The State and Prioritization of Advanced DA Applications for the Smart Grid

Draft White Paper

Nokhum Markushevich
Utility Consulting International

There is a number of Advanced Distribution Automation Applications that are well specified, tested and implemented in power utilities. These applications are “shovel-ready” for the starting stages of the Smart Grid in distribution. With the growing penetration of new technologies, such as AMI, Demand Response, Electric storage, Electric Transportation, etc., the existing DA applications should be updated to benefits from the new technologies and at the same time to increase the efficient use of these technologies. In addition to the existing applications, a number of new applications can be introduced for planning and operations in the Smart Grid.

In the sub-sections below, a non-exhaustive list of DA applications that can be implemented in the first stage of Smart Grid implementation is presented. The list includes the real-time applications and some of the planning applications needed to support the most efficient performance of the real-time applications in the Smart Grid. The list also presents references to the published documents that can be used for development of Use Cases and requirements for the updates of the applications to incorporate the impacts of the new Smart Grid Technologies. The narratives describing the existing portions of the applications or the applications, for which the use cases exist, is mostly taken from reference [3]. The suggested new functional requirements are presented in bold font.

D1. Distribution Operation Modeling and Analysis (DOMA)

This application is based on a real-time unbalanced distribution power flow for dynamically changing distribution operating conditions. It analyzes the results of the power flow simulations and provides the operator with the summary of this analysis. It further provides other applications with pseudo-measurements for each distribution system element from within substations down to load centers in the secondaries. The model is kept up-to-date by real-time updates of topology, facilities parameters, load, and relevant components of the transmission system [2, 3-11, 24, 25 - 27].

The Distribution Operation Modeling and Analysis shall support three modes of operation:
1. Real-time mode, which reflects present conditions in the power system.
2. Look-ahead mode, which reflects conditions expected in the near future (from one hour to one week ahead)
3. Study mode, which provides the capability of performing the “what if” studies.
The key sub-functions performed by the application are as follows:

1. Modeling Transmission/Sub-Transmission System Immediately Adjacent to Distribution Circuits

2. Modeling Distribution Circuit Connectivity
    - Data Management Issues between AM/FM/GIS and DA Distribution Connectivity Database
    - Data Management Issues between Customer Information System and AM/FM/GIS and DA Distribution Connectivity Database
3. Modeling Distribution Nodal Loads.
   The update of application to meet the Smart Grid requirements shall include the model of the Demand Response means, Electric Storage, Electric Transportation, and Renewable Generation.
4. Modeling Distribution Circuit Facilities
   The update of application to meet the Smart Grid requirements shall include modeling of power electronics devices, Distributed Energy Resources, controllers, Customer EMS master controllers, renewable generation controllers, etc.
5. Distribution Power Flow, including the updated load models
6. Evaluation of Transfer Capacity
7. Power Quality Analysis
8. Loss Analysis
9. Fault Analysis, **including Distributed Energy Resources, Electric Storage, and Electric Transportation contribution**
10. Evaluation of Operating Conditions, including:
    - Determination of dynamic substation bus voltages limits
    - Estimation of the available dispatchable real and reactive load obtainable via volt/var control, **including the capabilities of Distributed Energy Resources, Demand Response, Electric Storage, and Electric Transportation.**
    - Provision of aggregated operational parameters for the transmission buses to be used in transmission operation models.

D2. Contingency Analysis (CA)

This application performs an N-m contingency analysis in the relevant portion of distribution. The function shall run in the following modes:

1. Periodically
2. By event (topology change, load change, availability of control change)
3. Study mode, in which the conditions are defined and the application is started by the user.
4. The application informs the operator on the status of real-time distribution system reliability and shall be used for operation planning [2, 3, 9, 11, 12, 14].

The updates needed to meet the Smart Grid requirements include the following:

   a. **Using the AMI outage detection capabilities for fault location**
   b. **Handling of the Distributed Energy Resources, Demand Response, Electric Storage, and Electric Transportation as generation resources available for backup of the load, when needed**
   c. **Using the capability for intentionally creating micro-grids to maximize the amount of energized loads**

D3. Fault Isolation and Service Restoration

This application shall support three modes of operation:

1. Closed-loop mode, in which the sub-function is initiated by the Fault location sub-function. It generates a switching order (i.e., sequence) for the remotely controlled switching devices to isolate the faulted section, and restore service to the non-faulted sections. The switching order is automatically executed via SCADA.
2. Advisory mode, in which the sub-function is initiated by the Fault location sub-function. It generates a switching order for remotely- and manually-controlled switching devices to isolate the faulted section, and restore service to the non-faulted sections. The switching order is presented to operator for approval and execution.
3. Study mode, in which the sub-function is initiated by the user. It analyzes a saved case modified by the user, and generates a switching order under the operating conditions specified by the user.

