U.S. Department of Energy

Electricity Transmission System Workshop

Discussion Summary

November 1-2, 2012

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INTRODUCTION

This report summarizes the inputs provided by external stakeholders and the associated discussions during the Electricity Transmission System Workshop, held in Arlington, Virginia, on November 1-2, 2012.[1] Participants prepared for the workshop by reviewing the U.S. Department of Energy's *Action Plan Addressing the Electricity Transmission System* (Appendix C). The Action Plan provides a context for on-going research and development activities related to transmission. It also describes current efforts to frame the challenges facing the electric grid using a holistic systems perspective. The Action Plan raised issues and proposed questions that served as a departure point for discussions at the workshop.

This Discussion Summary is an important part of the process of developing a comprehensive research roadmap for grid modernization at the transmission level. This process involves engaging key stakeholders to identify opportunities and challenges, research and development (R&D) needs, and priorities for action. Participants in the workshop helped target specific issues associated with grid visibility, understanding and flexibility. This material, along with the Action Plan and other inputs, will help guide DOE decisions on research and development investments over the next five years.

Participants from this workshop, other stakeholders, and the public at large are encouraged to provide additional input to this ongoing process. This document will be released in draft form with a formal request for information.

[1] This report summarizes inputs and discussions at a workshop sponsored by the United States Department of Energy. While this report is believed to be an accurate summary, neither the United States Government nor the Department of Energy, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information provided in this report.

EXECUTIVE SUMMARY

Process

The Transmission Workshop involved a diverse group of electricity-sector experts with interest in a modernized electricity transmission system. The workshop included two breakout sessions, whereby four smaller groups (of approximately 25 people) brainstormed to identify and prioritize challenges facing the industry and stakeholders in the areas of grid visibility (the ability to "see" an event or condition), grid understanding (the ability to "know" what is happening or about to happen), and grid flexibility (the ability to "do" something appropriate in response). Each group addressed the questions proposed in the DOE Action Plan, discussed assumptions, and offered perspectives on both the challenges and opportunities associated with transitioning to an advanced electricity transmission system.

> **Vision**
>
> ***A seamless, cost-effective electricity system, from generation to end-use, capable of meeting all clean energy demands and capacity requirements, while allowing consumer participation and electricity use as desired.***

The first breakout session was organized to discuss the proposed vision of the future grid and identify specific challenges on the transmission system to achieving that vision. Each group worked to pinpoint 6-to-8 challenges facing the grid as it integrates all the various technologies being (or that will be) deployed while ensuring a safe, reliable, and cost-effective transmission system. The breakout groups used the DOE Grid Tech Team's (GTT) framework (Appendix D) to structure their discussions. The challenges were organized around three critical aspects of the grid: visibility, understanding, and flexibility. The results from all four breakout groups were subsequently consolidated and synthesized by the GTT into a single list of key challenges facing the transmission system.

The second breakout session used the aforementioned list of synthesized results as a starting point for discussion. The groups refined the list and identified 3-5 top challenges. The groups then brainstormed potential activities and initiatives that DOE could pursue to address the key challenges. The resulting activities represent opportunities that could have the greatest impact on modernizing the electricity transmission system. It is important to note that these breakout sessions were not in any way trying to build agreement or consensus around any particular ideas or proposals.

The summarized discussions from both breakout sessions were assembled and presented internally to all the attendees. In the days following the workshop, the moderators and note-takers from each group drafted summary reports and submitted them to the GTT for review. The GTT used those reports to consolidate the workshop's findings into this document. The findings and results from both sessions of the workshop are important to the GTT and to the DOE's goal of developing an R&D roadmap for grid modernization.

Synthesized Challenges

At the conclusion of the first breakout session, the GTT synthesized the full list of challenges reported back from the separate groups into a single list of nine key challenges facing a modernized transmission system. These synthesized challenges were used to catalyze discussions in the second series of breakout sessions focused on opportunities and solutions for overcoming the challenges. These include the need for:

- Improved understanding of the availability, utility, maintenance, exchange, and security of data and associated requirements.
- Methods to synthesize, process, integrate, visualize, and validate data for actionable intelligence.
- Information and communication technology (ICT) and sensor systems for the future grid and advanced applications.
- Validated models and simulation algorithms to explore new dynamics, concepts, and technologies.
- Adequate tools for grid operators and planners to perform credible analyses over multiple scales for the future grid.
- Metrics and definitions for grid flexibility.
- Methods to value, evaluate, and control various technologies for flexibility on a level playing field.
- Advanced technologies for grid flexibility and mechanisms to extract flexibility from existing assets.
- New grid architectures including information, control, communication, and physical systems.

Common Themes

The findings in this document consist of the common themes that were presented by groups in both the first and second breakout sessions of the workshop. These themes represent the most critical challenges and opportunities associated with modernizing the electricity transmission system. The detailed results were compiled and compressed into the following sections that can help inform the DOE's development of a targeted R&D roadmap.

The themes from the breakout sessions were captured in the following four categories:

- Information & Communication
- Models, Simulations & Tools
- Metrics, Validation & Valuation
- System Architecture Paradigms

INFORMATION & COMMUNICATION

The information and communication theme focused largely on data acquisition, management, communication, visualization, and usage. Various technologies being deployed make it possible to produce an overabundance of data, but in some cases there may be insufficient understanding of the quality and usability of some of that information. As an illustration of this issue, the potential for using data streams from phasor measurement units (PMUs) currently deployed to provide system awareness and operations has not been fully realized, inhibiting deployment of additional sensors that may be beneficial. Applications for the PMU data are still very basic and the value proposition for additional sensors has not been demonstrated yet. Further efforts are needed to develop methods to identify, filter, extract, and aggregate useful information from the data for specific applications that are sufficiently flexible to meet requirements over multiple temporal and spatial scales.

Another challenge is developing an adequate information-technology (IT) and communications infrastructure to achieve comprehensive system visibility. The current state of this infrastructure is highly inconsistent across utilities and regions. For example, many utilities have inadequate connectivity from control rooms to substations and field assets. This issue is driving a redefinition of the concept of a “Smart Grid” beyond deployment of smart meters to encompass IT systems in general. More specifically, a modernized grid will require cost-effective, reliable and commercially available monitoring hardware that communicates between diverse products and users. These hardware devices must be capable of communicating automated, detailed information to help operators understand the source of a fault or a potential fault, the availability of system flexibility, and other system characteristics.

Interoperability between both new and existing products, equipment, and technologies is a critical requirement to ensure clear and efficient interactions between devices and systems. The lack of standardized communication protocols is another challenge to grid visibility. Equipment vendors often use different data transfer techniques—which are often proprietary—that cannot communicate with other devices and systems without added hardware or software, raising overall costs.

The transmission system currently lacks visibility into the distribution network, especially of deployed distributed resources. As these technologies are added in large quantities to distribution systems, the aggregate effects will impact the transmission system. Integration of these inputs—with data that is validated in real-time—will provide the visibility that transmission operators need to react and respond to critical events with a level of efficiency and accuracy that is unavailable to them now.

Knowledge of what neighboring entities are doing with respect to unit status, grid topology, transactions, control schemes, etc., is needed to facilitate wide-area understanding. Ultimately, issues associated with ownership and governance of data needs to be resolved to effectively coordinate data sharing and utilization. The key issues that need to be addressed include who can see the data, who can use the data, what they can do with it, who will manage it, and who will pay for its management.[2] Furthermore, utilities are obligated to protect data confidentiality and that additional level of complexity must be considered in the design of a modern system. Cyber security is another element that must be incorporated into every facet of information and communication systems for a future grid.

MODELS, SIMULATIONS & TOOLS

In addition to the challenges within information and communication, the electricity grid of the future will rely on models, simulations and tools to help operators and planners manage the system efficiently, effectively, and safely. Once all the relevant information is collected, the ensuing challenge is to process it in a way that facilitates comprehensive understanding of the system. A major concern was the lack of a comprehensive database of the grid system. In a general sense, there's a relatively narrow understanding of the current grid infrastructure and how we are currently using the overall system, and what constitutes normal behavior under steady-state conditions.

Various new technologies and tools are already being used in the field but there is significant room for improvement. The deployment of PMUs, for example, has provided tremendous visibility capabilities, but the applications to interpret the data being generated are still lacking. Generally speaking, operators need tools that will generate actionable intelligence on the current state of the grid, and provide critical state-estimation and predictive information on issues that may pose potential problems. Such models and tools will create an important paradigm shift, giving operators signals to *proactively* avoid problems, instead of receiving signals that something has already gone wrong.

The development of operator tools should allow for large amounts of data to be clearly represented and easily understood. Current tools and models pose a host of challenges that include the following:

- The state of the art in modeling, visualization, planning, and operational tools is not well documented and impedes both adoption and development of new tools.
- Models do not adequately account for the coupling of transmission and distribution as the penetration of distributed generation, demand response, distribution-connected storage, and dynamic loads increases.
- The speed of models is insufficient for look-ahead capabilities (faster-than-real-time simulation of future scenarios).
- There is often little integration of planning and operational tools, both within an organization and across regions.

In order to close these gaps, suggestions were made to develop models, simulations and tools that can:

[2] e.g. collection and storage

- Facilitate rapid understanding and decision-making through incorporating increased data streams and advances in computational power; to move beyond state estimation to "state observation."
- Allow for model interoperability so that models can be run showing power, cyber, and market impacts across different software platforms, as well as across transmission and distribution systems with appropriate levels of granularity.
- Include comprehensive models of the system that encompass electrical and thermal dynamics, fuels transportation, environmental impacts, etc. that could be used to evaluate traditional methods of planning and operation and determine where they cease to be useful.
- Support both planning and operations, enabling more holistic decision-making and better quantification of lifecycle costs, including the correlation between temporal and spatial data.
- Incorporate forecasting and stochastic risk assessments for contingency analyses, tracking system trends, and other applications for utility and/or operator toolsets.
- Replicate what is observed in reality and are validated through testing, computational analysis, and demonstrations.

Another important issue is having better understanding of load composition (e.g., power electronics as a fraction of load), which would improve the accuracy and utility of models. Improved wind and solar forecasting models would also enhance system reliability and facilitate cost-effective integration of these resources at higher penetrations. Models, simulations, and tools that exhibit these characteristics can catalyze improvement of the overall system's flexibility. Ultimately, the grid's flexibility will depend on how well it supports integrated analytics that provide greater understanding of the system and the interdependencies of its various technologies and components. For example, more dynamic and adaptive models that frequently update according to increased sensor data can enable capabilities such as reconfiguration of flexible AC transmission system (FACTS) control parameters to increase overall system flexibility.

METRICS, VALIDATION & VALUATION

A critical requirement for grid modernization is the determination of what exactly should be measured, how it is measured, and what the results mean for stakeholders. The metrics, validation, and valuation theme applies across all aspects of the grid. A key concern was the need for metrics to define visibility objectives as they relate to transmission operating requirements. These metrics would help specify data availability and data requirement needs[3] from the appropriate stakeholders. In the end, the development of such metrics will help ensure that the right information gets to the right stakeholders at the right time and with the right frequency.

[3] e.g., sampling rates

Such metrics will also address data validation, which is another key area of concern. Operators must have strong confidence in the data they are using to inform their decisions. Current strategies are lacking regarding data validation, which could be done by cross-checking with redundant sources or correlated data. Metrics used for reinforcing and demonstrating improved confidence of measurements is essential to fully utilizing new and existing streams of data.

Another key challenge was a fundamental lack of clarity of what "grid flexibility" actually means. At the outset, metrics and performance standards for grid flexibility need to be identified and defined. For example, a quantitative metric such as time dependency may be valuable but there are many time scales to consider, from intra-hour to long range planning horizons (e.g., 20 years). These definitions can help establish baselines for performance and cost-benefit calculations that will enable stakeholders to make better-informed decisions between various assets and components that could provide flexibility. Another consideration is that metrics for flexibility may depend on regional differences.

