Advanced Circuits, Controls, and Protection for the Distribution System of the Future

Progress and Plans for Utility Host Selection

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Technical Update, December 2007

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REPORT SUMMARY

EPRI's Advanced Distribution Automation (ADA™) Program is developing the technical foundation for the distribution system of the future. ADA is a concept for a fully controllable and flexible distribution system that exchanges both energy and information between system components. The result is a highly automated, responsive, and resilient distribution system that delivers benefits to a broad range of participants.

This specific project will assess advanced distribution circuits, controls, and protection and document them for sponsor use. Assessments will include both technical and economic issues. Assessments will be done in partnership with host utilities that are planning to field test key new distribution system capabilities.

Results & Findings

In 2008, the project scope will be broadened relative to prior years, and the project title will be changed to *Advanced Circuits, Controls and Protection for ADA*™. The broadened scope will address assessments of advanced circuits, controls, and protection and document results for sponsor use. Assessments will be conducted in partnership with host utilities. Hence, in 2007 efforts to identify host utilities with whom EPRI will team were begun. This work will continue into 2008, and actual teaming will begin in 2008. A request for information was developed to seek utility hosts for field testing, and a proposal was submitted to the Department of Energy (DOE) to seek collaboration with their program.

Challenges & Objective(s)

As noted, 2007 was a transitional year, going from a narrow project scope (focused mainly on integration of distributed generation into distribution design) to a broader project scope. Concepts for distributed generation integration are still within the scope of the project. However, the broadened scope is more practical in that distributed generation integration should be done in concert with other distribution system advances to achieve necessary interoperability and best system performance results. In other words, distributed generation integration should not be isolated from the larger body of advances happening in distribution system technology.

Applications, Values & Use

Electric utilities will use the results of this project to aid in automating their distribution systems based on an improved understanding of available options and knowledge of actual field experience. They will achieve better practices in implementing ADA and will do so by more efficient development processes. Through the advanced systems, they will realize significant gains in energy efficiency, system reliability, outage management, and a variety of customer services. These, in turn, will improve customer satisfaction and demonstrate to the public and regulators that a serious effort to improve energy efficiency is being made and that utilities are

good stewards of environmental resources. The results can be used at all levels of automation, ranging from a utility just beginning to automate to a utility doing advanced automation of an entire distribution system.

EPRI Perspective

As utilities modernize their distribution systems to include wider use of ADA, they need to assess relevant distribution circuit configurations and reconfiguring capabilities, including associated control and protection systems. They also need to better understand the value of these emerging capabilities and the ways they can be most effectively used in advancing future distribution system development and operations. Utilities also need to conduct actual field experience assessments of emerging capabilities to understand advantages and disadvantages of specific capabilities in specific cases. In this project, EPRI is organizing a coordinated activity to support utilities in this assessment work through a collaborative R&D effort.

Approach

Working with project sponsors, EPRI will identify key emerging circuit configurations, reconfiguring approaches, and associated protection and control techniques that merit field evaluation. Concepts will be screened as to their functionality and performance specifically in ADA and advanced distribution system operations. New concepts in which there is high interest will be prioritized, and available project funds will be applied to field experience assessment activities in order of priority, up to the limit of available funding. The work takes advantage of prior EPRI requirements definition and design work on advanced circuits, protection, and control for ADA and past utility projects. The objective is to complete a round of field assessments every two years.

Keywords

Advanced distribution automation
Distribution system of the future
Distribution circuits
Distribution systems
Distribution system control
Distribution system protection

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INTRODUCTION

EPRI ADA™ Program objectives

EPRI's Advanced Distribution Automation (ADA™) Program is developing the technical foundation for the distribution system of the future. ADA™ is a concept for a fully controllable and flexible distribution system that exchanges both energy and information between system components. The result is a highly automated, responsive and resilient distribution system that delivers benefits to a broad range of participants.

ADA™ will be a "revolution by evolution" in which utilities migrate to the distribution system of the future over time via incremental adoption of the needed technologies, software, and standards.

EPRI's ADA™ roadmap [1] identifies five key areas of development needs (functional areas) for R&D project to realize the ADA™ vision:

- Electronic/electrical technology development for the distribution system of the future
- Sensor/monitoring systems for ADA™
- Communication systems and standards for ADA™
- Advanced distribution system controls
- New distribution system configurations and reconfiguring capabilities

The relationships between these areas are illustrated in Figure 1-1. The EPRI ADA™ Program consists of a group of projects that address these five areas. The EPRI project covered by this technical update report addresses the final two areas in the list above.

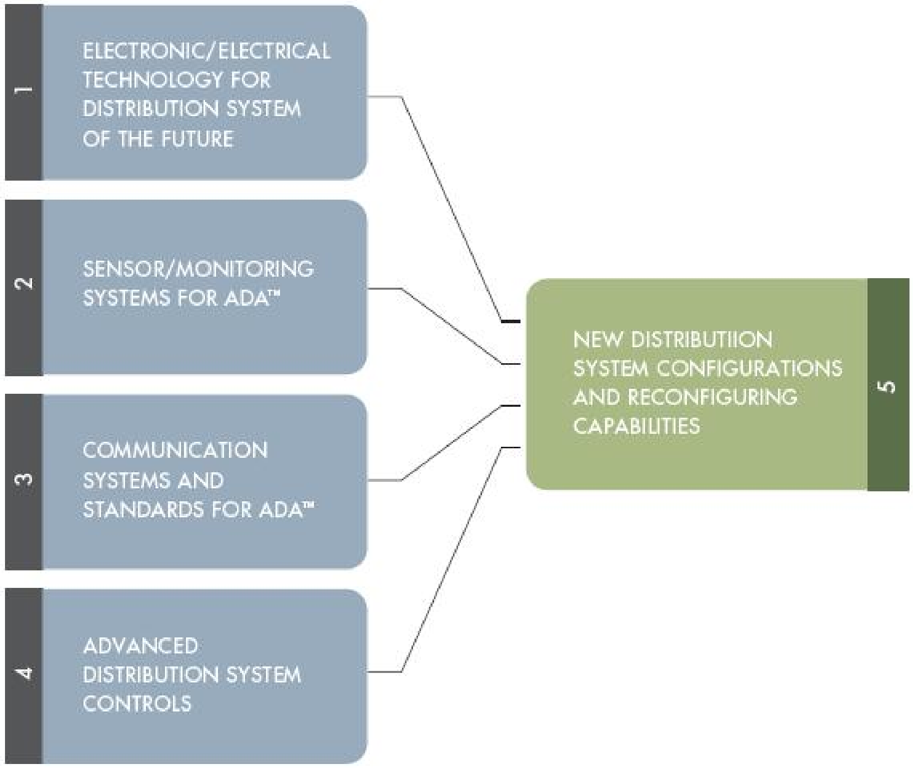

Figure 1-1
Areas of development and relationships of the ADA™ program

The Distribution System of the Future will be based on ADA™ that includes two key aspects:

- ADA™ will enable new system configurations and reconfiguring capabilities, which will increase the flexibility and reliability of the distribution system, as well as aid in preventing outages or recovering from outages that do happen.
- ADA™ will enable integration and strategic use of new intelligent electric devices (IEDs) embedded in power electronic components, advanced volt amperes reactive (VAR) management systems, power quality enhancement equipment, distributed generation, and fault anticipators. These IEDs not only enable the more flexible electrical architecture mentioned above, but also provide the means for expanded customer service options. These IEDs also act as components of a larger monitoring system capability. Integration of an Advanced Metering Infrastructure (AMI) will also be a key component in the monitoring system infrastructure for ADA™.