The generated switching orders are based on considering the availability of remotely controlled switching devices, feeder paralleling, creation of islands supported by distributed energy resources, and on cold-load pickup currents [1, 2, 3, 9, 11, 12, 14, 15, 18, 20, 26, 27].

The updates needed to meet the Smart Grid requirements include the following:

a. **Using the AMI outage detection capabilities for fault location**
b. **Handling of the Distributed Energy Resources, Demand Response, Electric Storage, and Electric Transportation as generation resources available for backup of the load, when needed**
c. **Using the capability for intentionally creating micro-grids to maximize the amount of energized loads**

D4. Voltage and Var Control (VVC)

This application calculates the optimal settings of voltage controller of LTCs, voltage regulators, Distributed Energy Resources, power electronic devices, capacitor statuses, and demand response means optimizing the operations by either following different objectives at different times, or considering conflicting objectives together in a weighted manner.

It shall support three modes of operation:

1. Closed-loop mode, in which the application runs either periodically (e.g., every 15 min) or is triggered by an event (i.e., topology or objective change), based on real-time information. The application's recommendations are executed automatically via SCADA control commands.
2. Study mode, in which the application performs "what-if" studies, and provides recommended actions to the operator.
3. Look-ahead mode, in which conditions expected in the near future can be studied (from 1 hour through 1 week) by the operator.

The following objectives, which could be preset for different times of the day and overwritten by operator if need to, are supported by the application:

- Minimize kWh consumption at voltages beyond given voltage quality limits (i.e., ensure standard voltages at customer terminals)
- Minimize feeder segment(s) overload

- Reduce load while respecting given voltage tolerance (normal and emergency)
- Conserve energy via voltage reduction
- Reduce or eliminate overload in transmission lines
- Reduce or eliminate voltage violations on transmission lines
- Provide reactive power support for transmission/distribution bus
- Provide spinning reserve support
- Minimize cost of energy
- Provide compatible combinations of above objectives

If, during optimization or execution of the solution, the circuit status changes, the application is interrupted and solution is re-optimized. If, during execution, some operations are unsuccessful, solution is re-optimized without involving the malfunctioning devices. If some of the controllable devices are unavailable for remote control, solution does not involve these devices but takes into account their reaction to changes in operating conditions [1, 2, 3-5, 8-13, 15-18 , 20-21, 24, 25].

The application, if so opted, shall also issue operational requirements to Demand Response means, to Electric Storage devices, as well as to Electric Transportation installations in order to optimally achieve its objective. The application shall be able to utilize selected AMI data directly from the Smart Meters, as well as from the typified object models updated by AMI information.

D5. Multi-level Feeder Reconfiguration (MFR)

This application recommends an optimal selection of feeder(s) connectivity for different objectives. It supports three modes of operation:

1. Closed-loop mode, in which the application is initiated by the Fault Location, Isolation and Service Restoration application, unable to restore service by simple (one-level) load transfer, to determine a switching order for the remotely controlled switching devices to restore service to the non-faulted sections by using multi-level load transfers.
2. Advisory mode, in which the application is initiated by SCADA alarms triggered by overloads of substation transformer, segments of distribution circuits, or by DOMA detecting an overload, or by operator who would indicate the objective and the reconfiguration area. In this mode, the application recommends a switching order to the operator.
3. Study mode, in which the application is initiated and the conditions are defined by the user.

The application performs a multi-level feeder reconfiguration to meet one of the following objectives:

a. Optimally restore service to customers utilizing multiple alternative sources. The application meets this objective by operating as part of Fault Location, Isolation and Service Restoration.
b. Optimally unload an overloaded segment. This objective is pursued if the application is triggered by the overload alarm from SCADA, or from the Distribution Operation Modeling and Analysis, or from Contingency analysis. These alarms are generated by overloads of substation transformer or segments of distribution circuits, or by operator demand.
c. Minimize losses

d. Minimize exposure to faults
e. Equalize voltages [1, 2, 3, 11,14, 22].

