ADMS Test Bed: Defining a Use Case for Data Improvement for ADMS Deployment

Preprint

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Presented at the 2019 IEEE Innovative Smart Grid Technologies Conference (IEEE ISGT)
Washington, D.C.
February 18–21, 2019

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Contract No. DE-AC36-08GO28308

Conference Paper
NREL/CP-5D00-72404
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Suggested Citation
Veda, Santosh, Murali Baggu, and Annabelle Pratt. 2019. *ADMS Test Bed: Defining Use Case for Data Improvement for ADMS Deployment: Preprint*. Golden, CO: National Renewable Energy Laboratory. NREL/CP-5D00-72404. https://www.nrel.gov/docs/fy19osti/72404.pdf.

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Defining a Use Case for ADMS Testbed: Data Quality Requirements for ADMS Deployment

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***Abstract*—Advanced distribution management systems (ADMS) provide a suite of tools to meet the needs of a modern grid: increased reliability and power quality, improved resiliency and security, reduced costs, and enhanced customer participation. A critical challenge that utilities face with adoption of ADMS is the quality of models and data that the ADMS uses for making control decisions. Data quality has a two-fold impact on ADMS adoption: 1. Data quality improvement might constitute up to 25% of ADMS deployment costs. 2. The accuracy of data and models used by the ADMS affects the utility's ability to meet its operational objectives. Thus, quantifying the data quality requirements and its impact on performance is critical to reducing the overall cost of deployment, enabling increased adoption and ensuring that the ADMS performs as specified. This paper offers the motivation, methodology, and evaluation strategy to fill this critical gap.**

***Index Terms*—ADMS, data quality, performance, ADMS test bed, measurement density**

I. INTRODUCTION

Modernizing the utility control center is critical to modernizing the grid. The traditional control centers feature a host of enterprise systems that each have a critical contribution to keeping the grid well and functioning: an outage management system aids in power restoration, a geographical information system (GIS) provides an inventory of utility equipment, a supervisory control and data acquisition (SCADA) system interacts with all the field devices and sensors, and so on. Seamless integration of these operational silos is a must to meet the customer needs for increased reliability, improved power quality, improved security, improved customer participation, and weather resiliency. The advanced distribution management system (ADMS) offers the potential to help meet these needs. The ADMS is a utility control platform that subsumes these enterprise-level systems to enable the integration of control objectives to meet the utility operational needs.

The paper addresses a critical challenge for successful ADMS deployment: identifying operational requirements and quantifying performance improvement. Specifically, the focus is on the effect of improved data quality on ADMS performance. Funded by the U.S. Department of Energy Advanced Grid Research & Development Program, the ADMS Testbed platform at the National Renewable Energy Laboratory is a key technology enabler for this research study.

This paper is organized as follows: Section II provides an overview of identifying operational requirements through defining use cases. Section III delves into the need for the model improvement use case. Section IV defines the model improvement use case. Section V describes the test setup for evaluating the use case through the ADMS Testbed platform. Section VI presents the test metrics for evaluation, and expected test outcomes.

II. ADMS APPLICATIONS AND USE CASES

In this section, the process for developing use cases and an overview of advanced ADMS applications are presented.

A. Developing and Testing Use Cases for the ADMS Testbed

The use cases for the ADMS Testbed are developed using a collaborative approach that involves multiple stakeholders, including utility and vendor partners. The utility defines the operational challenge that is to be addressed through an ADMS deployment. The use case is further refined through discussions with the vendor partner. Fig. 1 shows a high-level overview of how the use cases are defined and evaluated using the ADMS Testbed.

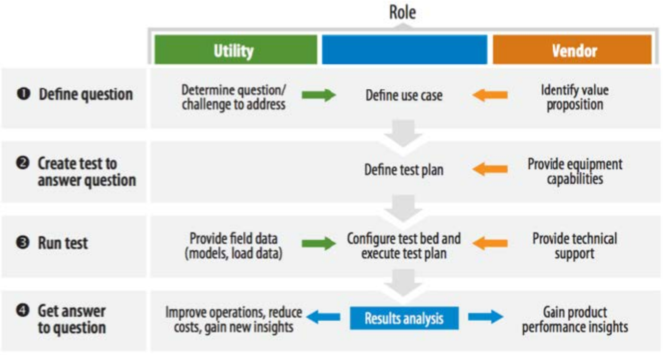

Fig. 1. Process for developing and evaluating a use case

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory. Funding provided by the U.S. DOE Office of Electricity Delivery and Energy Reliability, as part of the Grid Modernization Laboratory Consortium.