While this project is focused on the fourth and fifth areas above, it is highly interactive with the other projects in the EPRI ADA™ Program, especially the evolution of real-time monitoring systems for the distribution system of the future.

Project scope of work

As utilities modernize their distribution systems to include wider use of advanced distribution automation (ADA™), they need to assess the relevant distribution circuit configurations and reconfiguring capabilities, including associated control and protection systems. They also need to better understand the value of these emerging capabilities, and the ways they can be most effectively used in advancing future distribution system development and operations. Utilities also need to conduct actual field experience assessments of emerging capabilities to understand the advantages and disadvantages of specific capabilities in specific cases. In this project, EPRI is organizing a coordinated activity to support utilities in this assessment work through a collaborative R&D effort.

As an initial step in the project, EPRI did requirements assessment and conceptual design work for integration of distributed generation into the distribution system of the future. This included addressing the circuit configuration, control, and protection requirements. The prior work is described in Section 2 of this report. Whereas a broader scope on new circuits, control and protection was originally planned, the focus was kept on distributed generation integration due to budget limitations.

Looking ahead into 2008, the broader scope that was originally planned is restored by changing the approach for doing the project. EPRI will team with utilities planning to test advanced concepts in advanced distribution circuits, control and protection and provide technical input to test set-up, analysis, and evaluation procedures. EPRI will provide a technical transfer and information exchange function between the utility hosts and the funders of the EPRI work. EPRI will develop reports to document the results and provide guidance for widespread adoption of concepts that appear promising from the evaluation work. The utilities will fund the hardware implementations and perform staged and operational testing. This approach is believed to be commensurate with the funding levels coming into the EPRI project. EPRI will also seek funding from DOE and other sources to enable a larger number of advanced concepts to be evaluated.

2007 is a transitional year in going from the narrow to the broadened scope. It is noted that concepts for distributed generation integration are still within the scope of the project. However, the broadened scope is more practical in that distributed generation integration should be done in concert with other distribution system advances in order to achieve necessary interoperability and best system performance results. In 2007, efforts to identify host utilities with whom to team were begun. These will be described in subsequent sections of this report. This work will continue into 2008 and actual teaming will begin in 2008.

In 2008, the project title is changed to '**Advanced Circuits, Controls and Protection for ADA™**' and addresses assessments of advanced circuits, controls, and protection, and documents them for sponsor use. The assessments include both technical and economic issues, and are conducted in partnership with utilities that are planning to field test key new capabilities. Working with project sponsors, EPRI will identify key emerging circuit configurations, reconfiguring approaches, and associated protection and control techniques that merit field evaluation. The concepts are screened and prioritized as to their functionality and performance in ADA™ and advanced distribution system operations. Examples include feeder autolooping approaches and intentional islanding of distribution circuits with sufficient distributed generation. The work takes advantage of the prior EPRI requirements definition and design work on advanced circuits, protection, and control for ADA™ and past utility projects in the area. The objective is to complete a round of field assessments every two years.

This project must be closely coordinated with another EPRI project '**ADA™ Monitoring System Infrastructure and Integration**', which addresses the development and evaluation of monitoring systems for ADA™ and the distribution system of the future. In past work in this project, a requirements definition and design basis were developed for the real-time ADA™ monitoring system. This work included determining the monitoring system objectives, its functions, technology options, and a general system design. The monitoring system is to be based on use of off-the-shelf technology wherever possible. The monitoring system will require integration of information from a wide variety of technologies and systems. This will include various IEDs throughout the distribution system, new sensor technologies that provide low-cost monitoring of specific signals, and widespread AMI. A key aspect of the monitoring systems will be to integrate data from AMI, which one utility has called "the ultimate supervisory control and data acquisition (SCADA)." In the next phase of the project, the design basis is used as a framework for testing and evaluating specific components, data processing capabilities, and other features identified as needed in the design basis. The project evaluates these monitoring system features and prepares for system integration into a final monitoring system specification.

The principal emerging international standard for communication architecture for real-time automation of distribution systems is IEC 61850. To achieve cost-effective interoperability of the large number of components in the monitoring systems, the components need to be migrated to this standard (at least in terms of having standard information models for the information being collected). EPRI will continue its involvement in this standard development and work with vendors and utilities to develop a rational plan for migrating monitoring system components to conform to IEC 61850 and report the status of the standards work as part of this project.

The monitoring system will also incorporate capabilities emerging from other EPRI projects as they become available, such as the Distribution Fault Anticipator (DFA) and embedded monitoring capabilities in devices such as the EPRI Solid-State Switchgear System (the 4-S) and the intelligent universal transformer (IUT). Vendor and utility cost sharing are sought for the field testing and evaluation of specific monitoring system features. Due to the time needed to set up these teaming arrangements, as well as test and evaluate monitoring system features, the next phase is a two-year project. Following this phase, a final report will be prepared that presents the findings and integrates the results into a specification for ADA™ monitoring systems that sponsors can use to procure entire systems. Based on member need and interest, a second round on monitoring system evaluations may then be initiated using the same process to evolve a specification for a second-generation system.