Additional objective may include:

f. Minimize energy cost by swapping loads
g. Unload transmission facilities by swapping loads

The updates needed to meet the Smart Grid requirements include the following:

a. Using MFR for swapping loads to reduce energy cost and assist in congestion management
b. Taking into account the Distributed Energy Resources, Demand Response, Electric Storage, and Electric Transportation as generation resources or as dispatchable loads
c. Using the capability for intentionally creating micro-grids to accommodate feeder reconfiguration

D6. Relay Protection Re-coordination (RPR)

This application adjusts the relay protection settings to real-time conditions based on the preset rules. This is accomplished through analysis of relay protection settings and operational mode of switching devices (i.e., whether the switching device is in a switch or in a recloser mode), while considering the real-time connectivity, tagging, and weather conditions. The application is called to perform after feeder reconfiguration, and, in case, when conditions are changed and fuse saving is required [1, 2, 3, 11, 18].

The updates needed to meet the Smart Grid requirements include coordinating feeder protection and re-synchronization with Distributed Energy Resources and with Micro-grids.

D7. Pre-arming of Remedial Action Schemes (RAS)

This application receives pre-arming signals from an upper level of control and changes the settings (tuning parameters) of distribution-side remedial action schemes (RAS), e.g., load-shedding schemes (a component of self-healing grid) or intentional Distributed Energy Resources islanding into micro-grids [1, 2, 3].

The updates needed to meet the Smart Grid requirements include coordinating remedial action schemes with Distributed Energy Resources, Demand Response, Electric Storage, Electric Transportation, and micro-grids. To do so, the DA function shall receive pre-arming requirements for two (or more) timeframes:

a. Immediate actions
b. Actions within given time limits.

After obtaining this information the function will determine which fast-acting remedial schemes shall be armed and which slow-acting means are available and can be counted on.

D8. Coordination of Emergency Actions

This application recognizes the emergency situation based on changes of the operating conditions or on reaction of some RAS to operational changes and coordinates the objectives, modes of operation, and constraints of other Advanced Distribution Automation applications. For example, Under-frequency Load Shedding Schemes trigger emergency load reduction mode of volt/var control, or the under-frequency protection of Distributed Energy Resources triggers the pre-armed intentional islanding. These are post-disturbance activities [1, 2, 3].

The updates needed to meet the Smart Grid requirements include coordinating emergency actions between the RAS, DA applications, Distributed Energy Resources, Demand Response, Electric Storage, Electric Transportation, and micro-grids.

D9. Coordination of Restorative Actions

This application coordinates the restoration of services after the emergency conditions are eliminated. For example, Advanced Distribution Automation System changes the order of feeder re-connection based on current customer priorities or inhibits return to normal voltage until there are disconnected feeders [1, 2, 3].

The updates needed to meet the Smart Grid requirements include coordinating restoration of disconnected loads in distribution with the availabilities provided by the transmission, generation and distribution itself. It applies to the restoration of load changed due to the emergency by RAS, DA applications, Distributed Energy Resources, Demand Response, Electric Storage, Electric Transportation, and micro-grids.

D10. Intelligent Alarm Processing

This application analyzes SCADA and DOMA-generated alarms and other rapid changes of the operational parameters in distribution and transmission and summarizes the multiple alarms into one massage defining the root cause of the alarms. For example, multiple sudden voltage violations along a distribution feeder and overloads of some feeder segments may be caused by a loss of Distributed Energy Resources excitation, or successful reclosing of a portion of feeder with loss of significant load may be caused by miss-coordination of the recloser settings and a particular fuse protecting a loaded lateral [1, 2, 3].

The updates needed to meet the Smart Grid requirements include recognition of the impacts by RAS, DA applications, Distributed Energy Resources, Demand Response, Electric Storage, Electric Transportation, and micro-grids on the adverse situations.

D11. Processing AMI data for creating and updating the distribution nodal load models (This is a new function).

Distribution automation applications use comprehensive distribution operation models. The most basic models are the connectivity models and the nodal load models. AMI will provide a large amount of information that can be used to create much more adequate models than the currently used "typical models". These models include real and reactive load models on per customer basis and models of the voltage drop in the secondaries (as long as the exact topology models for the secondaries are unavailable). In order to obtain these models in a representative and timely manner, the data collected by AMI shall be processed to summarize the essential characteristics of the loads and aggregate the load models at the point of connection in the distribution operation model used by DA applications.

