TECHNICAL AND SYSTEM REQUIREMENTS FOR ADVANCED DISTRIBUTION AUTOMATION

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INTRODUCTION

Advanced Distribution Automation (ADA) will be a revolutionary approach to managing and controlling distribution systems. It will achieve a fully controllable and automated distribution system including the integration of distributed resources to optimise system performance. This paper describes the results of an EPRI roadmap development project that defines the important research and development needs to achieve the completely automated distribution system of the future.

The paper accomplishes the following objectives:

- *describes the vision for ADA and characterizes its benefits for the power system of the future*
- *identifies the system and technology requirements for realizing this ADA vision over the next 20 years*
- *identifies research needed to develop ADA and identifies coordination opportunities for accomplishing this research*

The paper reviews existing distribution automation programs and research initiatives from North American and international utilities, manufacturers, and research organizations. It includes results of a strategic planning session held in New York in August 2004 with participation of industry, academics, utilities, and research organizations from around the world to help define the research agenda and identify important coordination opportunities.

ADVANCED DISTRIBUTION AUTOMATION (ADA)

Electricity distribution system challenges are greater than ever. Demand continues to increase, customers expect improved reliability and power quality, the system must allow for the integration of distributed resources, and regulators limit the investments that can be made to achieve these objectives. Electric distribution companies must continue to achieve improved economies of operation and find innovative ways to improve the system performance through technology application. Distribution automation will play a key role in operating and managing the distribution system of the future.

There are important needs or technology development and standardized approaches for applying the technology across the industry. Much of the research needed to provide the foundation for these technologies and their application needs to be performed in a collaborative manner with widespread international participation. The collaborative research model will result in consistent approaches for technology application that can result in significant economies when applied across the industry. This is the reason for creating an ADA™ research initiative.

The ADA™ Program envisions distribution systems as highly automated systems with a more flexible electrical system architecture operated via open-architecture communications networks. As the systems improve, they will have increased capabilities for system performance (energy throughput), reliability, and customer service options.

Traditional distribution systems were designed to perform one function—distributing power to end-users. ADA™ will transform traditional systems into multifunctional systems that take full advantage of new capabilities in power-electronics, information technology, and system simulation. ADA™ also enables new utility customer service options.

The major components of ADA™ are:

1. Flexible electrical system architecture, including integration of new Intelligent Electronic Devices (IEDs), distributed resources (DR), and new electrical and electronic technologies.
2. Communication and control systems based on an open communication architecture and information exchange model.
3. Real time state estimation tools to perform predictive simulations and to continuously optimise system performance (energy, demand management, efficiency, reliability, and power quality) in real time.

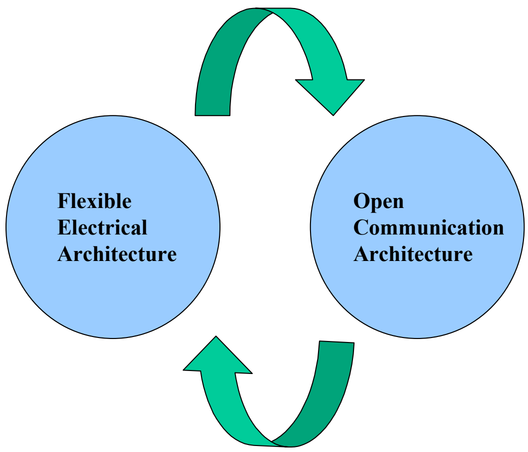

Figure 1. The electrical system architecture and the communication architecture must be developed together to achieve an automated system.

Figure 1 illustrates the interrelated nature of the electrical system architecture development and the communications architecture development in order to achieve an automated system. The real-time system analysis tools bridge these two architectures to continuously optimise the system performance and operation.

ADA FUNCTIONAL REQUIREMENTS

ADA will consist of many individual functions and applications. These functions incorporate many new systems, equipment, and applications that will be part of the overall ADA system. Five important functional requirements can be defined for the overall system [1].

1. Communication and control infrastructure allowing integration of all distribution equipment and end user technologies into the ADA system.
2. Automation of all controllable distribution equipment and functions, including system reconfiguration management to optimise performance and reliability.
3. Application of advanced technologies (e.g. power electronics) where appropriate for advanced control and system performance enhancement.
4. Integration of distributed generation and storage resources.
5. Modeling and real-time simulation systems to optimize performance (via predictive control) and response to disturbances.

Communication and control infrastructure

ADA is not possible without widespread communication between the controllable devices and one or more control unit(s). At times the control unit may be a central processor and at other times it may be another controllable device as in peer-peer communication.