The value provided by these interrelated projects includes:

- Provide the basis for integration of distributed resources (generation and storage) with distribution operation
- Optimize real-time system operations, prevents outages, and aids in basic automated operations in the near term
- Increase energy efficiency, reduces O&M costs, and increases system security

- Help utilities begin to automate or more fully automate their systems, which in turn improves energy efficiency of distribution operations, because ADA™ improves overall system performance and energy throughput
- Improve system functionality, allowing better power quality and a wider variety of customer services to be delivered to customers
- Enable automated response to mitigate outages or speed recovery from outages
- Improve interoperability of increasing diverse distribution system components
- Support migration from legacy proprietary systems to open systems based on international standards
- Improve decision-making among the choices for the technology, software, sensor, data processing, AMI, and system integration options that a utility may adopt

2 GENERAL APPROACH

Previous EPRI work in this project

Distribution System Design for Strategic Use of Distributed Generation (2005)

This project was undertaken to identify distribution system design characteristics that limit widespread distributed generation (DG) penetration in utility distribution systems and to suggest new system design paths that increase strategic use of DG by distribution system operators. For the shorter term, the 2005 report [2] outlines impact studies and integration techniques that should work for low-penetration scenarios. For the intermediate term, utilities can gain significant power quality and distributed resource benefits through relatively inexpensive changes to their protection systems. Feeder-level and substation-level controls can also evolve toward the full mini-grid and micro-grid concepts. EPRI can facilitate this evolution by making sure that IEC Standards 61850, 61968, and 61970 all support the necessary DER impact studies and adaptive control/protection schemes.

DER-limiting features of distribution systems

With the recent advances in distributed generation (DG) technology and reduction in DG unit costs, DG is expected to play an important role as a vital in the distribution system of the future. DG has much prospective strategic value in improving the reliability and the economics of the distribution system. Yet, there are many barriers that can prevent proper operation of distribution systems with heavy DG penetration. Some of these barriers are design characteristics of current distribution systems and others are operation and maintenance characteristics, regulations and lack of adequate tools for distribution engineers. Examples are:

- Limitations of Distribution System Protection
- Interaction between Voltage Regulators and DG
- Interaction between Capacitor Banks and DG
- Limited Functionality of Current Distribution Systems SCADA
- Limitations of Commercially Available Distribution Systems Analysis Software
- Regulatory and Business Environment
- Limitation of Distribution Network to Support Intentional Islanding
- DG Response during Network Disturbances

- Thermal Rating Limitations of Distribution System Equipments
- Limitation of Installing DG units on Secondary Spot Networks
- Power Quality Problems
- DG Grounding and Transformer Connection Issues

Distribution system re-design path

The 2005 report also describes the long-term evolution of new distribution system designs that can accommodate high penetration levels of DG. The objective is to identify staged system redesign actions to be taken by the utility to insure safe penetration of DG into their networks and to fully take advantage of DG units as one type of IED in a coordinated future distribution system. One of the key factors to determine the success of this transition into the advanced distribution system is to develop a multi-layered hierarchy for protection, control, monitoring and analysis based on intelligent solutions and communications.

One key principle is to define the system's control hierarchy so that it supports controlled separation into relatively balanced sub-systems at each level. This will reduce, or even eliminate the effects of wide area system disturbances on most of the customers. Taking another look at the power system hierarchy, several components of the power system hierarchy are defined, from the point of view of power system control. See Figure 2-1.

- Bulk and transmission systems: they are the backbone of the system.

- Transmission System Islands: these typically form as a result of the tripping of multiple bulk or transmission lines that isolate a sub-part of system from the rest. Since this is an uncontrolled action, it is rare that even an approximate load – generation balance is achieved at the time of islanding

- The Sub-Grid: the Sub-Grid is a new concept that can be defined as a controlled transmission island. Based on continuous monitoring of the load and generation in different areas of the system, in case of an emergency the power system can be split into Sub-Grids with a relative balance between the load and generation. Under normal conditions all Sub-Grids operate in parallel as part of the power system. Each Sub-Grid contains one or more Mini-Grids (mGrid). Each Mini-Grid contains one or more Micro-Grids (μGrid). This concept is also sometimes described as a ***cellular distribution system***.

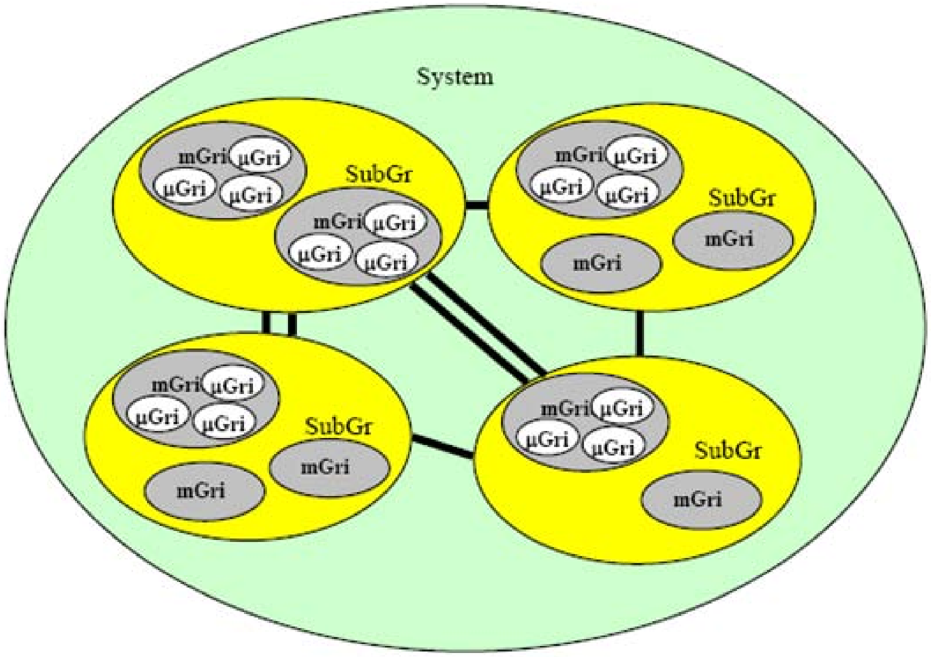

Figure 2-1
Power system hierarchy

- The Mini-Grid: the distribution system of a substation can be defined as a Mini-Grid. It can be isolated from the rest of the power system when all power transformers are taken out of service due to fault, abnormal system condition or intentionally in order to reduce the effect of a wide area disturbance on the distribution system. A Mini-Grid will typically include one or more distributed generators or wind parks connected directly to the distribution feeders, with a goal to sell energy to different users in the Mini-Grid. It will also include one or more Micro Virtual Power Station (μVPS). A Micro Virtual Power Station in this case is defined as the total power produced by all distributed energy resources in a Micro-Grid.

- The Micro-Grid: Micro-Grids include one or more distributed energy resources of different types and, depending on their output, may support the full load of the facility, or a subset of critical loads in case of separation from the Mini-Grid. If the total output of the μVPS is more than the load at any moment in time, the Micro-Grid will export power to the Mini-Grid.