D12. Optimal Allocation of Switching Devices

The optimal allocation of switching devices is driven by the dominant objectives of distribution operation. It shall take into account the current and future basic topology of the distribution system and the capabilities of the multi-level feeder reconfiguration by using automated switching devices. It should also take into account the presence of Distributed Energy Resources, Demand Response, Electric Storage, Electric Transportation, and micro-grids and the need in synchronization of Distributed Energy Resources and Micro-grids with the basic power system [1, 2, 22].

D13. Optimal Allocation of var and voltage controlling devices in distribution

The optimal allocation of var and voltage controlling devices in distribution is driven by the dominant objectives of distribution operation. It shall take into account the current and future basic topology of the distribution system and the capabilities of the multi-level feeder reconfiguration by using automated switching devices. It shall also take into account the available contribution of real and reactive power from Distributed Energy Resources, Demand Response, Electric Storage, Electric Transportation, and micro-grids, as well the impact of reactive resources in distribution on the transmission operations [1, 2, 23].

D14. Prioritization of SMI Allocation for the benefits of DA (This is a new function)

The advanced DA applications are constraint by loading and voltage limits. The most restrictive constraints in distribution are the voltage limits at the customer terminals. There are always some customer terminals that experience either the lowest, or the highest voltages. These voltage-critical points are not always stable, they move from one place to another at different times. The distribution operation model used by the DA application is supposed to determine the voltage-critical points. The accuracy of this determination depends on the accuracies of the component models, such as load models, secondary voltage drop model, connectivity model, etc. These models shall be periodically validated. One of the validation methods is comparison of the modeled value with the accurately measured one. It can be done retroactively by using stored data, or it can be done in the near real-time frame. In order to maximize the benefits from the advanced DA functions, the SMI shall be first installed in point of most interest for the model validation purposes. These sites can be determined by defining the most probable critical points [1, 2].

D15. Prioritization of Demand Response Allocation (This is a new function)
Installation of Demand Response in voltage critical nodes and/or downstream from load-critical segments of the distribution system and the ability of controlling the Demand Response from the DA applications significantly increases the benefits of DA applications [1, 2, 11-12]**.**

If even the list presented above should be reduced for the first stage of Smart Grid implementation, the following applications can be recommended:

1) Real-time Distribution Operation Model and Analysis (DOMA)
2) Distribution Contingency Analysis (CA)
3) Fault Location, Isolation, and Service Restoration (FLISR and Intelliteam)
4) Voltage, Var and Watt Control (VVWC)
5) Multi-level Feeder Reconfiguration (MFR).

To raise these applications to the level of the Smart Grid challenges, they should be enhanced in two directions:

a) Integration with the DER, Demand Response, and AMI [12-13] (Volt/var control function will become Volt/var/Watt Control function (VVWC)
b) Functional integration with EMS applications.

The integration will better utilize the potential of both: the original DA applications and the new advanced technology, providing significant additional benefits.

Implementing these functions to their maximum extent will require optimal allocation and prioritization of controllable equipment in the distribution system (automated switching devices, controllable capacitors, voltage regulators, demand response installations, etc.). These planning activities cannot be accomplished without knowing what is expected from the DA applications, because different stakeholders may have different dominant objectives and other requirements for these applications. Therefore, in the planning environment, the decisions on choosing the DA applications and on selecting of the actuators should be made at the same time.

Meeting these integration requirements will require development of standard object models and interfaces between different sources. Figures 1-3 are sample illustrations reflecting the needs in the object models and interfaces. These illustrations are updated from the previously published ones in [3-7].