Valuations have the potential to shape the way stakeholders understand and make decisions about the grid. For example, enormous amounts of time and money have been spent on improvements in grid-related data collection and storage. However, there is not a sufficient understanding of what the best uses are for some or all of that data nor was there proper assessment of the value of the data being collected. The need for valuation can be extended to analysis of the costs and benefits of new and existing equipment and technologies. Such analyses would need to extend beyond simple financial estimates of upgrades and into benefits analyses of reliability and cyber security. There is also a crucial need to know when, during the lifetime of legacy equipment, it is beneficial to replace it and with what new equipment or technology. Such understanding can simplify the decision-making process when assessing the value of transmission assets and upgrades.

Another example is the use of large-scale energy storage for enhancing grid flexibility. Modeling the value proposition of storage must be further developed and the business cases also need to be demonstrated in comprehensive pilot deployments. Though the future of storage may be promising, there are many existing assets that can provide increased flexibility if properly modeled and managed. For example, incorporating forecasting for line capacity, weather conditions, and loads can influence the accuracy of day-ahead markets. This could free-up transmission capacity and system reserves that would enhance flexibility. A fundamental challenge for the industry is to identify the value of various options for flexibility, weigh the options against one another, communicate results to stakeholders, and translate optimal decisions into markets.

SYSTEM ARCHITECTURE PARADIGMS

The theme of system architecture paradigms was broad and encompassing, spanning information architectures, physical architectures, modeling and simulation architectures, control architectures, and associated changes in markets and institutions. A primary concern is the complex interdependencies between these various architectures and how they may change and evolve in a future grid. Naturally, plans for future architectures must be developed along with means of comparison to existing systems and practices. Decisions regarding infrastructure replacement and improvement, information architectures, market structures, and technology development should also be made to accommodate major uncertainties of the future grid. A regret-minimization (as opposed to a risk- or cost-minimization) approach should be taken when considering grid advancements. This will require an in-depth understanding of the current paradigms and proposed modernizations.

With regard to future development of the transmission system, suggestions were made to improve grid flexibility, including control architectures and cyber and physical security. Grid flexibility is challenging to address because of the strongly-coupled dynamic nature of the grid. As it stands today, the transmission system lacks intelligent and adaptive protection systems as well as low-cost control devices that would allow grid operators to respond instantaneously or ahead of oncoming problems. A system with enhanced security and flexibility is one that would include wide-area situational awareness coupled with the capability of low-cost control devices that enable it to respond quickly.

Other aspects that should be considered in maintaining and developing the transmission system with new architecture paradigms are:

- Standardization or a co-simulation architecture that allows various proprietary technologies to be simulated together to facilitate evaluations.
- Understanding the impact of orders-of-magnitude increases in control points on the system, which may include developing a combination of centralized and decentralized controls.
- Smart control systems to allow operators simplified control, including real-time, intelligent software that is able to predict the needs of grid operations.
- Development plans for new technology that can integrate with existing systems without requiring extensive, costly renovations.
- New technologies that improve grid flexibility, such as power flow controls, low-cost low-loss power electronics, and AC-DC hybrid network topologies and devices.
- Warning systems of distributed devices that monitor the grid’s status and respond to prevent or minimize impacts of future blackouts and power disruptions.
- Cyber-security protections at all levels of the system structure, including the identification and detection of attacks and tracking of field assets.
- Methodologies for maximizing the availability of ancillary services, such as market mechanisms and ways to better align compensation and the value of flexibility products.

A key consideration for new system architecture paradigms is how to structure data processing and "roll it up" for higher level functions. For example, certain local applications will require actual specific load data while regional applications may only need net-load data. This type of data-system architecture is important, particularly at the interface of the distribution and transmission networks, where visibility is especially strained. Another aspect is to maintain an appropriate level of transparency down to raw data or intermediate quantities to increase the believability of results and give operators confidence in their understanding. Finally, protocols for transferring the data need to be developed to enable smooth communication between devices, systems, and organizations in a way that reflects cohesive system architectures.

Workshop participants identified a series of challenges and opportunities associated with transitioning to an advanced electricity transmission system. Advances in technology, information, and communication are important drivers for modernization of the transmission system and the broader electricity grid. Increased data streams, and enhanced capabilities in models, simulations and tools will significantly improve the ability of operators and planners to see and understand the grid. Improved situational awareness and more accurate risk assessments will be essential in the planning and operation of a modernized system. Development and application of metrics, validation, and valuation schemes to assess novel technologies and solutions that can improve the visibility, understanding, and flexibility of the grid will enable decision-makers to balance and weigh various paths to modernization. At the core of modernization are new system architecture paradigms that will profoundly affect the informational, knowledge, and physical aspects of the future grid. Targeted R&D opportunities identified for these four themes are summarized in the following tables.

Targeted R&D Opportunities

Information & Communication	
Data Standardization & Interoperability	Develop open, standardized data sets for planning, operations, R&D, and policy analysis
	Encourage use of Common Information Model (CIM) for DOE research to expedite its use throughout industry
	Create test bed grid model (load flow, short circuit, protection, etc.) based on IEC 61970 and IEC 61850
	Use standards to promote information interoperability across system layers
Data Management and Security	Develop advanced data management concepts for quality, duration, validation and delivery
	Develop ways in which to consolidate all of the information from generation, transmission, and distribution into straightforward actionable information
	Develop and demonstrate data fusion capabilities to assimilate data in real-time using existing data streams to realize a high fidelity, holistic view of the system and share real-time information with operators
	Research design and operation of data platform contingencies to enable future operations, control and cyber security of grid
	Facilitate the development of the appropriate data chain of custody and define necessary levels of security for transfer, access, and storage of data
Data Technology and Infrastructure	Develop test bed for advanced data networks for testing and interoperability
	Develop plug and play data acquisition technologies that emphasize resiliency
	Develop next generation information networks for high speed time-synchronous data to real-time operations, planning, and control
	Research data structures and the mechanisms that are needed for all the temporal and spatial requirements to virtualize full grid simulation including power, markets, weather, and extreme events
	Develop cost-effective two-way communication techniques and technologies
Data Sharing	Define data applications, categories, sources and destinations, and identify barriers that need to be removed to allow for seamless data exchange.
	Develop data and information sharing standards, protocols, and mechanisms for data that covers a large cross-section of the electric industry
	Develop methodologies that allow data dissemination and control to be consistent when data is transferred to partners
Knowledge Transfer	Conduct educational activities regarding the capabilities and limitations of existing technologies

Models, Simulations & Tools	
Next Generation Tools	Develop high performance computational methods for large, high resolution models of grid with near real-time operation
	Develop next generation EMS with stochastic optimization tools and contingency analysis tools that incorporate VG, DG, DR, weather, new loads, and distribution level behavior
	Develop advanced methods and metrics for tools that forecast weather, load, generation, and transmission
	Develop multi-scale modeling platforms (temporal, spatial, physical), consolidating both planning and operations for transmission and generation
	Develop enhanced impact valuation tools to inform policy, regulatory, planning, and operations
	Develop advanced visualization for real-time tools
	Develop models that can incorporate new technologies as they are developed
	Develop rapid algorithms for system identification and control from grid measurement tools' data streams
	Model aggregate distribution system data in order to increase the visibility and control of distribution operations for transmission operators
Tool Interoperability	Develop integration and interoperability strategies and methods for grid modeling suites
	Create program to transition grid planning and operations tools to parallel computational architectures
	Promote standardized modeling environments and model interfaces
Modeling Cyber Security	Develop national test bed to simulate cyber-physical system of future grid; in coordination with other federal institutions, national labs, and academic resources
Integrating Research Results	Facilitate collaboration between researchers, vendors, and operators to improve implementation

Metrics, Validation & Valuation	
Metrics and Valuation of Grid Architectures	Develop frameworks & metrics to clarify the tradeoffs among competing factors, including cost-effectiveness and reliability in system architectures
	Identify key grid performance attributes (such as reliability, economics, flexibility, resiliency, scalability, adequacy) and metrics to measure them
	Continue critical development of reliability standards, metrics, & technologies
Data Availability & Application Mapping	Create matrix to map data requirements to applications and use cases, and availability by region, formation, and resolution
Data Validation	Support development of standards by which data are validated
	Develop methods for distinguishing incorrect data from events
Defining Flexibility	Define "flexibility" and develop associated metrics for load response, fuel and generation mix, business models, and geospatial diversity of intermittent generation
Flexibility Assessment	Study current responsiveness of markets, technologies, and physical structures to uncertainty and identify potential gaps
	Develop consistent rating standards for resource measurements and asset flexibility
	Develop a regional flexibility cost/supply curve of investment options
	Develop systematic approaches for accessing greater flexibility from existing assets
Capabilities Assessment	Examine capabilities of legacy and emerging tools to handle emerging power system
	Define attributes for models and modeling tools, such as scalability and consistency across transmission and distribution operations and planning
	Develop platform to model and evaluate communication platforms

System Architecture Paradigms	
Regional Transmission Expansion	Examine utilization of existing rights-of-way for increasing transmission capacity density or expanding build-out
	Perform scenario analysis of future possibilities including alternative vehicles and distributed generation that may possibly decrease the need for physical transmission infrastructure
	Evaluate common fault risks of interdependent infrastructures
	Examine technical, economic, and regulatory aspects of underground transmission
	Facilitate the development of offshore transmission
Protection and Security	Study potential value of adaptive islanding to improve resilience and security
	Develop new ways of doing protection and controls leveraging new technology such as fiber optics
Institutional Changes	Develop cost/benefit analysis for innovations in balancing area (BA) coordination for operational and interconnection level planning
	Using DOE’s convening ability, help to frame vision for future grid (2050)
	Research interdependency of grid with natural gas, water, and communications systems
	Develop transactive control concepts to engage demand and distributed resources optimally
	Establish research on load characterization and consumer response elasticity

System Architecture Paradigms (continued)	
Advanced Technology	Research system reliability impacts of future fuel and generation scenarios
	Develop grid standards for devices to fulfill desired attributes of future grid
	Develop operations and control methods for dynamic and stochastic aspects of the grid
	Research distributed, hierarchical control enabled by real-time monitoring and distributed intelligence
	Develop advanced cost-effective controllable devices and transmission
	Test control function and operation of HVDC loop with high capacity lines (under and above ground) and high capacity, low loss circuit breakers
	Increase research into lowering the cost and response time of grid-scale energy storage and demand response
	Develop next generation conductors
Advanced System Design Concepts and Architectures	Investigate potential future architectures in the grid-related domains and align with GTT vision
	Conduct research on the fundamental design & operation of large microgrids
	Develop a hierarchical distributed control system that can tie together any configuration of distributed generation, microgrids, & transmission
	Work on analysis tools and simulators to study various options for cyber-physical architectures
	Conduct research on how to operate grid on a wider bandwidth of the nominal system frequency
Advanced Grid Visibility and Communication	Develop wide-area control algorithms for transient & small signal stability
	Develop wide-area communication networks that guarantee reliable data transfer
	Research co-optimized management of infrastructure, including demand response, dynamic line rating, AC/DC networks, corridors for major transmission overlay, etc.

Conclusion & Next Steps

The Transmission Workshop generated highly productive discussions among electricity sector stakeholders. The synthesized results from the breakout sessions offer a thorough perspective on the opportunities and challenges associated with modernizing the transmission system.

Moving forward, the summary of the discussions presented here will help target key challenges and opportunities associated with grid-integration at the transmission level. The information gleaned from the workshop, as described in this document and together with the DOE Action Plan (Appendix C) and other inputs, will play an important role as reference material to inform the development of a research and development roadmap for DOE and help guide R&D investments over the next five years.

This document will be released in draft form with a formal request for information. These discussion summaries, along with other inputs to the road-mapping process will help reinforce the broader efforts of the Grid Tech Team and enable DOE to support the research and development of solutions to achieve a 21st century transmission system.