EPRI Design for First-Generation Advanced Radial Feeder for the Distribution System of the Future (2006)

In 2006, a standard IEEE radial test feeder, with added wind power DG amounting to 75% of the feeder load, was modeled and analyzed for voltage control, fault protection, and power quality (flicker) problems. Existing software tools were used to conduct the study as a utility engineer might conduct it, but with software enhancements made to support this project. The result showed that DG poses little impact on fault protection for this example, but it requires adaptive voltage control and some flicker mitigation. An ADA™/DG feeder design was designed, to include seven IEDs (at the substation, two line regulators, two capacitor banks, and two DG sites), with low-cost communication links for each IED. An eighth IED in the substation would be custom-programmed to implement the adaptive voltage control settings. Low-cost (i.e., slow and less reliable) communication links are acceptable between these IEDs, since the links are not involved in fault protection. Flicker mitigation would be done with modifications to the wind turbine control system, or perhaps by installing a DVAR. There are no IEDs compliant with IEC 61850 available for applications out on the feeder. Therefore, DNP3 mappings to the IEC 61850 object model were prepared for two such devices, a line regulator and a capacitor bank controller. This allows the voltage control algorithm to be implemented entirely in the IEC object model.

Advanced Distribution Circuits Development Plan Description

The 2006 report [3] recommended the following tasks be performed in the next phase of the project which was to encompass the advanced distribution circuits design, field development and experimentation. The objective was to apply the concepts of the advanced distribution circuits developed in the first stages of the project in order to produce and extrapolate technical and economical analysis for the studied cases.

Task 1 Feeder Characterization

This task will consist in conducting an up-to-date and more detailed analysis of the feeder circuit based on the programmatic feeder characterization criteria. The output of this task should be a well documented description of the feeder or circuit into consideration including general issues applying to it (objective, geographical specificities, regulatory issues) and all the technical information needed to characterize it.

Task 2 Development of Solutions (systems and/or equipments), Requirements and Specifications

This task will include documentation of the system and/or equipment requirements and specifications for the development of the advanced distribution circuit procurement packages in Task 3. More precisely, an assessment of the needs and corresponding specifications for the system and/or equipment to be installed on the identified circuit will be made taking into account all the specificities defined in the Task 1.

Task 3 Develop Testing Protocols

The objective of this task is to develop the test protocols and test plans for operating the system and/or equipment of technology applications. Test and operation plans will be developed initially for each of the system and/or equipment and then an integrated operational test plan will be developed. The testing will include acceptance testing of all systems and/or equipments by both the vendor and the utility. Commissioning tests include making sure the systems and/or equipments functions as intended are in place and that all primary interoperability requirements are met. This task will develop testing protocols and supporting modeling efforts to analyze the contribution of the systems and/or equipments provided to the distribution circuit.

Task 4 Procurement Packages for Designated Feeder/Circuit(s)

This task will coordinate and document the development of the procurement packages for the specified systems and/or equipments based on the previous tasks results. This will also include all the interoperability issues needed to integrate the systems and/or equipments into the existing circuits.

Task 5 Economic and Business Case Analysis

The project team will conduct economic and business case analysis for the systems and/or equipments integration demonstration. The initial effort will develop an initial estimate of the potential benefits of the project during the project development period, and then in task 8 verify the benefits and business case(s) after the project has been in operation for 18 months. The utility teams will provide data and analysis to determine benefits.

Task 6 Acceptance Testing

Implement acceptance testing with vendor based on protocols developed in Task 3.

Task 7 Commissioning Testing

Conduct commissioning tests based on testing protocols developed in Task 3.

Task 8 Feeder Operation, Testing, Integration, Optimization and Benefit Analysis

Under this task the project team will conduct tests and measure the system and/or equipments benefits. An 18 month test and demonstration program will be implemented. The project team will measure, collect, organize data and results to conduct analysis in a consistent manner. The project team will examine the distribution system operating impacts of the functional uses of the system/equipment to provide strategic value to distribution operations, based on the results from the experimental testing at the utility team members host sites.

The salient features of the tasks recommended above will be carried forward in the expanded approach for the project in 2008, except that EPRI will team with utility hosts for specific advanced concepts, as was discussed in Section 1 of this report.

Future Work

The purpose of the work is to use the results of the testing at the host utilities to support the evolution of future distribution systems with new active distribution system components. This work supports the ongoing development of active distribution management systems and/or equipments, especially through the field evaluation of important active distribution management functions in real world systems and the use of these demonstrations to develop simulation models that can be used to extrapolate the application of the technologies to a much broader range of applications--for both benefits assessment and evaluation of technical issues.

Objectives

The main objectives of the work that will be carried out by EPRI are:

- To support the utility members of the team in definition and implementation of test activities to evaluate their chosen concepts for advanced circuits, control, and protection.

- To obtain data from the utility tests that can be used to develop simulation models for the associated technologies that can then be applied in other applications for assessment of benefits and technical issues. These models will be coordinated with simulation architecture and model guidelines being developed by the Grid-D development team, under the Grid Modernization Collaborative (GMC). Rob Pratt at Pacific Northwest National Laboratory is the contact for this transfer of information to Grid-D.

- To perform analysis of test results to assess the value of specific concepts for advanced circuits, control, and protection.

- To use the extended testing and system evaluations of the advanced concepts to verify models and benefits.

- To use the experience gained from the extended testing and modeling to develop initial guidelines for widespread use of promising concepts. These guidelines will include important technology elements - consistent with the principles of the Gridwise Architecture Council (GAC). Results on domain information that is needed by standards groups developing communication architecture standards will be provided directly to the standards working groups. Results pertaining to the IEEE SCC21 standards will be provided to the appropriate working groups under SCC21.

Scope of future work

The plans developed in 2007 will be implemented in 2008. The overall information flow in the work is shown in Figure 2-2. Host utilities will perform testing as shown on the left. EPRI will help plan these tests, and EPRI will conduct the assessment and analysis work in the middle block of the figure (modeling, simulation, assessments for broader applications, guidelines and information model inputs). The field trial results will be used to generate guidelines for widespread adoption of promising concepts. The results of this assessment work are then disseminated in the deliverables, as shown in the right-hand blocks.