Adding communication links to individual distribution components is becoming more prevalent, in part due to the reduction in communication costs. The communication costs have come down due to new technology developments and increased competition. Economic analysis is more likely to show that the cost of adding communication links is offset by the resulting improvement in system reliability and improved O&M efficiencies.

Distribution automation communications media can be placed into the following three major categories [2]:

1. Power Line Carrier
2. Landlines
3. Wireless

Power line carrier systems have been most successful in automatic meter reading (AMR) and load control applications. For distribution applications, power line carrier suffers from the "open circuit problem". In other words, communication is lost with devices on the far side of an open circuit. This severely restricts the usefulness of power line carrier systems for applications involving reclosers, switches, sectionalizers, and outage detection. However, advancements in Broadband Powerline (BPL) technologies and loop configurations may make this an attractive option for automation applications, especially when combined with customer service offerings based on BPL [3].

Landline communication options include telephone and fiber optics. Leased telephone lines are often brought into substations for SCADA-RTU communications. For distribution automation, telephone lines are not often used because of the costs associated with installation of the phone line, the dielectric isolation equipment, and the monthly cost. Fiber optics is a very technically attractive solution, offering comparatively unlimited bandwidth. Its dielectric and EMI/RFI noise immunity characteristics make it an ideal fit for the high-voltage operating environment. Single-mode fiber is a very practical solution for transmission applications. Unfortunately, the installed "cost per drop" for single-mode fiber is still too high for most distribution applications.

Wireless solutions have shown the greatest potential for automating distribution networks because they communicate virtually anywhere at a very low cost. Companies exploring wireless solutions have two choices; install a private (owner operated) wireless network or utilize an existing infrastructure of a public network. Private wireless networks allow utilities to have more control over their communications system but requires a significant up-front investment in infrastructure as well as the on-going maintenance costs. Utilizing an existing public network, for example, the public cellular network, allows a utility to forgo upfront infrastructure as well as most of the on-going maintenance costs. These cost saving must be weighed against the fact that the network is not captive to the utility. With security features like secure socket layers (SSL), 128-bit encryption, and frame relays, the security risks of using a public network are becoming negligible.

ADA systems will also incorporate communication and control functions that integrate with end use technologies for implementation of demand response and real time pricing systems. These systems will help optimise the performance of individual distribution systems as well as provide the means to better match generation resources with load characteristics.

Automation of controllable equipment and functions

The automation process will be accompanied by an integration phase in which equipment and information will be consolidated. The integration of protection, control, and data acquisition functions into a minimal number of platforms will reduce capital and operating costs, reduce panel and control room space, and eliminate redundant equipment and databases.

The automation and functionality of the system will evolve to a very complete and comprehensive scheme. The system will be given more data along with more switching and corrective action responsibilities. The security and integrity of the automation system will also be enhanced with dispersed control, more redundancy and more sophisticated "fail safe" strategies.

The first stage of automation occurs at the substation because this is where communications is most readily available. Future ADA systems will extend the control out onto the distribution system and even into customer facilities in order to optimise the performance and response of the overall system. Figure 2 illustrates this transition process.

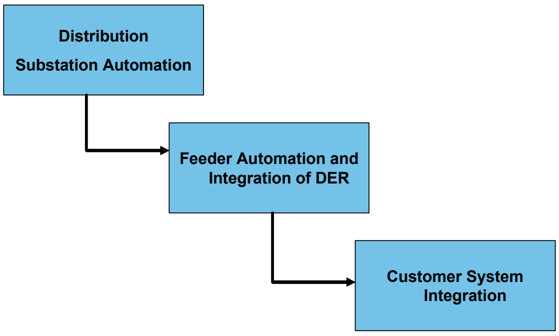

Figure 2. Stages of ADA implementation.

Application of advanced technologies
Optimizing the performance and the response of the distribution system in the future will take advantage of advances in power electronics technology. Important advantages of power electronics technology applications will include:

- Faster, transient-free switching for better response to disturbances and system reconfiguration.
- Continuous voltage and var control, as well as control of harmonic distortion
- Ride through systems for improved power quality and reliability for customers that require this level of service

Important technologies to realize these benefits include:

- Static compensators for voltage and var control
- Active filters for harmonic control
- Series compensators for ride through support and voltage control
- Energy storage systems with power electronics to optimise performance and the system interface
- Intelligent universal transformer (IUT) for complete management of the customer interface
- Solid state switches for fast, transient free switching and system reconfiguration

Many of these power electronic technologies may be integrated with distributed resources or end-use devices. However, their controls must be integrated with the overall ADA system.