Breakout Session Summaries

Challenges

RED GROUP

Overview

This session sought to identify the most pressing challenges for the transmission system in realizing the vision for the future grid put forth by the DOE Grid Tech Team (GTT). Initially, participants provided comments on the GTT vision. Subsequently, the group brainstormed challenges, using the GTT framework of grid visibility, grid understanding, and grid flexibility as a guide.

In addition to challenges in these three areas, a number of institutional and overarching challenges were identified. Lastly, participants consolidated and prioritized the issues that were identified to arrive at a concise list of the most pressing challenges for achieving the GTT vision.

Discussion Summary

General

A few matters were underemphasized in the GTT vision. The future power system and the dialog around its development should acknowledge the level of regional diversity of resources, infrastructures, regulations, and values. Keeping the discussion relevant to each specific area's needs will facilitate faster and more appropriate improvements to the grid.

Additionally, there is a need to identify the role of transmission and sub-transmission and the relationship between the transmission, sub-transmission, and distribution systems in future scenarios with significant distributed generation. Island-based architectures need to be investigated in this context. Lastly, the "two-way" interaction described in the GTT vision does not adequately allow for multilateral transactions and exchanges of information and energy. Especially in regards to exchange of information, researchers should be considered in addition to energy providers and consumers to facilitate faster, more effective R&D in the future.

Institutional challenges are presented in the areas of the blurring of traditional divides (transmission/distribution, federal/state) and a lack of coordination between balancing areas or other entities. Regulatory innovation is needed to address the seams between existing regulations or between regulatory bodies.

Optimization of the power system presents challenges in maximizing overall value across the right parameters for all relevant stakeholders. In the near term, emphasis should be placed on optimizing the system with existing resource mixes, technologies, and operational strategies. For both the near- and long-term, there is a need to define the parameters for optimization given the multitude of players on the grid, the multiple temporal and spatial scales spanned by the system, and the varying objectives. Lastly, as the system evolves, these changes should be co-optimized with other infrastructures (natural gas, transportation, etc.) to provide greater resiliency, security, and efficiency.

Beyond technology development, there are other activities that would benefit the space. Basic science, mathematics, and computational approaches underpin all of the modeling, controls, and technologies. Advances in these crosscutting topics can improve the breadth of technologies being developed.

Across the dimensions of the GTT vision, demonstrating the business case and value proposition of new tools, technologies, and operational strategies is essential to driving adoption. Many analyses may inadequately capture externalities and full lifecycle costs (e.g. over- versus under-ground transmission), or improperly account for the benefits to multiple entities in an interconnected system.

Greater efforts are needed to transition research to deployment. Workforce development and operator training are needed for new tools, technologies, and paradigms. Additionally, identification of the state of the art is essential for demonstrating the incremental value of proposed upgrades to regulators and investors to enable deployment.

As changes are made to the power system, a stable long-term vision is needed to ensure that the system evolves in a holistic manner, rather than in a series of disjointed steps each meant to address short-term objectives. Efforts should be made to future-proof the system, so that investments made today don't constrain the possible architectures and technologies that can be accommodated in the future.

Visibility

There is a need to transition visibility tools and strategies from research to the field more rapidly. Standards like the common information model have been developed but are not widely implemented. Additionally, there is an abundance of data systems that have been investigated in a research context that are not applied in practice. Practical implementations must be developed that address privacy, cyber-security, and data latency constraints.

The data streams from phasor measurement units (PMUs) deployed on the system are underutilized for system awareness and operations, inhibiting deployment of additional sensors that may be beneficial. Applications for the PMU data are still very basic and the value proposition for additional sensors has not been demonstrated yet. Ownership and governance of the PMU data is needed to coordinate data sharing and utilization.

The importance of forecasting (load, solar and wind resources, etc.) is growing, but there is a lack of atmospheric observations optimized for energy applications. These forecasts rely heavily on data designed for weather and aviation purposes, which may not be the optimal set of measurements for emerging energy applications.

A lack of information-sharing between neighboring entities impedes overall system visibility. This issue is especially evident between balancing authorities in the West.

Demonstrating believability of measurements is essential to fully utilizing new and existing data streams. Strategies are lacking for data validation (cross-checking with redundant sources or correlated data). Operators and decision-makers are hesitant to act on information unless it demonstrates overwhelming credibility.

Inadequate IT systems and communications infrastructure present an impediment to achieving comprehensive system visibility. While the state of this infrastructure is highly varied across utilities and regions, many utilities have inadequate connectivity from control rooms to substations and field assets. Where there is connectivity, slow latencies can impede decision-making.

Understanding

The state of the art in modeling, visualization, planning, and operational tools is not well documented and impedes both adoption and development of new tools. Gaps in the existing models and tools should be identified to facilitate development of complementary and improved capabilities.

A number of challenges are present in the current models. Models do not adequately account for the coupling of transmission and distribution as the penetration of distributed generation, demand response, distribution-connected storage, and dynamic loads increases. The speed of models is insufficient for look-ahead capabilities (faster-than-real-time simulation of future scenarios). Deterministic methods may be inadequate for describing the behavior of power systems with significant uncertainty as the penetration of variable generation and responsive loads increases. As stochastic models are developed, strategies also must be developed for using these model outputs for decision-making. Improved wind and solar resource forecast models would enhance system reliability and facilitate cost-effective integration of these resources at high penetrations. Lastly, better understanding of load composition (e.g. power electronics as a fraction of load) would increase the accuracy and utility of models.

Visualization tools that facilitate rapid understanding and decision-making are needed. These tools must also maintain an appropriate level of transparency down to raw data (or intermediate quantities) to increase believability of results and give operators confidence.

There is often little integration of planning and operational tools, both within an organization and across regions. Knowledge of what neighboring entities are doing is needed to facilitate wide-area understanding. A coupling of planning and operational tools would enable more holistic decision-making and better quantify lifecycle costs. As solar, wind, and load forecasting models are further developed, they must be appropriately integrated into the utility or operator toolset.

Better methods for detecting and identifying cyber-attacks would enhance system security. Additionally, means of tracking field assets for cyber-security purposes (e.g. knowing what hardware has what firmware and thus needs what patches or upgrades) would be beneficial from a security and operations standpoint.

Investigation of potential future control architectures and development of appropriate metrics for comparison against existing practice are needed. Models and tools must facilitate open-mindedness about new technologies and strategies by demonstrating credibility of results.

Flexibility

Grid flexibility is not limited to physical options, and includes market design (flexibility products, energy imbalance markets). Investigation of markets that better align compensation and value of flexibility services is needed. Additionally, systematic methods for maximizing the availability of ancillary services are lacking.

Business models for flexibility assets must be developed and end-to-end demonstrations must be performed to validate.

There is likely additional flexibility in existing infrastructure and assets than is currently utilized. Strategies must be developed that maximize the flexibility of existing assets (e.g. greater modeling certainty can enable less conservative safety factors on device operation).

Storage technologies should be further developed to reduce costs and increase reliability and lifetimes. Additionally, modeling of the value proposition of storage must be further developed, and the business case demonstrated in comprehensive pilot deployments. In addition, use of large loads as demand response should be similarly further investigated.

Creative strategies are needed for encouraging adoption of new flexibility technologies in a risk-averse industry. Emphasis should be placed on development of analytic capabilities for planners and operators to simulate and evaluate options.

Key Challenges

Business Cases & Value Propositions

The business case and value proposition for new technologies, assets, and operational strategies must be credibly assessed through accurate modeling and comprehensive, end-to-end demonstrations. Additionally, innovative business model concepts for reducing risk must be developed.

Long-Term Vision for Power System

The lack of a stable long-term vision for the future power system has resulted in unpredictable policy and regulatory signals that necessitate rapid, stop-gap solutions to be deployed. Greater continuity would facilitate holistic planning and evolution of the power system.

Data Sharing, Governance & Utilization

Development of standard processes for data sharing that incorporate constraints in privacy, cyber-security, and data latency is needed to transition research concepts to practical operations. Additionally, oversight of existing PMU data streams is needed to drive utilization for wide-area situational awareness.

Cyber-Security

Improved methods for preventing, detecting, identifying, and responding to cyber-attacks are needed to ensure system security amidst a rapidly expanding number of sensing and control points and increased data exchange across regions.

Information & Analysis Believability

Information displayed in operator tools must be appropriately validated and cross-checked in a timely manner to facilitate rapid and informed decision-making.

Modeling & Simulation

New models must be developed and validated to address increasing interaction between transmission and distribution, greater uncertainty with the proliferation of variable generation and dynamic loads, and forecasting of variable resources. Additionally, new numerical methods and computational strategies must be developed to enable fast look-ahead modeling capabilities.

Applications & Tools

The state of the art in planning and operations tools is unevenly deployed. Efforts should be made to encourage adoption and also to advance the state of the art. Development of new tools must include appropriate levels of integration between planning and operations tools and across entities (balancing authorities, utilities, etc.). Additionally, operators should be involved in tool development to enhance usability.

Market Design for Flexibility

Current markets may not adequately align price and value of flexibility services. Market designs should be investigated that maximize availability of services and facilitate adoption of new flexibility technologies.

Flexibility Technology Development

Flexibility technologies including storage should be further developed and analyzed to bring down costs, improve reliability and bankability, and demonstrate business cases.

ORANGE GROUP

Overview

This session focused on brainstorming the future vision and technological challenges confronting the national transmission system. The discussions were divided among the three grid focus areas, visibility, flexibility, and understanding, as outlined in the workshop agenda. Discussion of each focus area began with each participant identifying one challenge facing the grid. Participants then brainstormed to condense, combine, and prioritize challenges to create a list of top challenges spanning all three focus areas. Prior to the session commencing, all participants at the workshop were asked to consider what the grid would look like and what the future vision would be if it were developed from scratch today.

Discussion Summary

General

There were a number of themes and visions discussed throughout the session. These topics were generally agreed upon by all participants and applied to challenges across all focus areas.

- Solutions developed for the challenges identified during this session, regardless of what they may be, should be simplified as much as possible. Solutions that add complexity to the system are more likely to incur unnecessary costs and will slow industry acceptance.
- Reliability and security (particularly cyber security) must remain at the forefront of any future technologies and developments.
- Research and development should be done with full system interoperability in mind. The ability to integrate tools, technologies, and communication devices that function together throughout the industry is vital to meeting all challenges discussed in this session.
- Consumers must be educated and their needs must be understood in order to further develop and implement a future grid that aligns with consumer needs. Understanding these needs is vital to developing a future vision of demand profiles and load/generation mixes throughout the industry.

Visibility

The discussion on grid visibility focused largely on data management, communication, and visualization. Visibility of, and communication between, both the transmission and distribution systems was also identified as a need that should be addressed throughout all of the challenges discussed.

Data acquisition and management was identified as a serious challenge in improving grid visibility. There is an overabundance of data with little understanding of the quality and usability of the data. Participants suggested a framework be created that identifies an organizational body to securely manage the grid data, determine what data is actionable, and who should have access to it. Analysis needs to be done to determine the cost and benefit of system information. The granularity and frequency required to make informed planning and operational decisions should also be analyzed.

Participants identified the lack of standardized communication protocols as a challenge hindering expansion of grid visibility. Protocols need to be developed and standardized to allow for smooth communication between devices, systems, and organizations. Currently, equipment vendors use differing data transfer techniques, sometimes proprietary, that cannot communicate with other devices and systems without added hardware or software implementation. This lack of standardization drives up cost and reduces interoperability.

Once the data management and communication challenges are addressed, system operators will need adequate tools to present the necessary information gleaned from the available data. Development of operator tools should allow for large amounts of data to be clearly represented and easily understood. Operators can then utilize newly developed tools to respond to grid events in real time.

Understanding

Participants identified two main challenge areas when discussing grid understanding. These challenge areas were modeling and cost analysis.