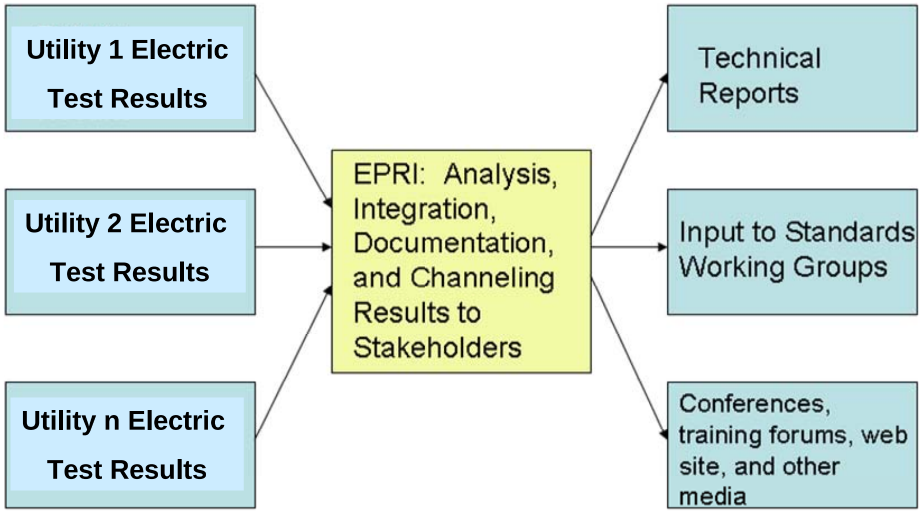

Figure 2-2
Information flow for the coordination work

The input to EPRI coming from the utility test cases will be provided by the utilities themselves and by other team members.

Sponsors' Advisory Committee

EPRI will organize and manage an advisory committee to provide overall technical guidance to the project and a coordinating and integrating function among the several utility host situations where testing is performed.

Develop Case-Specific Advanced Concepts for Test and Evaluation

EPRI will work with the host utilities to become familiar with their individual chosen approaches for advanced, circuits, control, and protection. EPRI will provide technical guidance to the utilities to help with the establishment of an evaluation process for the effectiveness of their chosen concepts in terms of long-term needs of the distribution system of the future.

Simulation System Development for Performance Assessment and Extrapolation

EPRI will work with the utility to collect information needed from the systems to support advanced simulation concepts and modeling that can be used for detailed performance simulations and assessment of these technologies in broader applications (for benefits assessment, for instance). This simulation capability will use existing tools, like the EPRI Distribution System Simulator (DSS) as a foundation for the work, as well as coordinate with the capabilities of existing commercial distribution simulation tools. The development will be coordinated with the collaborative distribution system modeling effort called the Grid-D, that has been organized as a lead-off activity in the Grid Modernization Collaborative (GMC), so that they can be plugged into the overall Grid-D simulation structure.

Documentation of Implementation Plans for Demonstration Projects

EPRI will work with the other team members to write implementation plans for the testing that addresses the following items:

- Tests to be performed, including objectives, approach, and data sought.
- Data to be recorded and pre-test analysis to be done.
- Post-test data reduction and analysis.
- Identification of linkages to subsequent assessment work.

These plans must be completed and ready in advance for implementation during the extended operational testing of the host system and/or equipment.

Performance Assessments Based on Results of the Extended Operational Testing of Systems

EPRI will assess the performance of the advanced distribution system concepts, using the results coming from the extended operational testing in accordance with the plans developed. The performance will be evaluated in terms of ability of the system and/or equipment to achieve the functions that were intended. The performance assessment will also examine the suitability of the selected approaches for more widespread application and integration using open architecture concepts.

Optimization Approaches for Active Distribution Management in Overall Distributed Control of Distribution Systems

The results of the performance assessment and other analyses (simulations that extrapolate the results to a wider range of applications, etc.) will be used to identify how to optimize strategic value of the system and/or equipments to distribution system operations, as well as for overall system benefits. This information will then be used to develop recommendations for active distribution management systems that are adaptable to distribution systems with widely varying characteristics.

Reliability and Power Quality Impacts

EPRI will examine the distribution system reliability and power quality impacts of the functional uses of the system and or/equipments to provide value to distribution operations, based on the results from the experimental testing at the utility team members host site. The assessment will use the simulation models to extend the analysis beyond the example systems and allow for the development of general guidelines.

Requirements Definition and Preliminary Information Model Development for Active Distribution System Management and Control

This work will build on the tremendous information from extended field tests to prepare guidelines for future active distribution management systems. The model development and simulation effort described above will provide additional information on the benefits and technical issues associated with the application of these technologies on a broader range of systems. The final step is to combine these results to identify the key requirements for the technologies from a generic sense and use these requirements to generate initial information models for their application as part of overall distribution management systems. Generic requirements for active management and control systems will be compatible with future distribution system operations, including circuits and substations that have varying levels of DER from 0% penetration all the way up to 100% penetration, as may be achieved in an islandable circuit. Integration of all major types of active distribution components will be included in developing recommendations for active distribution management systems. A requirements definition for future active distribution management systems will be performed, addressing the following attributes:

- **Real-time monitoring system requirements**: Active distribution management will require distributed monitoring that can provide information about continually changing conditions in real time to distribution management systems. The monitoring system must provide feedback on control actions as well as on normal variations in system conditions. Monitoring of all active components (switchgear, capacitor banks, DER, etc.), either directly or indirectly, is necessary for coordinated interoperability with the rest of the distribution system components. This subtask will examine the requirements for active real-time monitoring, including use of the active components as nodes in a real-time monitoring system. The active components can contribute to the overall monitoring of the distribution system in that they have status information on voltage, current, power factor, climatic conditions and other parameters at their sites that can be use to support strategic operations.

- **Communication interface and information models**: To achieve interoperability in the distribution system environment with other active distribution components, it must be easy to hook all active components up to a common, standardized communication infrastructure. All components need an embedded information model (also called object model), that enables easy integration to the communication infrastructure and avoids the need to custom engineer a communication system for every case. This assessment work will seek to identify the information modeling and standardization needed for active management and control systems. This will encompass the standardized modeling needs for the active components, other monitoring system components, and the active management and control system devices. The principal body of relevant communication architecture standards is IEC 61850 and IEC 61970 under IEC TC-57.

- **Data processing requirements**: The distributed control of active components and the rest of the distribution system will require that the large amount of data coming from the monitoring system be processed to determine what is happening in the distribution system and what control actions are needed. Hence, an adaptable data processing capability is needed to filter out key event information and support the control system in taking actions according to predetermined algorithms.