Some use case questions could be:

- How should the ADMS interact with assets such as smart inverters and grid-edge devices to maximize VVO performance/benefits?
- How should the FLISR be configured if the feeder load consistently exceeds 50% or if there is a large PV penetration?
- What are the operational benefits of deploying an advanced application to a specific utility?

B. Overview of ADMS Applications

The ADMS as a platform hosts several advanced applications, each tailored to meet specific operational objectives [1], [2]. After a review of these applications, five were selected by the ADMS Testbed team partners and industry stakeholders for further study [3]. Fault location, isolation, and service restoration (FLISR) and Volt/VAr-optimization (VVO) are deployed by utilities to meet current operational requirements. Online power flow and distribution system state estimation are core ADMS applications. Market participation might be a future need.

Use cases are then defined to capture the diversity in how the advanced applications are used by a utility. For example, the VVO application can be used to maximize energy savings [4], whereas other utilities might use VVO for voltage flattening, power factor improvement, or a combination of these objectives [5]. This paper addresses the data quality requirements for successful ADMS deployment.

III. MODEL IMPROVEMENT USE CASE

ADMS is a primarily model-driven control platform that requires accurate data to correctly model the distribution network and meet benchmark performance standards. When utilities deploy an ADMS system, the typical data source for the ADMS models is the utility GIS. The GIS provides limited information compared to what is required for power flow convergence in the ADMS. Each advanced application in an ADMS will require additional information that is not already available or not needed (and hence not verified). The process of data cleaning and mapping can take several months, and it could constitute up to 25% of the ADMS project costs [6]. Utilities with experience in deploying an ADMS consider data verification a separate project.

Given the significance of good data for robust ADMS deployment and given the uncertainties around the status of data that exist in utility systems, there is a need to address this challenge to reduce the cost of deployment and mitigate risks from poor data and thus enable increased adoption of ADMS platforms. The following questions are pertinent to issues around data for ADMS deployment: What level of data cleanup needs to be performed for successful deployment? Can the need for data cleanup be offset by deploying additional sensors? Can sensors such as advanced metering infrastructure (AMI) be used in addition to SCADA points to improve ADMS performance? What is the impact of the reduced data quality on the performance of ADMS and its applications?

IV. USE CASE SETUP

The ADMS Testbed project team developed a methodology to address these questions. Accordingly, four levels of data quality and four levels of measurement density were identified. The objective is to quantify the performance of the ADMS for VVO application for different combinations of data quality and measurement density. This experiment would allow for quantifying the input costs to add new sensors and field verification (to improve data quality) against actual improvement in ADMS performance. Such an exercise has not been undertaken before. The project team will use feeder data from a utility partner and a commercial ADMS platform from a vendor partner to perform the experiments.

A. Levels of Data Quality

The following four levels of data quality have been defined to evaluate the impact of data quality on ADMS performance. Although these levels were identified for the VVO application, these levels will capture the performance improvements for other ADMS applications as well.

Level 1: This is base-level data extracted from the distribution utility GIS with defaulting to enable the power flow to converge.

Level 2: In addition to Level 1 data, field verification will occur at select locations to obtain wire sizes (where unknown), obtain or confirm step transformer attributes, and collect capacitor, regulator, and recloser attributes. These asset locations will be noncontiguous.

Level 3: In addition to Level 2 data, phasing information will be collected through field verification at select locations.

Level 4: In addition to Level 3, field confirmation will be performed for each primary circuit to obtain distribution transformer attributes and phasing. In addition, the GIS data will be verified by identifying new assets not shown in the GIS and identifying assets that no longer exist in the field.

B. Levels of Measurement Density

Measurement density is the second dimension of the experiment. Although accurate models provide a foundation for robust ADMS deployment, the availability of real-time data from the field is critical to the effectiveness of advanced applications in meeting the control objectives. Pervasive real-time measurements might even offset the need for further field verification. A second motivation for including measurement density is to leverage the AMI sensors ("smart meters") for operations. Although the AMI infrastructure has been deployed widely, their utility has been limited to customer billing applications. The AMI data have a lot of potential to improve the operational effectiveness of the utility control center when integrated with advanced control applications. Accordingly, the following measurement density levels are defined:

Level 1: Only the measurements from the feeder head for each feeder will be used for ADMS operations.