As discussed during grid visibility, there is a need for understanding of the electrical system that extends from the transmission to the distribution system. It was suggested that modeling tools be developed that unify the transmission and distribution system with granularity that includes three-phase motors and distributed resources. There is a need to understand the correlation between temporal and spatial data and modeling so that both may be used with system planning and operation tools. There is also a need for an interface that allows model interoperability so that models can be run showing power, cyber, and market impacts across different software platforms and will produce the same results given the same inputs.

Analysis into the costs and benefits of new and existing equipment and technologies was also identified as a need. Such analysis would need to go beyond simple financial estimates of upgrades and into benefits analysis of reliability and cyber security. The need to know at what point in the lifetime of legacy equipment it will be beneficial to replace it, and with what new equipment, was expressed by participants. Such analysis can simplify the decision-making process when assessing the value of transmission assets.

Flexibility

Defining what encompasses grid flexibility was a key issue among participants. Flexibility went beyond generation and transmission capabilities to include decision-making, benefits analysis, and optionality. Decisions regarding infrastructure replacement and improvement, information architectures, market structures, and technology development should be made to accommodate major uncertainties of the future grid to maintain the long-term benefits of near-term solutions. A regret-minimization, as opposed to risk-minimization or cost-minimization, approach should be taken when considering present day grid advancements. Better understanding is needed to value and distribute the benefits from flexibility to those that provide it through future market designs.

Following this definition of grid flexibility, there were a number of technological challenges that the participants identified. Equipment interoperability, among both new and existing products and technologies, is needed to ensure clear, simple operation and communication between devices. New devices need to be developed such that their integration into existing systems does not require extensive, costly renovations. New technologies also need to be developed that improve grid flexibility, such as power flow controls, low-cost low-loss power electronics, and AC-DC hybrid network topologies and devices. These technologies should also have interoperability at the forefront of their design criteria.

The needs for asset management and a smart control system were also identified by participants. Extending the life and improving the flexibility of existing assets on the transmission system is needed to reduce near-term costs and create a more sustainable grid as the rate of technological advances continues to increase. A smart control system would allow operators simplified control of the system while reducing equipment upgrades needed.

Key Challenges

1. Understanding the availability, utility, maintenance, use, and exchange of data.
    a. Need for the development of an information architecture.
    b. Need for determining what data is needed by which party and for what reasons.
    c. Need for determining granularity, spatial, and temporal needs of actionable data.
    d. Lack of standardized communications and exchange protocols.
    e. Lack of equipment and technology interoperability.
2. Framework for evaluating and quantifying the cost-benefit of technology and data.
    a. Need for development of a cost and benefit analysis or model to determine value of new technologies and existing infrastructure.
3. Seamless modeling and tools.
    a. Need for stochastic modeling tools for system operations, planning, and decision-making.
    b. Need for integrated view of transmission and distribution with high-fidelity physics and market analysis as an all-in-one package.
    c. Lack of harmonization in modeling and tools between planning and operations.
4. Engagement, outreach, and information sharing to non-technical stakeholders.
    a. Decisions necessary to create an advanced grid require informed consumers and decision makers. Social science must be integrated with power system engineering.
    b. Fragmented regulatory process between local, state, and federal entities inhibits data sharing and coordinated planning.
5. Defining and valuing flexibility.
    a. Must evaluate economic, technological, and regulatory decisions made today to accommodate major future uncertainties.

    b. Need for understanding of how to return benefits of flexibility to providers of it.
6. Developing technologies to support flexibility.
    a. Mixed AC-DC networks with new control theory.
    b. Low cost, low loss power electronics.
7. Development and deployment of multi-disciplinary and multi-dimensional systems.
    a. Need for standardized modeling and communications framework.
    b. Lack of standardized interfaces among both utilities and vendors raises cost of diversity and flexibility.

YELLOW GROUP

Overview

This session focused on identifying R&D challenges on the transmission system for a future grid in anticipation of changes on the distribution system. Discussions began with a review of the GTT vision followed by the strategic focus areas of visibility, understanding, and flexibility. For each focus area, every participant was asked to contribute a thought. This was followed by a group discussion to identify the two to three top challenges within the focus area. The group was very interactive, and while there were a few more consistent voices, everyone in the room participated significantly in the discussion.

Discussion Summary

General

Overall, the group agreed with the vision statement presented by the GTT. There was wariness of the words “significant scale up of clean energy,” citing the DOE should not be “picking winners and losers.” There was also a comment regarding the inclusion of maximizing asset utilization in the vision statement but this concept is lumped with the term cost-effective. This led to a broader discussion of optimization and the difficulty in determining what is optimal. There was recognition that there will be different definitions of optimal depending on the perspective.

The group also expressed support for the strategic framework and how it organized grid technologies. One participant commented that they hadn’t looked at the grid this way before. There was also another comment stating that the flow of visibility, understanding, and flexibility actually goes in both directions. Participants also appreciated the focus on research opportunities as an appropriate role for DOE. A point was raised that the DOE should make investments based on what will provide the nation with maximum reliability and economic benefit. One example is installing HVDC in existing rail corridors. In addition to providing needed transmission, trains that currently carry coal could be electrified, saving 25 billion gallons of diesel fuel annually.

Visibility

The utility industry is getting more data from increased data points, straining the IT and communications infrastructure. Large data processing and management is vital for addressing this issue. The industry does not need to develop new methods to deal with large data but it should learn and leverage advances from other industries, such as social networking. Instead, efforts should be given to developing methods to extract useful information from the data for applications on multiple timescales. One example would be for use in markets such as day-ahead operations and on the five-minute level.

There is also a need to consider how communications architectures define or limit the design of algorithms. Decoupling the two would ensure flexibility to accommodate the development of new algorithms.

Another consideration is how to perform distributed processing of data and “roll it up” for higher level functions. For example, certain local applications will require actual load data while regional application will only need net loads. This capability will be important to bridge the seam between transmission and distribution since the distribution system is not currently visible to the transmission system. There is also a need to establish criteria to determine who needs to have access to what data. There was a suggestion to start with data that is available today on the distribution system such as dynamic loads, vulnerabilities, and protection settings and make it useful for transmission. There is also a need to think about the physical location of where data is aggregated and stored. WECC currently has a reliability center where raw data goes.

“Smart grid” technologies have been slowly redefined from smart meters to IT. The sequencing and the timing for the deployment of these technologies are important. It will take time and utility resources to make changes to the system and guidance on what technology upgrades should occur first and where they should be located would be very useful. For example, SCADA will still be used in the near term so there is a need to develop a path to bridge from old to new. Other concerns raised were the potential reliability implication of these technologies and the impact to the system if there are problems with one or more measurement points.

Tools and state estimators for operators that can use the data streams are needed. The deployment of PMU’s has provided tremendous capabilities but the applications are still lacking. The synthesis and visualization of data is also needed, similar to how LMP maps show where prices are high and low. Operators need actionable intelligence, providing information on trends instead of a signal that something is wrong. One application would be the ability to monitor inter-area oscillations. Another is to have real-time visibility into transmission capacity. An important aspect to consider is who will be using the processed information. A human will require a very different tool than one designed for a computer.

Other comments during the discussion focused around institutional issues. Cyber security aspects of data and the need for an entity like FERC to enforce standards were raised. New protection mechanisms and the allocation of costs for the needed upgrades were also mentioned. Coupling of wholesale prices with retail prices can also provide visibility and transparency into electric costs. Another need raised was a common information model for data. Standards and protocol development is challenging but will have high impact.

Understanding

Millions of dollars have been spent on the collection and storage of data but there hasn’t been sufficient understanding on what the data can be used for. Applications and the value proposition of data collection needs to be determined. There should also be improved understanding of which applications could be reliably conducted by a computer instead of relying on a human. Another need is addressing the wide discrepancies in utility databases. Methods to assess the quality of data and tools to find and mitigate errors would be very helpful. Access to these databases to help inform vendors of utility needs could also be beneficial in driving innovation.

An important challenge is to take the increased data streams and advances in computational power to move beyond state estimation to “state observation.” Tools that can take real-time data to inform real decision making are also very important. Tools that incorporate forecasting and stochastic risk assessments for contingency analyses and understanding system trends would also be desirable. Another useful trait would be the incorporation of electrical and thermal models for the system. Analysis of the impacts of renewables integration on grid reliability was also raised as a need. The incorporation of the location of high quality resources into planning was suggested but this concept is already applied in the interconnection studies.

A fundamental need is to improve models so they can replicate what is observed in reality. PMUs have a value proposition in enhancing models since they allow for validation of models. Another critical need is the interoperability between models and tools. Currently, each entity (utilities, vendors, and operators) maintains their own data and develops their own models which may provide different results for the same system or technology. Standardization or a co-simulation architecture that allows various proprietary technologies to be simulated together would be very useful.

Understanding the impact of orders of magnitude increase in control points on the system is a critical need. The development of control architectures and control theory for this new paradigm is also important. In the future, controls will be designed to be centralized and decentralized depending on the part of the system they affect. Accordingly, it will be important to understand the interfaces for their respective applications. One example is the control and aggregation of multiple assets such as EVs to provide load balancing and storage for the grid. There is also a need to determine what information is needed for decision making and the impact of communications delays on control and protection.

Flexibility

There was a fundamental question of what flexibility for the grid meant. Most have an intuitive feel for what it is or should be but there are no well-defined metrics to evaluate it. Metrics are needed to help inform decisions between various assets and components that could provide flexibility. For example, a quantitative metric such as time dependency may be valuable but there are many time scales to consider, from intra-hour to long term planning horizons (e.g., 20 years). There may also be regional differences in the requirements for flexibility. A suggestion was made to couple these requirements to the amount of renewables on the system. An additional challenge is establishing the entity that will develop flexibility metrics everyone will utilize.

Various methods for increasing grid flexibility that don't require new hardware were discussed. There are many existing assets that can provide increased flexibility if properly modeled and managed. For example, incorporating forecasting for line capacity, weather conditions, and loads can influence the accuracy of day-ahead markets, freeing up reserves that provide flexibility. More dynamic and adaptive models that update frequently from increased sensor data can enable capabilities such as reconfiguration of FACTS control parameters, increasing flexibility. It may also be possible to relax operation criteria through improved understanding.

Energy storage could make a difference but current cost, value proposition, and lifetime are concerns. Existing work by EPRI and Sandia on value streams has made some steps to addressing some of these concerns. The fundamental challenge is still understanding the value of flexible technologies and translating it to markets or real revenues. New market mechanisms for flexibility products such as time shifting energy are needed. HVDC is also an opportunity to increase flexibility but protection systems such as circuit breakers are needed before multi-terminal functions can be achieved. Controls and coordination of these technologies, as well as aggregated EV, is another need. Studying the impacts of environmental regulation on flexibility and better use of combustion turbines would also be valuable.

Key Challenges

- Data Management and Processing – Determining what information is needed, when it is needed, and for what applications is a big challenge. Condensing information from many sources, especially from the distribution system is another important aspect.
- Technology Implementation Planning – Providing guidance in the sequencing and timing for the deployment of measuring and sensing technologies is needed to optimize limited utility resources.
- Validated Models and Model Interoperability – Dynamics models and algorithms are inadequate at replicating what is observed through PMUs, limiting their usefulness. The models developed for various technologies are also not interoperable between tools.
- Advanced Tools and Automation – Tools should be able to utilize data for real time operations instead of forensics. Getting the right information to the right entity, whether human or automated, is another aspect that needs to be resolved.
- New Controls and Architectures – Controls and architectures need a fundamental rethinking to accommodate the significant increase in potential control points and the implications for a mix of centralized and decentralized control.
- Definitions and Metrics for Grid Flexibility – Flexibility requires a better definition and metrics that can help determine the value of technologies that can provide it.
- Extracting Flexibility for Existing Assets – Increased visibility and understanding of the power system can be used to increase system flexibility and optimize the use of existing assets.
- Grid Hardware and Systems – Technologies such as energy storage, HVDC, and FACTS devices can be used to provide flexibility but their value proposition, control strategies, and characterization requires further investigation.