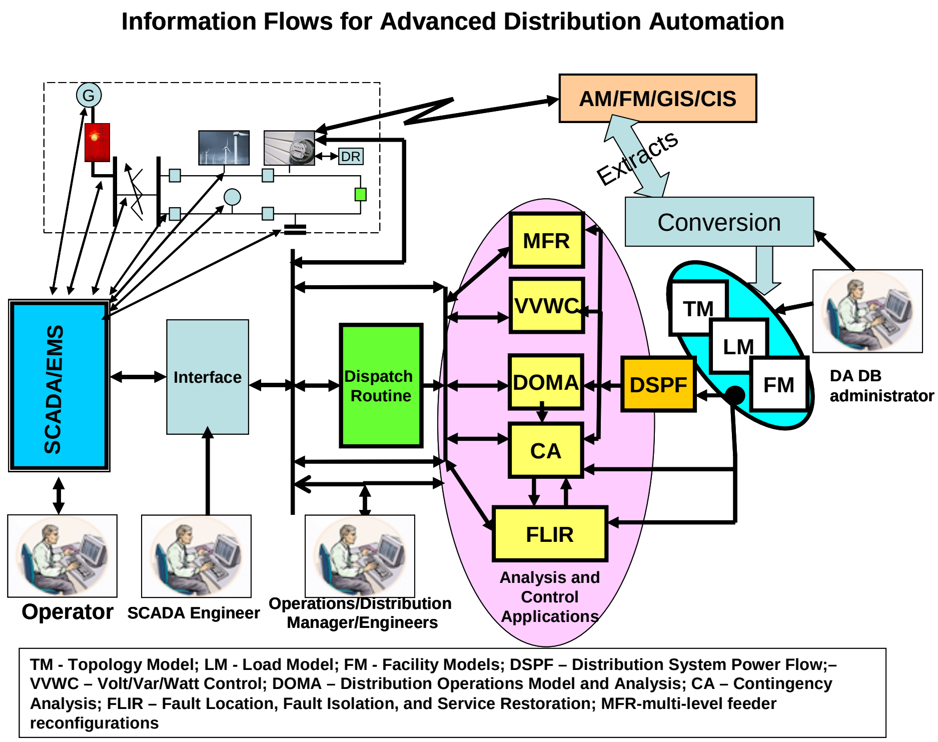

Figure 1. In addition to interfaces with SCADA, specific interfaces between DMS and AMI and DER will be needed

FUNCTIONAL INTEGRATION BETWEEN DMS ADVANCED APPLICATIONS AND EMS NETWORK ANALYSIS

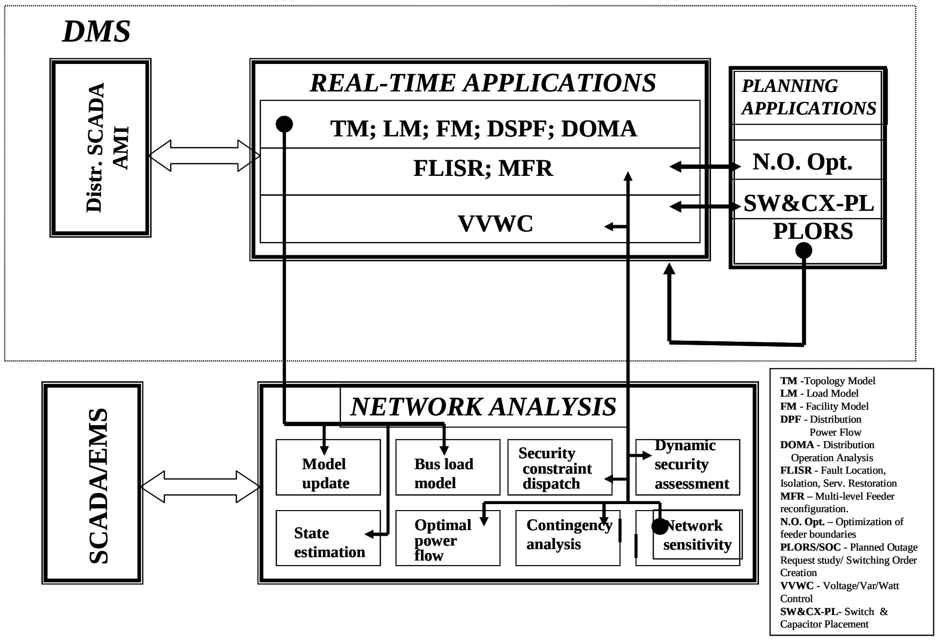

Figure 2. DMS function will provide additional information to the EMS functions, and EMS functions will use additional controllable variables available in distribution.