Integration of Distributed Energy Resources (DER)
The distribution system will need to transition from a single function (energy delivery) system to a multi-function (energy exchange) system in order to fulfil the ADA vision. Automation and control functionality will need to be increased and this functionality will be integrated with distributed resources throughout the distribution system.

A major functional goal of the ADA vision is to seamlessly integrate small power generation and storage devices throughout the system. This integration process will ideally maximize the benefits of DER while minimizing some of the potential liabilities. The development of a flexible electrical architecture as well as the development of an open communication architecture are both critical to achieving this goal.

The development of standardized interconnection systems for DER resources will facilitate the rapid introduction of additional DER resources onto the system. These systems must be integrated with the overall distribution automation system as part of system performance management. In order to maximize some of the reliability and power quality benefits associated with DER, the electrical architecture will also need to be able to break apart into "micrognds" or self sustaining islands, during certain power system disturbances or even to optimise steady state performance [6,7].

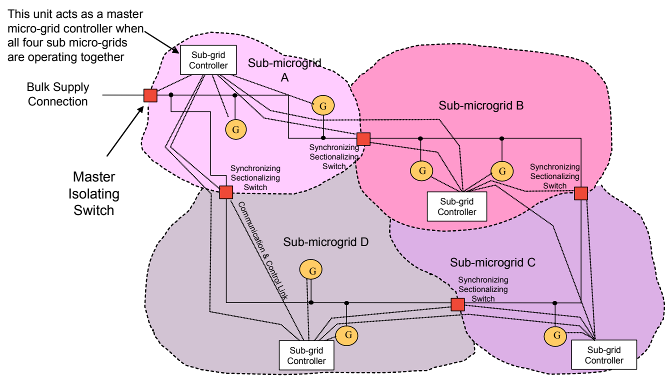

Figure 3. Example of microgrid concept to maximize the advantages of distributed resources as part of ADA.

In order to facilitate the integration and real-time dispatch of DER, a secure real-time communications and control infrastructure must be provided. Security and redundancy of the communication system will be critical to offsetting the added complexity associated with the integration of these resources. The Utility Communications Architecture (UCA) meets the need for a standard, self-defining, object-oriented communications protocol [8]. The standards development work for this architecture is ongoing under IEC 61850 [9].

Modelling and real-time simulation systems
Control of all equipment and even customer systems will require an extensive real-time system model and information system along with supporting simulation tools to continually optimise system performance. The first requirement is a system information model that facilitates the wide variety of applications that will have to operate on this model. The information model must take into account future as well as existing technologies that are part of the distribution system. The Common Information Model (CIM) provides the foundation for this requirement but significant development is needed [10]. Important elements include:

- Substation equipment
- Protection systems
- Distribution system topology with line and cable characteristics
- Distribution switchgear and characteristics (including solid state switches)
- Var control and voltage control technologies (regulators, series compensators, shunt capacitors, shunt compensators)
- Transformers (substation and customer)
- Intelligent universal transformers with full functionality in the future
- Distributed generation and storage devices with controls and protection systems
- End use technologies, load characteristics
- Demand response and real time pricing systems and components
- GIS systems

Important applications that must become real-time capabilities for the ADA system include:

- Load flows, voltage profiles, var flows, etc.
- Harmonic distortion level calculations and simulations
- System loss simulations to optimize topology and equipment controls
- Price response simulations as part of demand management and system performance optimization
- Fault location
- Optimized restoration following fault conditions
- System restoration following major outages, including coordination with end user and DR systems

All of these systems require extensive data collection and management systems to match the system representations with real-time conditions. These functions will require faster simulation and state-estimation systems for the distribution systems. These systems will also be required to continually predict future conditions on the distribution system to develop optimisation approaches for the system performance.

THE ADA VALUE PROPOSITION

The first task in justifying major investments in automated systems is to establish the value proposition. This value proposition will also drive the next generations of product and standards development leading to the completely automated and flexible system. The value proposition for ADA will have to consider four (4) categories of benefits that will be extremely important for the power system of the future:

1. **The value of reliability and quality.** Outages and disturbances cost over $100B per year at the present time [11,12]. Improving system reliability and quality will have tremendous advantages for end user productivity and result in benefits for the entire economy. Systems must be structured to allocate the costs and benefits for the investments in improved reliability.
2. **Improved operations and asset management.** This is currently the biggest driver for substation and distribution automation. The systems result in direct savings in investments and operation of the delivery system. Improved asset management, reduced manpower requirements to operate the system, faster response and clearing of faults all have tremendous benefits. The ADA system will take these benefits to another level with advanced diagnostics, local intelligence, and integrated operation of DER and customer systems to benefit the entire power system.
3. **Reduced losses.** ADA will result in continuous optimising of system performance, resulting in the most efficient delivery system possible. This will take into account reconfiguration options, integrated voltage and var management using conventional and advanced technologies, advanced power electronics, and integrated operation of customer systems and DER (with real-time pricing systems for incentives to be part of the system optimisation).
4. **Overall system energy management, reliability, and security**. ADA systems will be integrated with wide area energy management systems for overall optimisation of generation mixes, system demand, power flows, and system security.