GREEN GROUP

Overview

The session began with a review of the topics and issues discussed in the opening presentations. For clarity the group discussed the definitions and meaning of the Grid Tech Team Framework (visibility, understanding, and flexibility) that were used throughout the workshop to structure the discussion. Many different viewpoints were represented in the breakout group, covering areas of expertise from utility operators to researchers. The breakout group identified technical challenges and problems facing the transmission grid in each area of the framework, along with identifying complementary institutional challenges. The institutional challenges were recognized and noted, but were not the focus of the breakout session discussion.

Discussion Summary

General

During the breakout discussion several needs and challenges were identified in the three framework areas. The following subsections summarize these focused discussions. At the conclusion of the breakout session, the group identified five key challenges, across the entire framework: (1) Getting the Data; (2) Synthesizing the Data; (3) Lack of Scope; (4) Lack of Tools (5) Lack of Definition; and (6) Metrics for Flexibility. The specific elements of these key challenge areas are described in the following section.

Visibility

The group discussed the importance of grid visibility in the context of being able to monitor and measure what is happening on the grid. As the topic was discussed, a key concern was the need for metrics to define visibility objectives. These metrics would help specify data availability and data requirement needs (e.g., sampling rate) from the appropriate stakeholders. The development of such metrics will help ensure that the right information gets to the right stakeholders, at the right time and with the right frequency.

The group also identified the lack of standardization as an issue. There is a need for a standard data protocol that streamlines how the data is reported and collected, but also allows for secure operation of the grid and protection of the data. Creating a robust data management system would help integrate the use of grid-related data as models and applications are developed and/or improved. In addition, the issues related to who can see the data, who can use the data, what they can do with it, and who will pay for the data management (e.g., collection and storage) will need to be addressed. Moreover, the value of sharing the data with researchers, while considering the utilities' need to protect confidential information, also needs to be considered.

Moving forward, sharing data across boundaries (especially seams, e.g. between balancing authorities) and between different transmission operators is needed to ensure that operators are informed and equipped to respond to events occurring within neighboring systems. Our current system also lacks visibility across the distribution system including deployed distributed resources. As these technologies are added in large quantities, aggregation effects will impact the transmission system. Integration of these inputs, with data that is validated in real-time, will provide a decision framework for transmission operators to react and respond to events.

Other concerns brought up by the group covered a broad range of topics. One concern was that the large amounts of data that will be created produce a 'big data' problem and will require software architecture and communications standards to manage it. Another concern was the lack of data on consumer behavior and how consumers would respond to changes. A third concern was the inability to accurately forecast weather and loads at the right time-scale for reliable grid response, and the lack of data to develop awareness at the local level.

Understanding

In the context of understanding, a major concern discussed by the green group was our lack of data of the grid system. We have a narrow understanding of our current grid infrastructure and how we are currently using the system. For example, with the natural gas boom and coal fired plants retirements, the grid is operating outside its historic generation mix creating unprecedented operational challenges, such as voltage stability concern within different regions. It is important to evaluate how we use what we have now and build that into how we will use it in the future. Traditional planning and operating models have been heavily influenced by institutional and cultural barriers. Going forward, we need to evaluate where traditional methods cease to be useful. Looking to the future grid, we will need to be able to integrate market variables into our planning and operating tools. Price signals alongside reliability standards and physical measurements will all be needed to create an optimal transmission system. Future planning is hindered by the lack of algorithms to synthesize data, to estimate and address missing data, and to calculate a better overall state estimation of the grid.

Another major concern identified was the current inability to validate the models, including forecast models that are developed. More demonstration platforms, such as microgrids, are needed that can be used to test and validate models to ensure they accurately represent the grid. In developing models, it is also necessary to reach an agreement of scenarios needed for the planning process. Moreover, it is necessary to ensure that we have adequate computing power to run and test these models.

A third barrier to improved understanding of the transmission grid is a lack of cost-effective, reliable, commercially available monitoring hardware built into the grid infrastructure. Moreover, the grid will require hardware devices that are capable of providing detailed and automated information to help determine the source of a fault and to react more quickly and strategically to a potential or present fault. This hardware will be especially useful along seams of transmission and distribution to improve not only understanding, but also visibility in the seams.

In addition to hardware advancements, better software with analytical and real time prediction capabilities is needed. Initially, consolidated data and software that can predict grid operations and provide coordinated control of the system will be sufficient. But, in looking forward, real-time and intelligent software that is able to predict the needs of grid operations will be necessary. This software will need to integrate variable generation resources into its forecasts and various operational functions.

Other concerns brought up during the discussion were the lack of standard large-scale databases and our lack of understanding in neighboring systems. Some members of the group also felt that we should be using probabilistic and not a deterministic approach in our models.

Flexibility

The group began by discussing the definition and importance of grid flexibility. Flexibility allows the grid to respond to information from many sources and to rapid changes in operation. An understanding of the flexibility capability of our current system is needed. Transmission needs to be a flexible resource on both a temporal and geographic scale. Metrics and performance standards for what defines flexibility need to be developed, especially with respect for renewables and storage. Defined metrics and performance standards will enable cost-benefit calculations so that decisions regarding technologies to incentivize grid flexibility are more informed.

Another issue discussed with regard to grid flexibility is the need for comprehensive, integrated models that provide greater understanding of the system and the interdependencies of its components. A systems approach to grid flexibility is needed, along with the creation of comprehensive models that focus on the interactions of technologies on the grid. Currently, the transmission space lacks intelligent, adaptive, protection systems coupled with low-cost control devices that allow the grid to fully understand what is going on and respond instantaneously. Such a system will need to factor in the cyber-security challenges of our future grid so that they are implemented into all levels of its structure.

In addition, grid flexibility would provide improved situational awareness for normal and emergency operations. Grid flexibility, at present, is challenging because of the strongly coupled dynamic nature of the grid. Creating a system with wide area situational awareness, coupled with the capability of low-cost control devices that allow it to respond and take action quickly, would greatly enhance neighboring grid systems' security relative to one another. In addition a warning system of distributed devices that can monitor the grids status and respond could help prevent and at least minimize restoration times for future blackouts and power disruptions.

Other concerns expressed by the group included the age and long life cycle of equipment on the grid that limits grid flexibility. The lack of bandwidth for two way communication within the components of the system was also discussed.

Key Challenges

1) Getting the Data

A key challenge in the transmission space identified by the group is how to collect data and information to increase grid visibility. In order to better utilize and understand our transmission grid, we need to be able to monitor and measure information about the grid. Understanding what data is useful, and how to identify what specific information is needed will be important. Another issue in collecting data is determining the appropriate timescale, e.g., whether data is needed on a sub-second, second, minutes, hourly or daily timescale, as data collection needs will vary depending on the measurement and the user of the data. In addition, it is important to define who will use the data (e.g., which groups need the data to make decisions and what their differing requirements will be).

Collecting large quantities of data comes with the logistical challenges of how to securely store the data so that it is protected, but still accessible to the appropriate users. There will be a need for data archival systems, so that the data collected can be usefully retrieved. In addition, the data collected will need to be validated, ensuring that measurements made in one transmission system are comparable to measurements made on a similar system. Sharing large data sets between utilities and users also requires standardization, ensuring that data collected from multiple utilities can be used with several models and can be reliably compared and calculated.

2) Synthesizing and Delivering the Data

Collecting data within the transmission infrastructure will produce large quantities of data. Creating a data architecture system that allows the massive amounts of data to be managed and mined for useful information is an important challenge. Programs and protocols for interpreting the data to make useful decisions will need to be developed. These algorithms must be able to synthesize the raw data and measurements into useful information.

Another challenge is how the data can be presented visually, so that transmission operators can use it to manage the grid. Integration of the data and presentation of it in a graphically useable fashion is necessary to better inform and enhance the decision-making ability of the grid operators.

There was also discussion on the possibility of having the entire dataset in which multiple software tools, having different time scales, could pull from.

3) Lack of Scope

Another challenge facing the transmission grid moving forward is a lack of scope and understanding of what level of awareness, in the data context, utilities need of their system and neighboring systems. It is necessary to develop an understanding of what data is currently collected, how it is used, and what gaps there are in our understanding that needs to be filled in the future to improve understanding and visibility of grid operations.

This lack of scope is compounded by the need to incorporate transmission needs on different timescales. Operators can rely on grid understanding in the short-term, responding to sudden and present issues on the grid. In contrast, planning activities will require longer-term data that allows planners to understand both historically what has happened on the grid as well as data and information that allows them to prepare for the future needs of the transmission grid (e.g., having the visibility to see an event coming).

4) Lack of Tools

Currently, as the group noted, there is a lack of tools to process grid data into useful information. There is also a need for algorithms to synthesize the data, algorithms that can estimate and deal with any missing data, and intelligent algorithms that can give us a better understanding of the state of the grid. The group emphasized that specific applications for different data need to be identified. There is already a lot of data, e.g., PMU data; procedures and tools to ensure its usability and accessibility are needed.

As grid measurements begin to play a larger role in the planning and operation of the grid, models and simulations techniques will be needed to guide decisions. These simulations and algorithms will need to consider institutional and cultural barriers in addition to technology challenges. Also, as new infrastructural interdependencies arise, analytical tools and responses will need to be developed to reflect their integration into the grid and its operational capacity.

5) Lack of Definition and Framework for Flexibility

Another challenge facing the grid identified by the group is a lack of understanding of the current flexibility and capability of the system. For example, the grid lacks a warning system that can measure distributed devices and their status. Unfortunately, the age and long life expectancy of grid assets limits the rate of introduction of devices to improve flexibility. Another related challenge is that the wide area of the grid requires situational awareness and understanding. Such challenges require a system-wide approach for grid flexibility.

Somewhat complementary to understanding the current flexibility capabilities of the grid is the lack of metrics through which the effectiveness of flexibility can be determined. An overarching definition of grid flexibility in terms of measurable metrics on a time scale and geographic scale is needed.

Current analysis lacks a framework for how to deal will the interdependencies of different resources. In current assessments, valuation of grid assets is deficient to consider the cost-effectiveness and cost-benefit they provide to the grid. Understanding the value of distributed assets will enable more informed decisions about their use.

6) Lack of Optimization Capability and Control

The final key challenge identified by the green group was the lack of cost effective, reliable hardware and software which would facilitate optimization and control analyses and decisions. New control and measurement devices with capabilities and software that enhance our ability to visualize and control the transmission grid are needed. Research is necessary to investigate the interaction and unintended consequences of adding new measurement and control devices onto the grid; such investigations will inform how the new technologies fit onto the system. These new technologies will also need to be designed with integrated cyber-security capabilities built into the devices, so that the future grid is inherently protected from purposeful or accidental cyber incidents.

Breakout Session Summaries

Opportunities

RED GROUP

Overview

In discussing the synthesized challenges from the first day, the group made sure to address both entirely new system design concepts and architectures to maximize the flexibility of the future grid and solutions that extract more value from the grid's existing assets. Much of the conversation centered on the challenges associated with measuring and understanding the current operation limits of the grid, and on ways to get the right information to the right people when it is needed.

Discussion Summary

General

Through these conversations, the group chose to combine some of the previous day's challenges, and selected three key challenges to grid modernization:

1. ***Addressing the varying temporal and spatial issues associated with collecting data, processing it, and presenting stakeholders with relevant, actionable information***

The group shared a concern about ability to collect and process the volume of data that will be available in the future. Security of the information needs to be a priority, and any entity that collects or distributes data will need very granular protection for data access. There needs to be continuous grid cyber security research to keep pace with new technologies and threats. As the industry modernizes, there needs to be a detailed shared understanding of the data chain of custody to allay concerns over the potential release of sensitive information.