- **Simulation tool requirements**: Active distribution management and control will require advanced analysis tools for planning and design, as well as state estimation tools to support the control system. It is possible that similar platforms can form the foundation of both types of simulation tools. This is the basic principle of a “common information model”. Advanced simulation tools will be developed and evaluated in this project and guidelines for simulation needs in the planning and design stages (e.g., benefits assessment and technical design evaluations) will be developed.
- **Algorithm requirements**: The algorithms execute active management and control based on information coming from the monitoring and state estimation tools. Algorithms will be continually improved based on available information and tools. The important need is to provide the flexibility to plug in new algorithms as they are developed based on overall information models and integration guidelines.
- **Compatibility with emerging concepts in distributed and central control for distribution systems**: Distributed control for future distribution systems is a topic with a high level of interest. The vision is to have a local controller for a circuit or group of circuits. The local control must be able to handle all active component functions and all the strategic uses of DER, such as emergency power, peak shifting, VAR support and others, at differing penetration levels. It has long been believed that DER will be more valuable for its distribution system support functions than for its gross energy production. However, to be successful the active management system must achieve coordinated interoperability of DER and other active components. For example, the use of DER for VAR support must be coordinated with the dispatch of other VAR resources, such as capacitor banks. This assessment will determine how to align the projects results to support the work on distributed control that is underway elsewhere. It will aid the developers of relevant technology and software in improving their products.

3
PROGRESS AND PLANS

Utility teaming process

General

In order to perform the next phase of the project, a Request for Information (RFI) is being produced to obtain utility hosts. This document outlines a detailed specification for future project phases of the project. The ***work scope*** of this specification encompasses design, field development, and experimentation for advanced distribution circuits, control and protection. Advanced distribution concepts imply distribution systems conceived differently from the traditional ways allowing them to integrate and manage:

- Distributed generation and storage
- Demand response and energy efficiency measures
- Innovative distribution automation architectures and functions
- Distribution monitoring system to know the state information, throughout the system.
- Data processing capabilities to handle large amounts of real-time data.
- AMI data to improve distribution operations
- New automated protection schemes
- Simulations tools to do state estimation and determine dispatch actions.
- Control systems, including control algorithms to dispatch the active components and achieve the desired real-time distribution management functions.

This RFI will be aligned with the project's multiyear plan. In particular, the project's broad steps are as follows:

- o Characterize distribution circuits for integration of new components in the future distribution system designs and develop analytical models that can be used for distribution assessments (both technical and economic analysis).
- o Develop models to assess the technical issues of the integration of the new system or equipments in the existing network.
- o Develop economic and business case analysis to support future deployment.

- o Test and validate the use of the new circuit, control, and protection concepts to be integrated into future distribution systems and the associated communication and interoperability issues.
- o Advance the use of standard communication /control systems and protocols for active distribution system management.
- o Develop simulation models and approaches for evaluating integration issues and cost/benefit assessments, and validate these models and approaches with the variety of demonstration efforts in this project. Integrate these modeling efforts with parallel distribution system modeling initiatives.
- o Develop tools and information to aid utilities in widely adopting the concepts that appear promising.

Additionally, as will be discussed later in this section, EPRI has submitted a proposal to DOE in partnership with three utilities to seek funding for testing and evaluation of three different approaches to active distribution system management in three different host situations. This is a supplemental step to the RFI for seeking host situations. EPRI will monitor activities in the industry continually to watch for new advanced concept field trial opportunities to add to the project (such as was done with the DOE proposal).

Objectives and process for the solicitation

EPRI is preparing an RFI for utility host situations for testing advanced concepts for advanced circuits, control, and protection. Based the opportunities offered by responses to the RFI, EPRI will choose specific cases for inclusion in the project. In responses to the RFI, prospective hosts will be asked to provide key information on the host situation, including:

- What advanced circuit, control, and protection concepts will be tested?
- What are the location and characteristics of the distribution system in which the test will be performed?
- What specific equipment and testing capabilities will the utility provide?
- What is the time table for installation and testing?

Working with project sponsors, EPRI will identify key emerging circuit configurations, reconfiguring approaches, and associated protection and control techniques that merit field evaluation. The concepts will be screened as to their functionality and performance in specific in ADA™ and advanced distribution system operations. New concepts in which there is high interest will be prioritized and available project funds will be applied to the field experience assessment activities in order of priority up to the limit of available funding.

Examples of things that may be assessed are feeder autolooping approaches and intentional islanding of distribution circuits which have sufficient distributed generation. These are only examples, and the concepts actually chosen for evaluation will reflect sponsor priorities and available host opportunities. The work will take into account the prior requirements definition and design work in the past EPRI ADA™ projects on advanced circuits, protection, and control for ADA™ and past utility projects in the area.

The total number of circuit, control, and protection concepts assessed will be a function sponsor priorities for use of the available funding in each year. Hence, the scope is adaptable annually to the level of funding received. Priority will also be given to cases in which there are cooperating vendors or utilities that can support the assessment work. Concepts not included in the first round of field evaluations will be candidates for inclusion in the next round, along with new concepts that may be identified in the next round.

A new prioritization of products and system approaches will be made at the start of each round, and new assessments will be launched in accordance with sponsor priorities. The objective will be to complete a round of field assessment every two years. The core documentation will be done in the form of a final report in the second year with a technical status update after the first year. This will allow time to identify specific concepts to be tested, set up the systems in the field, and perform the evaluation. Additional technology transfer activities will be implemented as funding may allow.

The RFI is planned for release in early 2008.

DOE Program for Electricity Delivery and Energy Reliability, Research, Development and Analysis

In addition to preparing EPRI's RFI to seek utility host situations for test and evaluation opportunities broadly in the area of advanced circuits, controls, and protection, EPRI also submitted a proposal in this area in response to a DOE solicitation. This proposal was focused specifically on active distribution system management, which is within the broader scope of the EPRI project. It is a particularly central topic to have proposed, because eventually all the advanced circuit, control and protection concepts will have bearing on the choices made in developing active management systems for the distribution system of the future. This section is summarizes the DOE RFP and the response that EPRI led in preparing.

Submitting a proposal to this RFP was a unique opportunity to leverage the ongoing work carried out by EPRI in the ADA™ project and bring results from a larger group of utility projects into the information sharing process. This section provides a summary of the DOE RFP including scope of work and explicit requirements as well as the main issues of the proposal that was made by the team in which EPRI participated. It also describes in detail the approach that EPRI plans to take in this collaborative project.

The approach taken by EPRI for evaluation of active distribution management in this proposed effort for DOE is an example of how EPRI will approach the broader menu of advanced distribution system concept evaluation work to be done in the EPRI project.