ADA STRATEGIC PLANNING MEETING

EPRI and Consolidated Edison hosted a strategic planning meeting in New York during August, 2004 to help develop the foundation for the ADA research plan. Important objectives of this planning meeting included the following:

- Provide a forum for discussion of distribution automation concepts and development needs.
- Help in defining the current state-of-the-art for existing distribution automation architectures and functions.
- Provide industry feedback on a vision for distribution system architectures and automation functions in the future.
- Facilitate coordination with other research initiatives related to advanced distribution automation architectures and functions, including:
    - DOE and the National Labs [13]
    - Distribution Vision 2010 [14]
    - International research initiatives such as. EdF, Microgrids Consortium, DISPOWER, etc. [7,15,16, 17]
- Provide the background for defining a new research initiative for ADA

The meeting included representatives of electric utilities, manufacturers, consultants, universities, and international research initiatives. The results of the meeting were used to help develop the research priorities for the ongoing initiative.

ADA RESEARCH INITIATIVE

The research initiative is structured in five (5) technical areas, as shown in Figure 4. Each of these technical areas has important research needs that need to be coordinated across the entire industry.

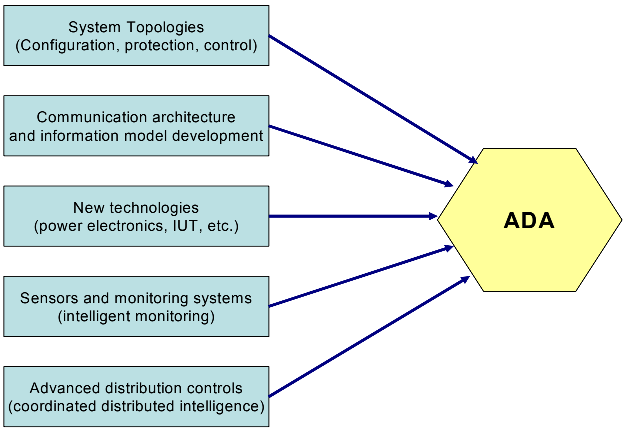

Figure 4. The five major categories of research for the ADA initiative.

The initial research priorities include the following:

- Develop tools for utility migration to open systems for automation equipment
- Develop tools for specifying automation equipment as part of system development projects
- Develop and refine device models for specific application areas
- Implement open systems in real world environments and capture lessons learned and necessary refinements
- Contribute to the development of key open standards specifications
- Develop a flexible electric distribution system architecture, including advanced configurations and capabilities, such as two-way power flow, intentional islanding, microgrids, dc ring buses, and looped secondaries
- Develop key electrical and power-electronic components that enable the flexible electric architecture and are cornerstones of ADA (such as the intelligent universal transformer and new solid-state switchgear)
- Develop fast simulation and modeling systems for distribution applications
- Develop tools to assist utility specification for larger system integration

The initiative is structured with an initial five-year time frame and a set of projects that are coordinated with other research activities in the industry (including international research initiatives). Preliminary focus areas for the initiative are shown in Figure 5.

CONCLUSIONS

Advanced Distribution Automation (ADA) will provide the infrastructure and technology for full integration of distributed resources to the distribution system and will substantially increase reliability and allow more efficient operation of the entire system. A coordinated research plan will allow integration of research efforts from around the world to facilitate the most economical migration to these advanced systems.

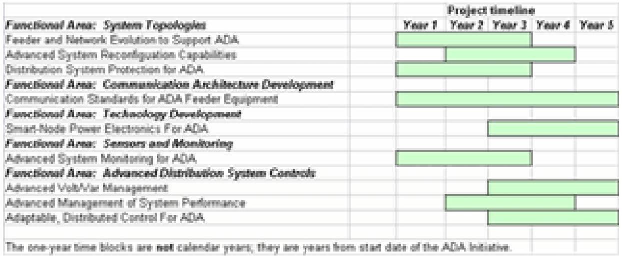

Figure 5. Preliminary research priorities for the ADA initiative.

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