To produce a complete picture of the entire system, information needs to be consolidated from multiple utilities that currently use different methods for collecting data. Standards for metadata, data collection, and research to develop data structures that accommodate a variety of time scales, geospatial factors and system status will all be key to address this. Similarly, the development of data fusion capabilities would allow for the assimilation of data in real-time that incorporate existing external data – such as weather – to give operators a holistic view of the system.

2. ***Need advanced technologies for grid flexibility (responsiveness) and mechanisms to extract flexibility from existing assets***

There was a sense among the group that the industry currently lacks a detailed understanding of the capabilities, limitations, and capacity of the existing system. To maximize the efficiency and flexibility of the grid, we need to assess the current responsiveness of markets, technologies, and physical infrastructure, beginning with consistent ratings standards for measuring resources, assets, and flexibility. As the grid becomes increasingly connected, there is a need for transmission system operators to understand what is happening on the distribution system. Research into modeling aggregated distribution system data – such as price and other consumer market signals – would increase visibility and give transmission operators more control.

Energy storage is a potential game changer. Research into lowering the cost and improving the reliability of grid-scale storage systems, as well as lowering the response times of larger storage like pumped hydro, would give utilities a way to absorb excess electricity.

While institutional challenges were outside the scope of this workshop, the difficulty with siting new transmission infrastructure leads to a need for more research into new technologies and approaches that could expand transmission capacity of existing resources. Possibilities include widening the operating frequency band, reconductoring, increasing power densities, leveraging railroads rights of way, and 6-phase operations.

3. ***Need new grid concepts and architectures - including information, control, communication, and hardware – to enhance resiliency, response and restoration***

To completely address all of the challenges the grid faces in the future, the industry needs to consider changes to its fundamental design and operation principles. The future grid could look completely different from the one we have now. We need to understand the potential benefits of different system design concepts and architectures. Potential topics include a system composed of HVDC loops using high capacity, low loss breakers, extensive interconnected microgrids. Similarly, with the volume of data that will be available in the near future, it seems impractical to assume it would all be collected in a central place. Research into distributed data collection and sharing relevant information – rather than all the raw data – could be beneficial.

In the near term, the industry needs ways to capitalize on recent PMU deployments to improve wide-area control of the grid, including control algorithms to improve signal stability. Testing and demonstration of control function and operation, and hardware in the loop, would help reduce the risk for utilities.

Key Opportunities

There is a need to address the varying, temporal, and spatial issues associated with collecting data, processing it, and then presenting stakeholders with relevant, actionable information.	
Data structures that can accommodate broad time scales, geospatial aspects, and system status	• Perform investigative research into data structures and the mechanisms that are needed for all the temporal and spatial requirements • Develop ways in which we can consolidate all of the information from generation, transmission, and distribution into straight forward actionable information • Develop and demonstrate data fusion capabilities to assimilate data in real-time using existing data streams (e.g. grid status, weather) to realize a high fidelity, holistic view of the system and share real-time information with operators • Allow for ongoing dialogue to develop standards for metadata, data collections, and dissemination
Cyber security solutions that can build trust in data security among partners	• Facilitate the continual updating of solutions to balance ever evolving threat and performance specifications • Develop methodologies that allow data dissemination and control to be consistent when data is transferred to partners • Facilitate the development of the appropriate data chain of custody
A foundational modeling platform or ensemble that can integrate existing models for a wider system view	• Consolidation of modeling for planning and operations that encompasses both transmission and generation • Development of simpler user interfaces for models without sacrificing power and fidelity • Develop models that can incorporate new technologies such as Supercon FCLs, Energy Storage, and Distributed Generation as they are developed

<table>
<tr><th colspan="2">There is a need for advanced technologies that enhance grid flexibility (responsiveness) and mechanisms to extract flexibility from existing assets</th></tr>
<tr><td>Assessment of the current abilities and limitations of the system (baseline study)</td><td>• Study current responsiveness of markets, technologies, and physical structures to uncertainty and identify potential gaps
• Develop consistent rating standards for resource measurements and asset flexibility
• Develop a regional flexibility cost/supply curve of investment options</td></tr>
<tr><td>Regional transmission expansion studies that include new technologies</td><td>• Conduct research into increasing power densities along existing rights of way
• Perform scenario analysis of future possibilities including alternative vehicles and distributed generation that may possibly decrease the need for physical transmission infrastructure</td></tr>
<tr><td>New technologies that can increase grid flexibility</td><td>• Facilitate the development of offshore transmission
• Increase research into lowering the cost and response time of grid-scale energy storage and demand response
• Conduct research on how to operate that grid on a wider bandwidth of the nominal system frequency
• Model aggregate distribution system data in order to increase the visibility and control of distribution operations for transmission operators
• Develop next generation conductors</td></tr>
<tr><th colspan="2">There is a need for new grid concepts and architectures – including information, control, communication, and hardware – to enhance resiliency, response, and restoration of the electric grid</th></tr>
<tr><td>Advanced system design concepts and architectures</td><td>• Test control function and operation of HVDC loop with high capacity lines (under/above ground) and high capacity, low loss circuit breakers
• Conduct research on the fundamental design and operation of extensive microgrids
• Develop a hierarchical distributed control system that will be able tie together any configuration of distributed generation, microgrids, and transmission</td></tr>
<tr><td>Advanced grid visibility and communication</td><td>• Develop cost-effective two-way communication techniques and technologies
• Research ways in which recently installed PMUs can be leveraged for enhanced grid analysis and control. Develop wide area control algorithms to improve transient and small signal stability
• Develop a next generation EMS that has better real time management of the grid and includes relevant data sets (e.g. weather)</td></tr>
</table>

ORANGE GROUP

Overview

The Orange Team began by reviewing the list of nine challenges that were identified the day before. Based on the discussion, the group discussed the scope and intent of each of the challenges, and several recommendations for editorial enhancements were noted. The challenges were then grouped into four challenge categories. The group generally agreed that all four challenge categories represent Top Challenges. The last portion of the meeting was devoted to identifying key RD&D opportunities that would address each of the challenge categories. Finally, the group developed the most important RD&D activity for each challenge category that DOE could pursue to address the challenges.

Discussion Summary

Information/Data

The **utility of the data** needs to be defined first with a clear understanding of the end game which must be used to prioritize what data are collected, analyzed and shared. Data management is driven by the philosophy of the entity collecting the data, and that defines what data are collected, and how it is stored, analyzed and communicated (e.g. visualized); philosophies vary dramatically within and between interconnections.

We need to define **why data needs to be shared**, how data will be shared, what's a library, who can curate library, etc., and get necessary approvals from every participating utility to share data. What is the appropriate amount of information exchanged within and between different levels? There is a lot of confusion about roles and responsibilities. Need to define where there are opportunities for aggregation. Could DOE help develop a 'safe house' for data?

Mechanisms for **collecting, storing, analyzing and communicating data** between entities are needed. Interoperability is needed, i.e. plug-and-play components for substations. This would be facilitated by creating an **open environment and standardization**. There is a need to develop **standards and standardize the modeling environment**, not the models. Standardization efforts could be shepherded by DOE and implemented by a non-government entity.

- There are concerns regarding non-compliance with FERC, issues of market advantage and cyber security that are barriers to sharing data. Can DOE play a role as broker between FERC and industry?
- There needs to be a better understanding about **how different aspects fit together** (e.g., viability, utility, maintenance, exchange, and security).

- A matrix illustrating the differences between **long-term vs. short-term types of data** would be useful.
- Taking system information parts and mixing them together is one thing, but to identify **concrete things to do**, research, that's hard; e.g., if you want a power-flow controller, every piece of hardware and software is different.

Tools & Models

First, decide **what models are needed** for what missions for different environments (research, regulatory, etc.). Models should have real applications; they should address what we need. How do we optimize new technologies inserted into the grid? Generating a list of **simple applications** that industry could use would be a great service, e.g., what are uses of time-synchronized data? How do you conceptualize using synchrophasor data to predict when you're near system failure? Challenges faced in WECC to create a data-sharing framework apply to a lot of other types of data.

Metrics are needed to focus data collection efforts and communicate results. Metrics should include ways to **quantify value**. Ways to **measure success** using these metrics are also needed. Key attributes need to be identified (e.g., flexibility, reliability, cost, resiliency, scalability, optimization, etc.) and should have associated metrics. **Value comparisons** should not be based on cost/benefit analysis, market values is alternative. We need metrics to value all the things in the architecture.

Existing data collection and analysis **architectures are incompatible** and do not enable wide-area analyses. New grid architectures need to be defined for information, control and physical assets that span distribution and transmission systems. The future grid will be comprised of millions of devices; simulators and models that can help operators and planners understand new architecture are needed. Who's going to define the new architecture? The use of **different models between operators and planners** makes it hard to maximize assets and communicate between groups. The **scales of time and space differ between operators and planners** and models need to reflect these different scales, and they also need to reflect the multidimensionality of the data beyond time and space, i.e. markets, contingencies, etc.

Incentives for adopting new practices, investing in infrastructure, and changing paradigms are needed. The missing piece is the value-only part. A regulatory framework to push wind and solar exists but there is no financing incentive framework. **Existing business models** do not support modernization efforts. We need to find a way to **value trade-offs** between cost-effectiveness and reliability, to understand the trade-offs in decisions. This is a major issue. Estimating price vs. reliability is difficult but we want a metric that relates reliability with cost. We spend a large portion of our resources on economics alone. You can't approach a regulator without talking about costs. For example, there is no incentive for probabilistic modeling.

The **definition of 'systems' is broader than technology**, it includes markets. All of the discussion is focused on analysis at the device layer, how widgets will work together, but analyses need to include market layers; they need to communicate with other aspects of the system, other layers, e.g. ability to manage the asset, risk levels, etc.

We have data but not information; **tools and models need to be scalable**. We don't have the right tools to scale-up results. There is a distinction between scalable tools and scalable models and we need both.

Model validation requires input from many people (i.e. MISO results increased from 50% to 70% after including people from outside MISO in validation efforts). There is a lack of defined process and organizational structure to validate models. Who carries the liability for model results and validation?

Historically, industry has been run deterministically. **Probabilistic planning** with risk levels should be explored for decisions, but not necessarily the regulatory environment. Are we happy with the way we currently assess the grid in terms of reliability? Not sure existing planning systems can accommodate renewable. Probabilistic planning is another option.

There was a discussion on **model duplication** with the conclusion that, in the case of Hurricane Sandy, it was useful to have predictions from multiple different models. We must understand the system and system behaviors that are pertinent to user needs.

Recognize the limits of the **human factor**, data must be processed/analyzed and then presented in a form (e.g. visualization, valuation, etc.) that has utility to the user. Analyses tools are needed to visualize results but also to communicate concepts to users with different backgrounds.

There are **physical limitations** in computer hardware, software and processing capabilities. The ability to predict dynamic behavior in minutes using large, complicated data sets may be computationally possible but not practical given existing resources.

Other

- What can we do with results from demonstration projects to **leverage what we learned**?
- Is there not enough **communication from DOE about what they are already funding**, e.g., demo project on capacity of lines?
- The more **regional the solution**, the more likely it is to be implemented.
- **Protection and control** – need new ways to do protection. Still using old algorithms.
- There is a "ton" of **excess capacity** that doesn't get touched and doesn't cost the consumer a penny. Need to focus technology and develop methods to get more out of **existing assets**.
- Explore and compare grid management scenarios that include a high-capability overlay vs. **segmentation** and optimizing smaller pieces. A high-capability overlay is a network with key elements in a series, find the weakest link and it fails, while segmentation means you lose all the advantages of economy of scale and diversity. Study both ways and see which one works best. DOE could identify the top 12 corridors in the US. DOE could explore the value in controlled/adaptive islanding. The 2008 blackout resulted in islanding but it occurred on an ad-hoc basis. If you go through a process in advance and determine how you're going to split things

up, then you could stabilize and reconnect afterwards. Use segmentation as an adaptive response to an event, an option to break apart in catastrophic situations but only as a fail-safe.