Summary of DOE RFP Scope

The DOE funding opportunity addressed two main DOE Program Areas of Interest contributing to the mission of the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability. The mission is: "**Lead national efforts to modernize the electric grid; enhance security and reliability of the energy infrastructure; and facilitate recovery from disruptions to energy supply**". The Areas of Interest are:

- The Visualization and Controls Program promotes a vision which stands as: "**By 2015, control systems for critical applications will be designed, installed, operated, and maintained to survive an intentional cyber assault with no loss of critical function**". To achieve it this programs conducts research and development and develops tools/algorithms to:
  - Improve the response time of the electrical transmission system to reduce the number and spread of outages.
  - Reduce operating margins by allowing the electrical transmission system to operate closer to its loading limits by sensing deterioration of system conditions and enabling faster response.
  - Reduce the risk of energy disruptions due to cyber attacks on control systems.
- The long term goal of the Renewable and Distributed Systems Integration Program is: "**Demonstrate peak load reduction on distribution feeders with the implementation of distributed energy and energy management systems at a cost competitive with system/capacity upgrades**". To achieve it, this program focuses on effectively integrating distributed resources (including distributed generation technologies, renewable generation technologies, energy storage devices, and demand response methods) for decreased peaking power demand on the grid and for providing necessary ancillary services. Other benefits are foreseen are to eliminate or defer the need for new transmission and distribution capacity and upgrades, reduce congestion, and decrease electricity prices and volatility. Dispersal of generation also increases reliability and reduces security vulnerabilities.

The EPRI team's proposal addressed the second area, and only it will be described further.

Renewable and distributed systems integration

In the RFP, this DOE Program Area of Interest sought applications for the development and demonstration of technologies and/or methodologies that will enable integration of significant amounts of distributed resources in the power generation and distribution mix for providing power during peak load periods and for other functions and services. The following information is a summary of material in the RFP.

Currently, the United States has an estimated 12 million distributed generation (DG) units installed across the country, with a total capacity of about 200 gigawatts (GW). Most of these are back-up power units and are primarily used by customers to provide emergency power during times when grid-supplied power in unavailable. This DG capacity also includes about 84 GW of consumer-owned combined heat and power systems. This significant asset base (and any new DG installations) could supplement grid-supplied power during periods of peak demand, as well as perform other enabling services such as improved system reliability and power quality, provision of ancillary services and reactive power, improved power delivery security, etc.

In addition to economic and institutional barriers, key technical barriers to broader use of DG include: new distribution system configurations or reconfiguring capabilities; improved understanding of steady-state and dynamic performance of complex grid configurations with multiple DG types, including interactions among DG types and between DG and other grid-connected equipment; and improved monitoring, control, and protection capabilities, etc. The types of DG encompassed are:

- Renewable energy generation technologies (e.g., photovoltaic arrays and wind turbines);
- Generation which may utilize renewable and non-renewable fuels (e.g., microturbines, reciprocating engines, fuel cells, combustion turbines, and steam turbines);
- Energy storage devices (e.g., batteries and flywheels);
- Equipment capable of utilizing waste heat;
- Load curtailed via typical demand response methods

In order to support the achievement of the different phases of the program, optional sub-areas were identified as to be included and used to meet the objectives. A brief description of these sub-areas follows:

- Low costs sensors for distribution cables: Information on the current, voltage, and temperature of cables **beyond the substation** is needed for state estimation, informed control, and diagnosis, as well as to validate models and simulations and to discover outliers. Each application which proposes work in this optional sub-area must address technology and methodology development to meet the following requirements:
    - Provide measurements of steady-state current, voltage, and temperature of cables at a sampling rate of 5 minutes or less, with the accuracy parameter specified
    - Durable
    - Noninvasive and easy to apply (e.g., as in sensor straps, sensor motes, etc.)
    - Self-powered or parasitic to the line power
    - Use of optimized form factor and production techniques to achieve a low-cost target, with the cost target specified
- Advanced monitoring for distribution automation: An integrated monitoring scheme is sought to be developed and demonstrated for automating distribution system control operations, including: volt/VAR management; fault detection, location, and isolation; multi-level feeder reconfiguration; service restoration; and emergency response. The EPRI team's proposal included material germane to this optional area.

- Consumer information gateway: An integrated communication solution that enables two-way communication between load serving entities and electric loads within consumer premises is needed to improve consumer participation in demand response. This communication solution will serve as an information gateway, allowing consumers to change their electricity consumption patterns in response to both price-based and incentive-based demand response programs, as an effective means to reduce peak load demand. The EPRI team's proposal included material germane to this optional area.

Requirements for the renewable and distributed systems integration area of interest

The applications proposed in the scope of this program area were expected to develop and demonstrate new distribution system configurations with integration of significant amounts of distributed resources as defined before. The distribution system integration was to contain an optimal mix of distributed resources and necessary innovative implementation technologies (e.g., switches, interconnects, etc.) for **an aggregated capacity of greater than 15 percent** of the capacity of a distribution substation, a single distribution feeder, or multiple distribution feeders. Further, such aggregation of distributed resources were to achieve **a reduction of at least 15 percent of the power** that would otherwise be normally supplied by the distribution substation or distribution feeder(s) (including projected load growth, if any) during peak load periods. This 15 percent reduction is a program-level goal to be reached within five years of the anticipated initiation of awards and must be demonstrated by comparison to the historical 5-year rolling average daily peak load for the proposed substation or feeder(s).

Studies were to be proposed to address distributed resources aggregation and integration issues, such as:

- Conform the resource integration design to the interconnection and interoperability standards,
- Assess the steady-state and dynamic performance of the distributed resource integration design (in grid-parallel and grid-connected modes) through modeling and simulations,
- Define the operational performance requirements and their assess their impact on the resource integration design,
- Assess the maximum capacity for distributed resources integration based on the characteristics of the circuits,
- Assess the benefits of the distributed resource integration regarding the objectives defined in this program including peak load reduction, reliability improvement, grid services,
- Assess the costs of the foreseen solution and compare it to other traditional practices.

As far as field demonstration is concerned, a minimum of 12 months of data were to be accumulated including operation in grid-parallel and intentional islanding modes.

As far as sub-areas are concerned, the associated requirements were the following:

- Low costs sensors for distribution cables: Each application which proposes work in this optional sub-area shall include **field installations of greater than 100 sensors**, with appropriate communication modules, on cables (overhead or underground) to provide optimal coverage of a distribution substation (inclusive of all feeder circuits and line sections) and shall conclude with collection of a minimum of three months of operational data.

- Advanced monitoring for distribution automation: Each application which proposes work in this sub-area must describe a complete set of sensing capabilities (i.e., measurement parameters and their data requirements) for the integrated monitoring. The integrated monitoring development should address and meet specific requirements including communication technologies, interoperability standard compliance, advanced data processing (simulation, modeling). A **pilot demonstration** of the advanced monitoring scheme at a distribution utility site should also be performed. The site selection should have the circuit designs and control equipment "typical" of distribution system control practiced today.