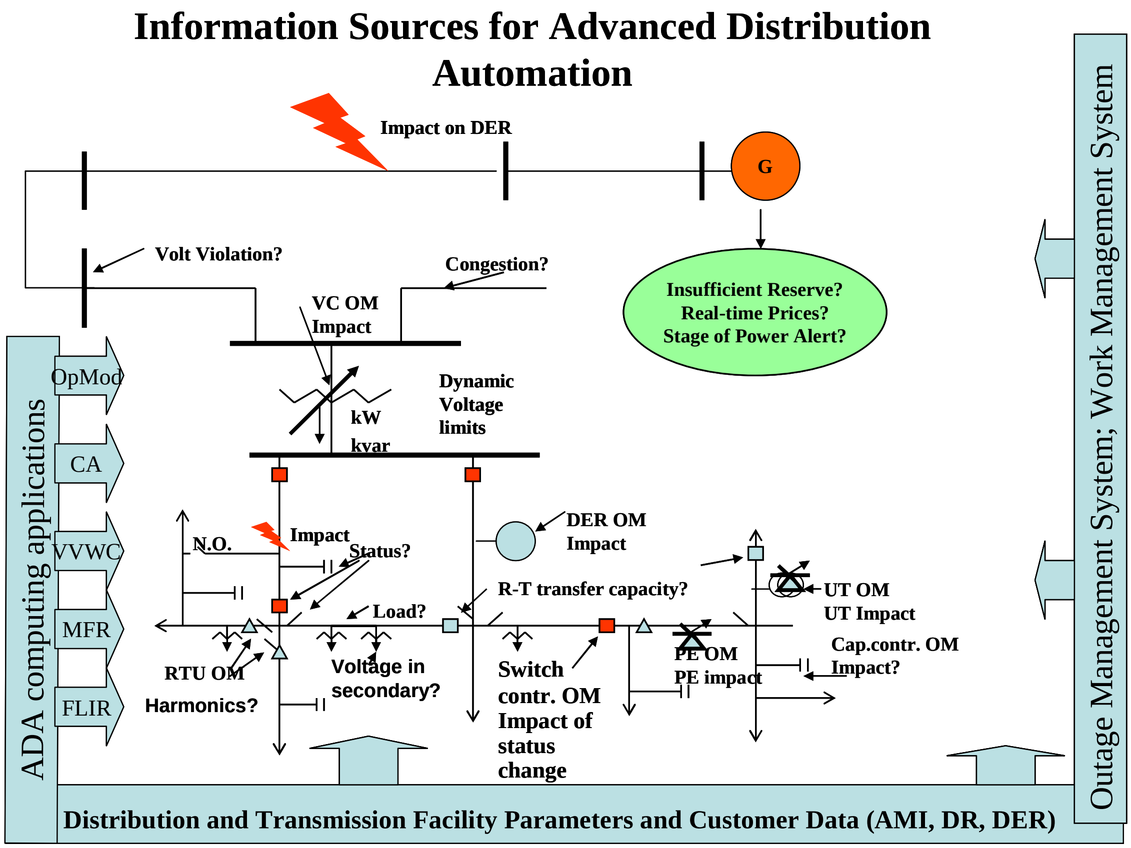

Figure 3. Multiple object models reflecting the functionalities and parameters of the object to be used in advanced distribution applications will be needed.

Conclusions.

1. There are well specified, field-tested and implemented in some utilities Advanced Distribution Automation applications, which meet many of the requirements of the Smart Grid
2. These applications can be upgraded to fully meet the requirements of the smart grid in a comparatively short time interval, definitely before significant penetration of the Smart Grid technology in the distribution systems.
3. In addition, new DA applications will need to be developed to fully utilize the advantages of the Smart Grid.

References.

1. EISA, Title XIII – Smart Grid
2. Federal Energy Regulatory Commission, Smart Grid Policy, (Issued March 19, 2009), 18 Cfr Part Chapter I, [Docket No. Pl09-4-000]