Level 2: In addition to Level 1, voltage regulators, capacitor banks, reclosers, and one tail-end AMI sensor per feeder will be used by the ADMS.

Level 3: In addition to Level 2, nine AMI sensors per feeder will be identified based on location. Thus, Level 3 will consist of a total of 10 AMI sensors per feeder in addition to the SCADA points at the feeder head and other utility assets.

Level 4: In addition to Level 3, real-time measurements from 10 additional AMI sensors will be used by the ADMS. Thus, Level 4 will consist of a total of 20 AMI sensors in addition to the SCADA points.

V. TEST SETUP

The experiment will be carried out in two phases: I) software-based simulations II) hardware-in-the-loop (HIL) interoperability testing and validation. The two phases are represented in the Fig. 2.

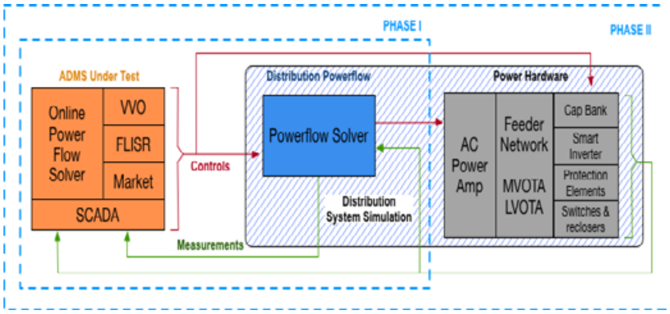

Fig. 2. Two-phase experiment

A. *Software-Based Simulations*

Phase 1 will use software-based quasi-static time-series (QSTS) simulations. The distribution power flow in Fig. 1 represents the distribution system. The ADMS under test will interact with the distribution power flow through two paths: control and SCADA. Through the control path, the ADMS, through its applications, will send control set points to the different components inside the power flow block as if it were interacting with real power system assets. The SCADA path will allow the ADMS to receive inputs from the distribution power flow as if it were receiving measurements from real field devices. Note that the ADMS under test is deployed in the same manner as it is deployed in the field. This enables an accurate emulation of the utility operations for the experiment. The ADMS under test will be loaded with the four levels of model quality, and the distribution power flow will be loaded with Level 4 model quality. For each level of model quality, the number and location of measurements used for the VVO execution will be adjusted to reflect the different levels of measurement density. Thus, the experiment will allow for measuring the ADMS performance for different combinations of measurement densities and model qualities. The study will be repeated for four days (high peak, load peak, and two shoulder days) to capture different operating conditions.

B. *HIL Experiments*

In Phase II, the QSTS-based distribution power flow will be replaced by a multi-timescale simulation that would include QSTS simulations, phasor model-based simulation, and electromagnetic transient simulations. This would enable the experiments to capture dynamic and transient characteristics of the distribution network and enable real-time HIL capabilities. In an HIL setup, the ADMS can be integrated with actual power system equipment, such as solar and battery inverters, and individual asset controllers at scale.

VI. TEST METRICS

The test metrics will be used to evaluate the ADMS performance for different combinations of measurement density and model quality. The following test metrics have been defined to quantify the performance of the VVO application. More specifically, the research will focus on conservation voltage reduction (CVR) [7] [8].

A. *CVR Energy Reduction*

The metric represents the amount of energy reduced using the CVR technique, computed using measurements from the feeder head. First, the baseline energy consumption, $E_{base,i}$ is computed for the feeder *i* by calculating the total energy consumed at the feeder head without application of the CVR control:

$$\textbf{CVR Energy Reduction}_{\mathbf{i}} = \mathbf{E_i} - \mathbf{E_{base,i}}$$

where E_i is the total energy consumed at the feeder head for feeder *i* for a specific combination of model quality and measurement density.

The CVR energy reduction will capture the impact of model accuracy and availability of measurements on the effectiveness to perform CVR. If the models are accurate, the ADMS would have an accurate estimate of voltages across the network, thereby performing CVR without causing voltage violations. If additional measurements (especially AMI measurements at the tail end) are available, the voltages can be reduced further without the need for conservative estimates for voltage drop across the service transformer; it also results in improved state estimation accuracy.