- Evaluate and compare **strategies to co-optimize AC and DC**. Determine who would manage this infrastructure.

In summary, Figure 1 below shows the Orange Team consensus on the how Day 1 challenges can be grouped into four basic categories. Key RD&D Opportunities were identified for each of these categories (see table below). Edits to the Day 1 challenges are shown in *italics*.

Top Challenges Identified on Day 1

Information

1. Need improved understanding of the availability, utility, maintenance, exchange, and security of data and associated requirements
2. How to synthesize, process, integrate, visualize, and validate data for actionable *information and* intelligence
3. What are the *Information Communications Technologies* (ICT), sensor systems *and actuators* needed for the future grid and advanced applications

Models & Tools

4. Lack of validated models and simulation algorithms, *as well as process and organization,* to explore *systems* dynamics *(physical, policy, markets)*, concepts, and technologies
5. Lack of adequate tools *(including visualization) and appropriate computing resources* for grid operators, planners, decision makers, investors and other stakeholders to perform credible analyses over multiple scales *(temporal, spatial, scenarios)*

Metrics

6. Lack of metrics and definitions for *all key attributes of* grid *performance objectives, including* flexibility, resiliency, value, etc.
7. How to value, evaluate, and control various technologies for *key attributes of grid performance,* including flexibility, on a level playing field
8. Need advanced technologies *and processes to extract value, including* flexibility, from existing assets

Architecture

9. Need new grid architectures *spanning both transmission and distribution,* including information, control, communication, and physical *infrastructures*

Figure 1 – Orange Team Day 1 Challenges editorial enhancements and grouping.

Key Opportunities

The following table identifies the highest priority (shown in bold) need, along with other potential focus areas for DOE for each of the 4 challenge categories created by Orange Team:

Information	1. Define data applications, categories, sources and destinations, and identify existing barriers that need to be removed to allow for seamless data exchange. Near-term application should be synchrophasor data. **2. Develop data/information sharing protocols and mechanisms for data that covers a large cross-section of the electric industry [HIGH PRIORITY].** 3. Promote information interoperability across all system layers through standards (e.g., IEC 61850). **4. Leverage existing demonstration and research projects (publicly and privately funded) [HIGH PRIORITY].**
Models & Tools	1. Identify critical modeling *needs* and applications. 2. Validate and verify critical models. 3. Promote standardized modeling environments and model interfaces. 4. Define attributes for models and modeling tools, such as scalability, consistency across transmission/distribution, Operations/planning. **5. Develop approaches and tools for specific applications to support decision making under uncertainty (planning, operations, regulatory, policy, etc.). For example, need to develop theory, methods and tools to quantify the operational and resource adequacy value of transmission [HIGH PRIORITY].**
Metrics & Valuation	1. Identify key grid performance attributes (reliability, cost, flexibility, resilience, scalability, adequacy) and how to measure them. **2. Address emerging critical gap to maintain process to deal with development of reliability standards, metrics, technologies [HIGH PRIORITY].** 3. Develop frameworks and metrics to more clearly understand tradeoff among competing factors/options, including cost-effectiveness, reliability, system architectures. 4. Develop metrics to assign value associated with new and existing technologies.
System Architectures	1. Work on analysis tools, simulators to study various options cyber-physical architectures. **2. Study potential value of adaptive islanding to improve resilience and security; Strategy of last resort; fail-safe [HIGH PRIORITY].** 3. Develop new ways of doing protection and controls; leverage new technologies like fiber optics. 4. Research co-optimized management of infrastructure, including demand response, dynamic line rating, AC/DC networks, corridors for major transmission overlay, etc.

YELLOW GROUP

Overview

In this session, participants sought to develop a list of specific RD&D activities the DOE can engage in to address the most significant transmission system barriers to realizing a future grid that meets the vision of the DOE Grid Tech Team (GTT). Initially, the group revised and refined a list of key challenges identified in the previous day's breakout session. Subsequently, the group established the three highest priority challenges through a direct vote. For each challenge area, participants generated specific activities for the DOE to conduct to address the challenges. Lastly, the group consolidated and prioritized the proposed RD&D activities into a concise list of the highest priority items.

Discussion Summary

The original list of key challenges condensed from the results of the previous day's breakout sessions is given below (1.1 – 1.9).

1.1 Need improved understanding of the availability, utility, maintenance, exchange, and security of data and associated requirements.

1.2 How to synthesize, process, integrate, visualize, and validate data for actionable intelligence.

1.3 What are the ICT/sensor systems needed for the future grid and advanced applications.

1.4 Lack of validated models and simulation algorithms to explore new dynamics, concepts, and technologies.

1.5 Lack of adequate tools for grid operators and planners to perform credible analyses over multiple scales for the future grid.

1.6 Lack of metrics and definitions for grid flexibility.

1.7 How to value, evaluate, and control various technologies for flexibility on a level playing field.

1.8 Need advanced technologies for grid flexibility and a mechanism to extract flexibility from existing assets.

1.9 Need new grid architectures including information, control, communication, and physical.

Reactions to this list primarily consisted of emphasizing or de-emphasizing certain aspects of a challenge area, or modifying the scope of the various challenges to minimize gaps and overlap. The main reactions are captured below.

There is already significant communication and sensing infrastructure in place, and efforts should focus on utilization of existing data (especially from PMUs) and identifying data gaps. Temporal and spatial resolution is a key aspect of data needs and should be called out explicitly. Challenge 1.2 is really about data management and ensuring data quality, and the visualization aspects should be emphasized elsewhere (in regards to operator tools). Usability of data and analyses is essential, and tool development should focus on its intended audience (grid operators and planners). Many control room operators may not be engineers, and visualization tools must facilitate rapid understanding and awareness for this audience.

These reactions were used to develop the revised list of key challenges below (2.1 – 2.9):

2.1 Understanding data requirements – e.g. availability, utility, temporal & spatial resolution, maintenance, exchange, and security.

2.2 Data management – how to synthesize, process, integrate, visualize, and validate data for actionable intelligence.

2.3 What are the information and communication technology (ICT) / sensor systems needed for the future grid and advanced applications?

2.4 Lack of validated models and simulation algorithms to explore <u>new</u> dynamics, concepts, markets, and technologies.

2.5 Lack of adequate tools for <u>grid operators and planners</u> to perform credible analyses over multiple scales.

2.6 Lack of metrics and definitions for grid flexibility.

2.7 How to value and evaluate various technologies for flexibility on a level playing field.

2.8 Need advanced technologies for grid flexibility and a mechanism to extract flexibility from existing assets.

2.9 Need to explore new grid architectures including information, control, communication, and physical.

The participants voted on the top three challenge areas. Challenges 2.1, 2.5, and 2.9 were identified as the highest priority, with challenge 2.8 closely behind.

Key Opportunities

Data Requirements, Maintenance, Exchange, and Security

There are information gathering activities in data availability and requirements that could help facilitate development and deployment of sensing and communication infrastructure and of next generation operator tools. Creation of a comprehensive matrix that maps various applications and use cases (say, power flow analysis) to their associated data requirements would assist researchers and industry. Additionally, creation of a matrix of available data streams by region, format, resolution, and availability would help guide application development and identification of data gaps.

Innovation in data sharing is needed to unlock the full potential for utilization of deployed sensors. While standard data formats exist in some instances, standard processes for sharing data between entities are needed to facilitate this exchange. Data pedigree is important for believability, and mechanisms for ensuring metadata are complete and accurate are needed to increase confidence in data from other entities. Similarly, methods must be developed for minimizing privacy concerns associated with inter-entity data sharing. Development of common definitions for terms like "security," "maintenance," and "availability" would further enhance accurate dialog around data, increased data sharing, and increased utilization of shared data. Lastly, there is a need to identify gaps in existing standards and coordinate with NIST and other organizations to support standards development activities that remedy these gaps.

Standard procedures for validation of data are needed to facilitate increased believability and utilization of recent and emerging data streams. Supporting development of these standard procedures by which data are validated should be considered as a potential activity. In addition, a number of research activities that underpin this effort should be considered. In particular, methods are needed for distinguishing incorrect data from events, and the possible impacts of instrument transformers on PMU sensor readings should be investigated.

A number of efforts should be pursued to expedite the adoption of the common information model (CIM). Encouraging or requiring the use of CIM for DOE-funded research would speed the process. Additionally, the creation of an open, comprehensive grid model based on IEC 61970 and IEC 61850 for use by researchers, academia, and industry would contribute. Supporting the development of standards development that brings PMUs under the purview of CIM is also a worthwhile activity. Lastly, there are gaps in the current CIM standards, for which vendors often implement their own stop-gap extensions. There is a need to support the extension of CIM to cover these gaps.

Inadequate understanding of cyber-security needs is a potentially significant barrier to data gathering, sharing, and utilization. Efforts should be made to define the necessary levels of security for transfer, storage, and access of the various data types.

Data Requirements, Maintenance, Exchange, and Security	
Data Availability & Application Mapping	• Create matrix to map data requirements to applications and use cases. • Create matrix of available data by region, format, resolution, and availability.
Data Sharing	• Support development of standard processes for sharing of data. • Develop methods to minimize privacy concerns associated with inter-entity data sharing. • Develop definitions for terms like "security," "maintenance," "availability". • Identify gaps in existing standards. • Coordinate with NIST and others to support standards development.
Data Validation Standards	• Support development of standards by which data are validated. • Develop methods for distinguishing incorrect data from events. • Investigate possible impacts of instrument transformers on PMU data.
Adoption of Common Information Model (CIM)	• Encourage or require use of CIM for DOE-funded research. • Create test bed grid model (load flow, short circuit, protection, etc.) based on IEC 61970 and IEC 61850. • Support standards development that brings PMUs under CIM. • Support standards development that extends CIM to cover gaps.
Cyber Security Requirements	• Define levels of security necessary for data transfer, storage, and access for different data types.

Tools for Grid Operators and Planners

There is need to accelerate the transition of new models and tools from research to implementation. Many demonstrations focus on transitioning technologies from lab to field, but deployment of tools is underemphasized. Additionally, increasing two-way communication and feedback between researchers, software vendors, and users could improve the utility of commercial tools and speed their commercialization. One potential activity would be to form a collaborative team of researchers, software vendors, and users to perform iterative development of a new tool. Researchers can identify what is possible, vendors can identify what is achievable, and users can identify what is usable. Additionally, this process can be used to develop standard processes for coordination of these parties during future tool development.

Tools that properly account for the presence of variable generation (VG), distributed generation (DG), demand response (DR), and new loads are lacking. There is a need to develop stochastic optimization tools incorporating these emerging technologies so planners can pursue holistically designed systems and resource portfolios. There is some existing work in this area—a valuable activity would be to monitor existing work and initiate new efforts as necessary. Additionally, contingency analysis tools that incorporate these technologies and the effects of distribution level behavior are needed. There are a number of disparate pieces of research in this area—they need to be combined with existing operator tools, and the resulting tool needs to be demonstrated to validate its efficacy and reliability. Lastly, a new generation of energy management systems (EMS) must be developed that incorporates these new technologies and the increasing interaction with the distribution system.

The speed of existing numerical algorithms for system identification impedes rapid decision-making and control. Efforts are needed to utilize knowledge from multiple domains (e.g. meteorology, communications) to develop advances in mathematics, computer science, and system identification theory that enable fast extraction of usable information (damping, oscillations, etc.) from PMU data streams.

An effort is needed to examine whether legacy tools have the capabilities required for operation and analysis of the future power system and develop new tools as needed. In addition to the emerging technologies being deployed on the grid, many new entities will enter the space in the coming years, the number of control points in the network will increase by orders of magnitude, and interaction with human agents will grow. All of these elements introduce additional complexity and uncertainty to the system, characteristics which may be incompatible with existing tools.

