use of existing transmission infrastructure, minimizing congestion
- Help members meet RPS goal with better future renewable resources siting and optimal transmission infrastructure changes

**EPRI Perspective**

Probabilistic or risk-based approaches are becoming more popular worldwide for system planning. The industry has developed some probabilistic planning criteria, tools and techniques over the past several decades. However, they will require critical review for completeness and applicability before they can become an industry-accepted approach to consistently measure bulk power system reliability. Past EPRI-sponsored research on probabilistic load flow and risk-based reliability assessment and recent extensive industry efforts on integration of renewable generation facilitate probability application in transmission planning for integrating utility-scale renewable generation.
Abstract
The main industry issue addressed in this report is the increasing penetration of intermittent generation. The system adaptation for forecasting errors associated with these types of generation is to increase reserve requirements, and the adaptation for their ramping characteristics is to diversify the portfolio of complementary dispatch resources. For small quantities of intermittent generation, there is no noticeable system impact—but at some point their forecasting errors and ramping begin to affect operations and operational planning

Objective
Computational efficiency is the biggest challenge for implementing the stochastic models that properly handle the uncertainties in forecasts of output from many intermittent resources. The main research question now is whether there are scalable methods that efficiently handle the expanded problem size. Realistic systems have tens of thousands of busses and uncountable numbers of scenarios representing the full uncertainties of system outages, intermittent generation, demand response, and the forecasting errors for intermittent generation and demand. This stage of the research focuses on increasing the size and complexity of the stochastic dispatch model to realistic proportions, creating a platform for experimentation and analysis. The long-term goal of this research is to characterize this effect, which likely depends on system characteristics such as the geographical concentration of the intermittent generation, the diversity of complementary resources, and the design and strength of the transmission system. Short-term goals are to improve both the realism of the model representation and the computational efficiency of the optimization and to test scalable techniques.

Approach
The first step was to move to commercial software systems commonly used for actual operations of power systems. Our modeling system of choice is a combination of the General Algebraic Modeling System (GAMS) coupled with the CPLEX, MINOS, and DECIS solution software packages. These are expected to provide more robust, efficient, and scalable computations. Next, the new stochastic dispatch model was calibrated with the prior prototype version, which showed an improvement in development times and solution times relative to the tools used in the prior studies. The third step was to assemble a new realistic model for a large system. These data came in the form of a power flow model of the PJM interconnection and the fabrication of additional parameters needed to fully represent a stochastic optimal power flow problem. The fourth step was to formulate and solve the stochastic dispatch models with a variety of formulations and techniques for comparison purposes. Finally, the software tools were analyzed for robustness, efficiency, and scalability.

Results
Although the use of commercial software and recently developed advanced modeling and algorithmic techniques has improved computational efficiency, robustness of development and execution processes, and scalability, this project is at an interim stage of development. The interim goal has been achieved: to lay the foundation for experimentation and case studies of complete, realistic power systems and for further technical development of use to the industry.

Application, Value and Use
Experiments are planned to further test scalability. The experiment documented here used a common probability distribution with ever-increasing numbers of events to increase the problem size. Although this allowed for a simple expository test, the next set of experiments will represent many sources of random events, where the cross product results in literally astronomical combinations of events. This will be a true test of sampling techniques. Case studies with full realism will stress test the advanced technologies and potentially reveal their existing weaknesses, which will need reinforcement. The case studies will also determine the credible applications for using these techniques. Some regions now use simple solutions, which also have their weaknesses. A key question—how important these weaknesses are—can be answered by benchmarking against the use of stochastic optimization results. Technical development is expected to enhance the scalability of the computation and modeling. Here, two areas are important: the computational efficiency and speed. Parallel computing, which is now a routine feature of even portable laptop computers, provides a route for speeding the computation. The sampling used in the large-scale system experiment can be improved.

EPRI Perspective
Since 2007, the Electric Power Research Institute (EPRI) has conducted research on reserve determination using stochastic optimal power flow methods. These studies demonstrated the successful application of this technology to small- and medium-size cases. In one study of a stylized 179-bus model of the Western Interconnection and large quantities of wind generation forecast error in California, the observation was that reserves as well as traditional contingency requirements were needed to hedge the forecasting error. In addition, the revised dispatch was more diversified, allowing for increased ramping and diversity in response to forecasting errors. Real systems are likely to seek different solutions for hedging the forecasting risk because they differ in their complement of resources, the configuration and strengths of their transmission systems, and the concentration and position of their intermittent resources. This scalable platform can be used to support the electric power industry for real and specific analysis to provide reserve in the face of increasing penetration of intermittent resources.
Abstract
This Technical Update provides an assessment of the present state of the art tools for allowing operators to reliably integrate variable generation. First, a summary of operating challenges presented by variable generation is provided. This summary is reinforced with actual case studies of actual operating experiences from numerous systems in which variable generation created abnormal operating conditions that had to be managed by the system operators. These experiences are then utilized to summarize operator needs for reliably operating the system in the future with high levels of variable generation. The report also provides a description of prototype operator tools that are under development by several utilities/ISOs to address the variable integration challenges. Finally, these existing prototypes are used as the basis for defining the functional requirements for a comprehensive operator decision-making tool for managing variable generation.

Objective
System operators must maintain reliability in the most economically efficient way possible. Variable generation presents challenges to this objective in that operators will face unfamiliar scenarios in which the system is required to be much more flexible than before. Without tools to make more efficient decisions, operators will tend to over-commit resources to ensure the system flexibility required exists in real-time operations. Development of a tool with the capabilities described in this report will provide operators with the situational awareness and time to identify the most efficient resources to be implemented to maintain reliability.

Approach
EPRI leveraged the experiences of utilities and ISOs that are on the leading edge of variable generation issues due to the already increasing levels of wind generation within their balancing authority areas. EPRI engaged numerous system operators through a survey instrument that was developed as part of the project and through detailed interviews that were conducted on site and through numerous teleconferences. The shared experiences were then merged and further developed based on EPRI staff's experience and expertise with wind integration.

Results
Several utilities and ISOs that are already integrating significant levels of wind generation have begun development of tools for aiding operators in making decisions to mitigate the new levels of uncertainty and variability experienced on their systems. This report provides a detailed summary of the capabilities of these tools and the generic requirements of such a tool for use in any power system.

Application, Value and Use
The functional requirements identified in this report provide the foundation for a collaborative effort to develop a prototype tool to be tested in operator control rooms. EPRI will engage various stakeholders including system operators and EMS vendors in early 2010 to determine the most desirable form of such a collaborative.

EPRI Perspective
EPRI is uniquely positioned to lead a collaborative effort to develop an operator decision-making tool for integration of variable generation. EPRI is highly engaged in numerous industry activities to identify the needs for system operators and planners for integrating variable generation, and as such, is keenly aware of not only the needs but also the ongoing efforts that can be leveraged. Further, EPRI's collaborative R&D business model for the electric power industry provides the needed mechanism for individual utilities and ISOs to leverage a broader set of resources from across the industry.