B. *System Average Voltage Magnitude Violation Index*

The system average voltage magnitude violation index (SAVMVI) [9] is an aggregate index that captures the voltage magnitude violations on the feeder. The ANSI C84.1-2011 steady-state voltage standard is applied to identify a voltage magnitude violation. The standard requires a regulation ±5% around 1 per unit (p.u.). Hence, the normal voltage range is between 0.95 p.u. and 1.05 p.u.

First, the magnitudes of the voltage violations are calculated for all the voltage measurements that are outside the normal range:

$$V_{viol\_mag} = \begin{cases} V_{bus} - 1.05 & if\ V_{bus} > 1.05 \\ 0 & otherwise \\ 0.95 - V_{bus} & if\ V_{bus} < 0.95 \end{cases}$$

The SAVMVI metric is then computed as the summation of magnitude of violation for all the voltages averaged over the total number of buses:

$$SAMVI = \frac{1}{N}\sum V_{viol\_mag}$$

where N is the total number of buses in the network.

C. Average Absolute Voltage Deviation Index

The average absolute voltage deviation index (AAVDI) metric provides a measure of the flatness of the voltage profile across the feeder. A flatter voltage profile allows the ADMS to reduce the voltage further to maximize the CVR benefits. First, the deviation of the voltages ($Vdev_{bus,t}$) at each bus is computed as the difference between the voltage value and the median of the voltages across the feeder at that time step:

$$Vdev_{bus,t} = \left|V_{bus,t} - V_{median,t}\right|$$

The AAVDI metric is then computed as the summation of the all the voltage deviations averaged over the total number of buses and time steps:

$$AAVDI = \frac{1}{N * T}\sum_{\substack{bus=1\\ t=1}}^{\substack{bus=N\\ t=T}} Vdev_{bus,t}$$

D. Cost of Device Operation

This metric will capture the cost of operating voltage control devices—such as voltage regulators, capacitor banks, and load tap changers—as the ADMS issues control set points during the course of VVO execution.

The test metrics will be computed for each test scenario described above. A heat map matrix will be generated for each test metric. This matrix will show levels of measurement density on the horizontal axis and the level of data remediation on the vertical axis. Each block on the matrix represents a certain test scenario. These blocks will be characterized as green (good performance), yellow (average performance), or red (poor performance) for the selected set of test metrics. Performance characterization will be based on ascertaining statistical significance and analysis of variance techniques for the different scenarios. A sample heat map is shown in Fig. 3 for illustration.

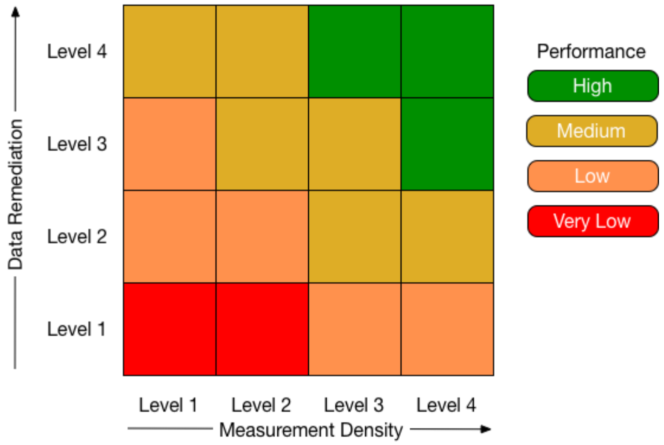

Fig. 3. Heat map of measurement density and data remediation showing hypothetical results

VII. CONCLUSION

The ADMS has the potential to usher in new technology, policy, market, and business paradigms that are necessary for operating modern electric grids. The key to enabling such a future is to identify and minimize the costs for deploying such systems. Data quality challenges not only impose direct costs (such as for field verification) but also result in additional indirect costs through reduced performance. Such uncertainties around benefits and performance need to be identified and quantified to enable increased utility acceptance and adoption.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of Energy under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory. Funding provided by the U.S. DOE Office of Electricity Delivery and Energy Reliability, as part of the Grid Modernization Laboratory Consortium. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

The authors acknowledge the project team members from Xcel Energy and Schneider Electric for their valuable inputs.

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