Tools for Grid Operators and Planners	
Transitioning Research Results to Practice	• Facilitate collaboration between researchers, vendors, and operators. • Assess and improve processes for two-way knowledge transfer between research and implementation.
Next Generation Tools	• Develop stochastic optimization tools for VG, DG, DR, & new loads. • Develop contingency analysis tools that incorporate VG, DG, DR, new loads, and distribution level behavior. • Develop next generation EMS.
Numerical Algorithms	• Develop rapid algorithms for system identification from PMU data streams.
Capabilities Assessment	• Examine capabilities of legacy and emerging tools to handle emerging power system (new entities, new technologies, and more control points, increasing human participation).

Exploration of New Grid Architectures

In order to explore future architectures, metrics are needed for comparing against each other, against the existing system, and against the GTT vision. Efforts should be made to define a means for this comparison (optimization of parameters, agent-based models, compatibility with existing system and existing regulatory framework). Subsequently, possible future architectures in the various domains (physical, informational, control, communication, market) should be identified and evaluated to identify architectures that are appropriate for implementation.

The creation of a software platform that facilitates this investigation of new architectures would accelerate the process, ensure that valid comparisons are made, and broaden the pool of potential architectures by enabling more ideas to enter the space.

Exploration of New Grid Architectures	
Characterization of Grid Architectures	• Define a means for comparing possible architectures. • Identify possible future architectures in the various domains (information, physical, control, communication, market) and compare against GTT vision.
Exploratory Tools	• Create software platform for investigation of possible future architectures.

Miscellaneous Activities

A number of ideas were generated that did not fit strictly into the previous categories. They are outlined briefly below.

- A common definition for "flexibility" is lacking, and impedes the development and technology-neutral evaluation of strategies for increasing system flexibility. Metrics for evaluating flexibility options are similarly lacking. Once a definition and metrics are established, research should be conducted to develop systematic approaches for accessing greater flexibility from existing assets (e.g. reduced safety factors on equipment operation due to greater modeling confidence, cycling of fossil generators, etc.). Lastly, new technologies and operational strategies that contribute flexibility to the system should be developed.

- Technical means for addressing the permitting and land acquisition impediments to building new transmission should be considered. These measures could include examining the utilization of existing rights-of-way for new transmission and evaluating the lifecycle costs and reliability implications of underground transmission.

- Educational efforts are needed to facilitate the adoption of new data streams, tools, and operating strategies and to ensure the full utilization of existing technologies, in particular PMUs.

- Interagency coordination between DOE and other federal and state agencies should remain a priority.

Miscellaneous	
System Flexibility	• Define "flexibility" and develop associated metrics. • Develop systematic approaches for accessing greater flexibility from existing assets. • Develop technologies and operational strategies that provide additional flexibility to the system.
Technical Means for Cost Reduction	• Examine use of existing rights-of-way for new transmission build out. • Examine technical, economic, and regulatory dimensions of underground transmission.
Knowledge Transfer	• Conduct educational activities regarding the capabilities and limitations of existing technologies (esp. PMUs).
Interagency Coordination	• Pursue continued coordination with other federal and state agencies.

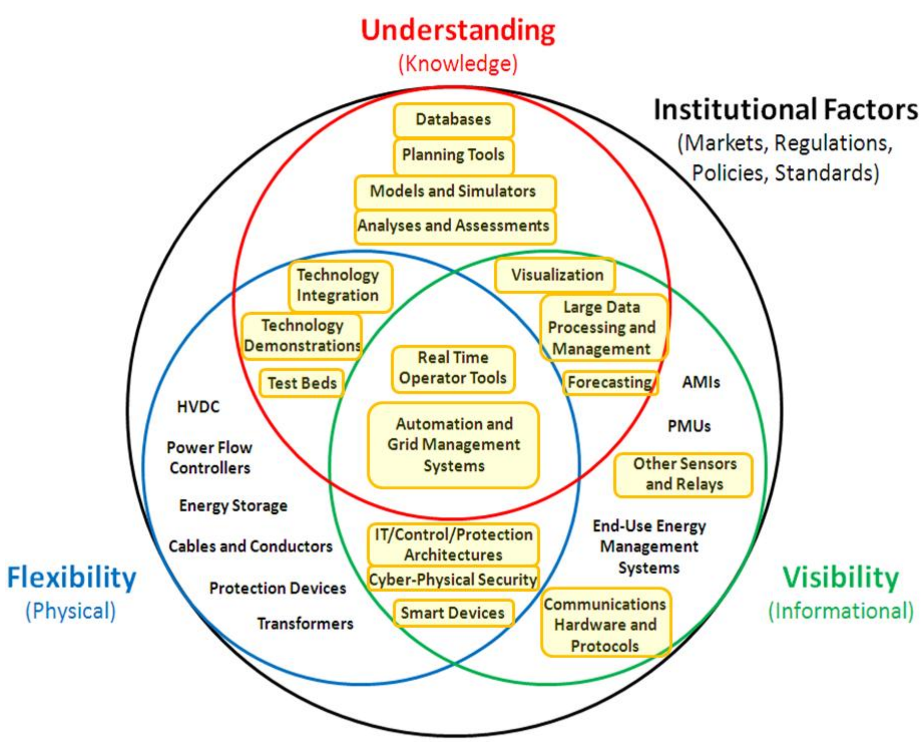
GREEN GROUP

Overview

The discussion began with evaluating the list of challenges as summarized in the previous breakout sessions. The purpose was to validate assumptions, refine ideas, reduce the list into categories of specific challenges, and then suggest R&D actions that DOE could undertake. The group's discussion began with a focus on grid architectures and tools for operational management. There was some disagreement on how to categorize data management and metrics. Some contended they could be in the same R&D portfolio, while others suggested that metrics needs a standalone R&D program. The discussion moved on to data management and processing data into actionable intelligence. The group emphasized the importance of forecasting and the use of models and test beds to help stakeholders understand the quantifiable values associated with different aspects of the transmission system.

Discussion Summary

By taking an inventory of topics discussed in the breakout session and comparing it to the DOE Grid Tech Team's Vision Framework for the 21st Century Electricity System, the focus of much of the group's remained on grid "understanding." Of the three overlapping areas, understanding was the only one whose topics were completely addressed. Visibility remained a close second, and flexibility was last, although it was strongly noted that some of DOE's R&D efforts should be applied towards physical components and aspects, and not just modeling tools. This less intense focus may have been in part because the group expressed some confusion, or at least some dissatisfaction, with the scope of the GTT definition of grid flexibility.



Key Opportunities

The key items that came out of the breakout group discussion were captured, organized, and consolidated onto slides that were later presented to the broader workshop. The result was a targeted set of challenges that best described the most critical aspects of modernizing the electricity transmission system. Those key areas are:

- Advanced Models and Operational Tools
- Metrics for Flexibility and Enhanced Reliability
- New Grid Architecture Paradigms
- Big Data

Advanced Models & Operational Tools

The way in which the current electricity transmission system functions makes it very difficult for operators and stakeholders to synthesize, process, integrate, visualize, and validate data for actionable intelligence. There is a significant gap in understanding that could be greatly improved with validated models (and methodologies) as well as simulation algorithms to explore new dynamics, concepts, and technologies. Furthermore, the future grid will require adequate tools to help operators perform credible analyses over multiple scales in space and time.

Metrics for Flexibility and Enhanced Reliability

It is one thing for operators and stakeholders to say "Yes, our system is reliable" or "Yes, our system is flexible." It is another challenge altogether for them to describe in detail *how* reliable or *how* flexible the system is. This challenge is amplified by the ambiguity of what it means for the system to be both reliable and flexible. By defining what those aspects of the system are, as it applies to the entire grid or in regions, it will be easier to develop clear metrics for detailed assessments of the transmission system's reliability and flexibility. Such metrics may also be used to compare the relative value of two or more technologies provide a similar service—e.g., comparing the benefits and value of different storage technologies.

New Grid Architecture Paradigms

The structure of a modernized transmission system needs to reflect important new dimensions including communications architecture, markets and two-way communications with loads. This new architecture must account for the integration of information management, controls, communications, and physical (system, holistic, stochastic) aspects of the system.

Big Data

A modernized electricity transmission system must resolve what to do with the massive amounts of data that could—and should—be sampled and stored. Looming questions remain unanswered regarding the ICT/sensor systems needed for the future grid and advanced applications. There is also a significant need for improved understanding of the availability, utility, maintenance, exchange, and security of data and associated requirements.

Specific opportunities for DOE R&D programs are summarized in the following tables.

Advanced Models & Operational Tools
a) Develop high performance computational methods for large, high resolution models of future grid (close to real time)
b) Create R&D program to transition grid tools (planning and operations) to parallel computational architectures
c) Develop central data monitoring / sharing function to track vulnerabilities
d) Research to ID requisite data/model fidelity to virtualize full grid simulation (power, markets, loads, extreme events)
e) Develop advanced methods and metrics for forecasting tools (weather, load, generation, fuel supply, other infrastructure interdependencies)
f) Expand and Improve operations and planning utilization of forecasts
g) Develop integration/interoperability strategies and methods for grid modeling suites (validation, verification)
h) Develop enhanced impact valuation tools to inform policy and business decisions (to better reflect emerging public goods benefits from future grid)
i) Develop platform to model and evaluate communication platforms
j) Research design and operation of data platform contingencies to enable future operations, control and cyber security of grid
k) Develop national test bed to simulate cyber-physical system of future grid (super-size); in coordination with federal and National Lab / academic resources
l) Develop Multi-scale modeling platform development (temporal, spatial, physics)
m) Support R&D to enhance cyber resilience of grid

Metrics for Flexibility and Enhanced Reliability
a) Accommodate increased intermittent generation (includes geospatial diversity) b) Accommodate intelligent, response load c) Adapt to changes in fuel / generation mix d) Deliver customer needs in reliability, quality, cost e) Explore the value of new business models f) Evaluate common fault risks of interdependent infrastructures
New Grid Architecture Paradigms
a) Using DOE's convening ability, help to frame vision for future grid (2050) b) Develop innovations in balancing area (BA) coordination for operational and interconnection level planning c) Develop methods for cost/benefit analysis of BA innovations/changes d) Develop operations/control methods for dynamic/stochastic grid of future that meet desired attributes / outcomes e) Research distributed, hierarchical control (vs. traditional) enabled by real-time monitoring and distributed intelligence f) Develop advanced cost-effective controllable devices / controllable transmission g) Develop transactive control concepts to engage demand and distributed resources optimally h) Develop inherently cyber / physical secure grid architecture i) Establish research on load characterization and consumer response elasticity j) Research interdependency of grid with NG, water and communications systems k) Research system reliability impacts of fuel / generation scenarios of future l) Develop "grid friendly" standards for devices to fulfill "desired attributes" of future grid (e.g. loads, generators, storage, etc.) (reactive power, frequency response, ramping, voltage collapse)
Big Data
a) Develop enhanced data analytics to inform operations & planning b) Develop open data sets for planning, operations, R&D, policy analysis (standardization for data exchange) c) Develop advanced data management concepts for quality, curation, validation and delivery d) Develop test bed for advanced data networks for testing, interoperability e) Develop next generation information networks for high speed time-synchronous data to real-time operations and control (NASPInet and beyond) f) Develop advanced visualization for real-time tools g) Develop "plug and play" data acquisition technologies that are "all hazards" resilient

CONCLUSION & NEXT STEPS

The Transmission Workshop was a productive engagement with electricity-sector stakeholders, and generated very thoughtful outputs. The information gleaned from the workshop, as described in this document, will play an important role to inform the development of a research and development roadmap. These findings identify key challenges and opportunities associated with grid-integration at the transmission level.

This document does not complete DOE's collection of input regarding the modernization of the electricity transmission grid. This document, along with the *DOE Action Plan Addressing the Electricity Transmission System* and other reference inputs will inform the decision-making process to help guide research and development investments over the next five years.

This document will be released in draft form with a formal request for information. These and other inputs to the road-mapping process will help support the broader efforts of the Grid Tech Team to identify key research and development activities to achieve a 21st century grid.