3. The Integrated Energy and Communication Systems Architecture, Volume II: Functional Requirements, http://www.intelligrid.info/; http://www.intelligrid.info/HTML/IECSA_VolumeII.htm
4. Guidelines for Assisting Understanding and Use of IntelliGrid Architecture Recommendations: Distribution Operations, Use Case for Distribution Operation Model and Analysis, EPRI Palo Alto, CA: 2006. 1013612.
5. IntelliGrid Architecture Development for Distribution Systems. Requirements and Device Information Models for Integrated Advanced Distribution Automation Applications, EPRI, Palo Alto, CA: 2008, 1013843 EPRI
6. Guidelines for Assisting Understanding and Use of Intelligrid Architecture Recommendations: Distribution Operations, EPRI, Palo Alto, CA 2006,1014702.
7. Technical and System Requirements for Advanced Distribution Automation, EPRI, Palo Alto, CA: 2004. 1010915
8. Studies Of Distribution Operations to Aid In Determining Object Models for Distributed Energy Resources (Phase 1), EPRI, Palo Alto, CA, 2004,
9. Guidelines for Planning Interoperable Distribution Automation Systems, EPRI Palo Alto, CA 2004, 1002161
10. Network and System Management (NSM) Development for Distribution Automation, EPRI, Palo Alto, CA, 2002, TR-1001701
11. Benefits And Challenges Of Distribution Automation (DA: Use Case Scenarios and Assessments of DA Functions, Draft report Prepared for: California Energy Commission by Xanthus Consulting International, Public Interest Energy Research Program, 2008
12. Distribution Automation and Demand Response, N. Markushevich and A. Berman, DistribuTech2008, Tampa, Fl, January, 2008; North American Policies and Technologies, Electricity, Transmission & Distribution, 2008, Volume 20, No. 8 ; 2009, Volume 21, No. 1 http://www.electricity-today.com/download/issue8_2008.pdf; http://www.electricity-today.com/download/issue1_2009.pdf
13. Integrated Voltage, Var Control and Demand Response in Distribution Systems, Nokhum Markushevich and Edward Chan, IEEE PES, March 2009, Seattle
14. What Can Distribution Automation Do For Power System Reliability?, N. Markushevich, A. Berman , J. Handley, DistribuTech, 2005
15. Experience of System - Wide Distribution Automation At JEA, Don C. Gilbert, Nokhum Markushevich and Alex Fratkin, Distributech 2004 conference
16. Distribution Volt and Var Control in Emerging Business Environment, Nokhum Markushevich (UCI) and Ron Nielsen (B.C. Hydro), CEA Technologies Distribution Automation Seminar, Halifax, Nova Scotia, Canada. June, 2003
17. The Specifics Of Coordinated Real-Time Voltage And Var Control In Distribution, Nokhum S. Markushevich, Utility Consulting International (UCI), Distributech 2002 Conference

18. Performance Of Advanced DA Applications Implemented in JEA , Nokhum S. Markushevich (UCI), Charles J. Jensen (JEA), Alex I. Fratkin (UCI), and Jerry Knowles (JEA), Distributech 2001 Conference
19. Adaptive Control Of Multiple Protective Devices In The Distribution Automation System At JEA, Charles J. Jensen (JEA), Nokhum S. Markushevich and Aleksandr P. Berman (UCI), Distributech 2001 Conference,
20. Implementation Of Advanced Distribution Automation In US Utilities, Nokhum S. Markushevich and Aleksandr P. Berman (Utility Consulting International), Charles J. Jensen (JEA), James C. Clemmer (OG&E), USA, CIRED Conference, Amsterdam, 2001
21. Dynamic System Load Control through Use of Optimal Voltage and Var Control, Nokhum Markushevich, Ron E. Nielson, 1998 Dynamic Modeling Control Applications for Industry Workshop, IEEE Industry Application Society, 1998, Vancouver, Canada
22. Optimizing Feeder Sectionalizing Points for Distribution Automation, Charles Jensen, Nokhum Markushevich, Alex Berman, DA/DSM Distributech Conference, January 1998, Tampa, Florida.
23. Analysis of Capacitor Control Under Conditions of Distribution Automation at OG&E, Nokhum Markushevich, James Clemmer, Alex Berman, Alla Royz, DA/DSM Distributech Conference, January 1998, Tampa, Florida.
24. Impact Of Automated Voltage/Var Control In Distribution On Power System Operations, Nokhum S. Markushevich, R.E. Nielsen, A.K. Nakamura, J.M. Hall, R.L. Nuelk; DA/DSM Conference January 1996, Tampa, Florida.
25. Integration Of Distribution Automation into Power System Operation, Edward H.P. Chan, Nokhum S. Markushevich; DA/DSM Conference, January 1994, Florida
26. Xcel Energy Smart Grid, A White Paper
27. San Diego Smart Grid Study, Final Report Prepared by the SAIC Smart Grid Team, October 2006