- Consumer information gateway: Each application which proposes work in this sub-area must include the **development and demonstration** of a gateway system and a **pilot demonstration** of the prototype gateway system to demonstrate the enabling functionalities in a real operating environment. The common requirements of the information gateway include an **integrated hardware/software system** that is interoperable with multi-vendor products, with interface specifications of its components that are well defined in accordance with applicable standards. The proposed gateway system must provide secure two-way communication with functionalities of: receiving time-based rates and system reliability signals; automating management and control of end-use electrical equipment for interruptible and curtailable services; and automating transmission of interval load measurements, i.e., what was consumed and when. For the proposed information gateway system, each application which proposes work in this sub-area must describe:
  - The target consumer markets,
  - The design, architecture and estimated unit costs of the gateway system,
  - The way price/reliability signals will be transmitted,
  - The types of loads to be controlled,
  - The integration with other utility-based applications.

Summary of content of the proposal response to the RFP by the EPRI/utility team

Objectives and approach

The objectives of this proposed project are to advance the integration and utilization of DER in meeting electric distribution system peak energy demands. The project will evaluate, demonstrate and quantify how the integration of distributed energy resources can provide value and benefits to the electric distribution system. Specific objectives are to: demonstrate the operability, integration and control of multiple DER to reduce at least 15% of feeder circuit loads. The project will provide economic analysis and information to solidify utility business models to support future deployment investments for DER; to evaluate and demonstrate advanced distribution system design, integration and active distribution system management techniques for enhancing the value of DER at high penetrations in electric distribution systems; and to create and disseminate a knowledge base to support more effective active distribution system management with high penetrations of DER, including easier, standardized approaches to future distribution system integration and design.

The project is organized in a two phase structure: Phase 1 related to feeder characterization, DER portfolio specifications for procurement and potential benefits assessment and Phase 2 related to field trials and validation. The specific objectives associated with both phases are:

- Phase 1:
  - Characterize distribution feeders for integration of DER in legacy and future distribution system designs and develop analytical models that can be used for distribution assessments with DER (both technical and economic analysis).
  - Develop test protocols to evaluate DER integration using both measurements and simulations.
  - Develop technical, economic and business case analyses to support future DER deployment and active distribution management system development.
- Phase 2:
  - Test and validate the use of a portfolio of DER to exceed 15% feeder load including but not limited to: permanent load shifting systems, low emission distributed generation, electric energy storage systems, load management systems, and active distribution management systems.
  - Advance the development of Li-ion energy storage and smart inverter systems for residential and commercial peak load shifting.
  - Deploy communication and distribution asset control systems for the efficient and effective management of DER.
  - Advance the use of standard communication/control systems and protocols for management of DER.
  - Advance the development and application of active distribution management systems to enable optimal DER utilization with electric distribution system.
  - Advance the electric integration of PV systems for feeder and roof-top applications.
  - Develop simulation models and approaches for evaluating DER integration issues and related cost/benefit assessments and validate these models and approaches with the field trials in the project. Integrate these modeling efforts with parallel distribution system modeling initiatives being funded by DOE.

Scope of work

Phase 1 will evaluate for each utility system the type, quantity, location and dispatch criteria for the DER applications, as well as how the individual utility active distribution management approaches can enhance the value and integration of DER to distribution systems. The project team will evaluate the economic and business models of distributed energy resources (DER) systems deployed in both a conventional and an advanced micro-grid distribution feeder circuit, and examine the opportunity for enhancing the value of DER, using DER as a tool to improve energy efficiency in distribution operations (e.g., loss reduction), improve reliability of electrical service and improve power quality.

Phase 2 field trials will illustrate a variety of technologies that, in combination, can be deployed at penetration levels exceeding 15% of feeder circuit capacity for each utility. In Phase 2, the project team will transfer results to electric utilities and other stakeholders to encourage adoption of the best–practices and practical solutions developed in this project.

Coordination with the DOE program

The EPRI team's proposal to DOE was submitted in late August; and at the time of this report preparation, no decision on funding has come from DOE. EPRI teamed with three utilities and a consulting firm in this proposal. The team details have been withheld from disclosure in this report, per request of other team members, until a decision on the proposal is made by DOE. The coordination of the work planned in the EPRI RFI process and in the proposal to the DOE RFP is illustrated in Figure 3-1. Available results coming from both initiatives will be included in the general EPRI approach (Section 2) on advanced distribution circuits, controls, and protection in order to achieve the objectives of the EPRI project, as presented in Section 1. A goal is to get maximum leverage and value from the knowledge and experience obtained on advanced distribution systems, by teaming work in the EPRI and DOE programs.

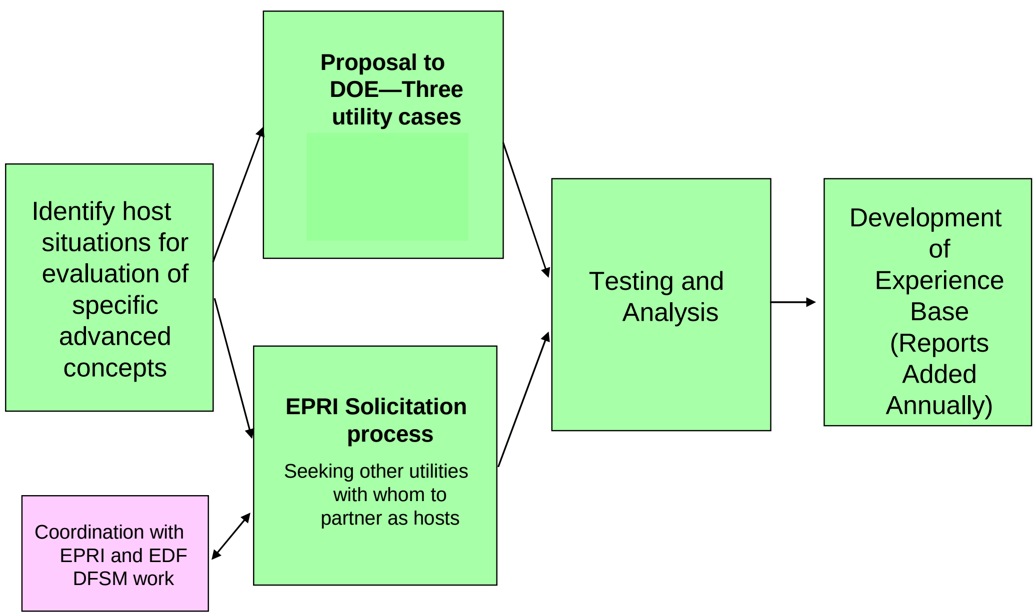

Figure 3-1
Coordination of the EPRI RFI solicitation process and the DOE RFP response. DFSM stands for Distribution Fast Simulation and Modeling.

4
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