Defining a Use Case for the ADMS Test Bed: Fault Location, Isolation, and Service Restoration with Distributed Energy Resources

Preprint

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Defining a Use Case for the ADMS Test Bed: Fault Location, Isolation, and Service Restoration with Distributed Energy Resources

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***Abstract*—Advanced distribution management systems (ADMS) integrate multiple enterprise-level functions into a single platform and offer advanced applications such as fault location, isolation, and service restoration (FLISR), to utilities to meet their operational needs for a modernized grid. These applications need to operate reliably even as distributed energy resource (DER) penetration increases on distribution systems. The ADMS test bed at the National Renewable Energy Laboratory offers utilities and vendors the opportunity to evaluate the performance of such advanced applications on distribution feeders of the future and to understand their potential benefits for a specific utility. This is done through defining use cases that address specific questions. This paper presents the definition of a use case on the performance of a commercially-available FLISR application on a feeder of an electric cooperative with DERs. After experiments are completed, results from this use case will be disseminated to the electric utility and research community to improve understanding of the challenges and benefits that DERs present to ADMS applications and the operation of a modernized grid.**

***Index Terms*—Energy storage, power distribution faults, power system restoration, renewable energy sources, switches.**

I. Introduction

A key component of modernizing the electric grid is the modernization of the utility control center. Traditional control centers rely on several enterprise systems to ensure reliable operation of the grid. These include a supervisory control and data acquisition (SCADA) system that interacts with all the field devices and sensors, an outage management system to support power restoration after an outage, and a geographic information system (GIS) that provides an inventory of utility equipment. Meeting the needs for increased reliability, improved power quality, improved security, increased flexibility through customer participation, and increased resilience to weather events will require seamless integration of these systems. An advanced distribution management system (ADMS) is a utility control platform that integrates these enterprise-level systems to meet the control objectives of the utility, and therefore it has the potential to address this requirement [1]–[3]. In addition, an ADMS platform hosts advanced applications—including Volt/Var- optimization (VVO) and fault location, isolation, and service restoration (FLISR)—to meet operational objectives [4]–[6].

To ensure the ability of the ADMS to support grid modernization, not only do these applications need to operate in a seamlessly integrated manner, but they must also function properly and reliably in the presence of DERs [7]. This paper investigates the operation of a commercially-available centralized model-based FLISR application in the presence of DERs.

The U.S. Department of Energy (DOE) Office of Electricity Advanced Grid Research program has made significant investments to promote the adoption of ADMS to support grid modernization [8], [9]. One investment developed an ADMS test bed at the National Renewable Energy Laboratory (NREL). This vendor-neutral ADMS test bed was established to accelerate industry development and adoption of ADMS capabilities for the next decade and beyond [7], [10]. The test bed emulates a power distribution system using software and hardware elements that can be interfaced with an ADMS or other utility management system using industry-standard communications protocols. This enables utilities, vendors, and researchers to evaluate existing and future ADMS applications in a realistic laboratory setting.

FLISR is a key ADMS application being deployed in utility distribution systems and there has been a lot of research and development of FLISR algorithms in recent years. In this paper, the operation of a commercially-available ADMS platform's FLISR application in the presence of DERs will be evaluated through laboratory experiments using the ADMS test bed, which will be set up to emulate an existing distribution feeder with increased DER penetrations to represent a future version of the feeder. This is considered a use case of the ADMS test bed project.

This paper contributes a methodology for studying the impact of DERs on a FLISR application and is organized as

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follows: Section II provides an overview of the process to identify use cases for the ADMS test bed project and summarizes past, current and potential future use cases. Section III describes the FLISR with DERs use case and Section IV describes the setup for evaluating this use case using the ADMS test bed. Section V presents the test procedures and test metrics for evaluation, and Section VI concludes.

II. Developing Use Cases for the ADMS Test Bed

Use cases for the ADMS test bed are defined to reflect how and under what conditions ADMS applications are used by a utility. We use a collaborative approach in which we involve utility and vendor partners as stakeholders, as illustrated in Fig. 1. The definition of a use case could start with a utility that defines an operational challenge that they want to address through an ADMS deployment. It could also start with a vendor that wishes to demonstrate the value of one of their applications under certain conditions. The ADMS test bed project team then develops a test plan with inputs from the vendor on their product's capabilities. The test bed is then configured, the test plan is executed, and the test results are analyzed in collaboration with the utility and vendor partners, who gain new insights into product performance.

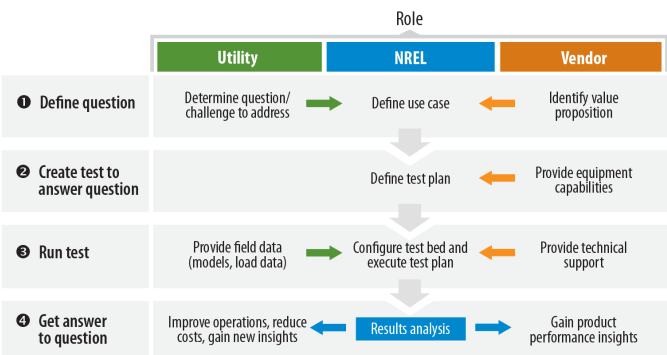

Fig. 1. Process for developing and evaluating a use case.

At the start of the ADMS test bed project, the project team reviewed all ADMS applications and selected five for further study through use cases in collaboration with project partners and industry stakeholders [11]:VVO, FLISR, online power flow, distribution system state estimation and market participation. We are currently simulating use cases related to VVO, which is an application deployed by utilities to meet operational requirements related to voltage management and efficiency. Some VVO applications rely on online power flow and distribution system state estimation, which are core ADMS applications. The first of the VVO use cases is an evaluation of the impact of model data quality on VVO performance [7], [10]. The second is coordinated peak load management between an ADMS that performs conservation voltage reduction and a prototype distributed energy resource management system (DERMS) [12], and the third is using advanced metering infrastructure (AMI) data for voltage management. The ADMS test bed has also been used by other projects to evaluate the performance of a data-enhanced hierarchical control architecture for voltage management [13] and to evaluate voltage management and load following by a prototype DERMS [14].

The final application selected for study, market participation, was identified as a potential future need. A project was recently launched that will use the ADMS test bed to evaluate an advanced ADMS application to aggregate DERs to provide bulk grid services. A potential future use case of the ADMS test bed project is an evaluation of ADMS coordination with a microgrid for dynamic constraint management and to support the bulk grid during peak load conditions.

III. FLISR with DERs Use Case

This section describes the FLISR with DERs use case and the test scenarios.

A. FLISR with DERs Use Case

FLISR is a critical application offered in commercial ADMS platforms being deployed in utility distribution systems [15], [16]. It operates groups of switches on distribution feeders to improve the reliability of power delivery after localizing outages. FLISR is an essential function for enabling a self-healing grid, and it directly affects grid reliability and resilience. In general, FLISR performs its function by:

- Detecting a fault when it has occurred on the feeder
- Locating the damaged portion of the feeder between two remotely controlled line switches
- Isolating the damaged portion of the feeder by operating remotely controlled switches
- Re-energizing undamaged portions of the feeder by using backup sources or connecting to other feeders using remotely controlled tie-switches.

Traditional distribution management systems (DMS) included FLISR functionality to perform automated switching actions for service restoration during faults. The FLISR in these systems offered limited functionality because of poor integration of the DMS subsystems [17] yet provided improved reliability over manual service restoration. The ADMS presents an improved platform to FLISR by providing access to other subsystems, such as a distribution network model; available grid resources; and field measurements. It allows the FLISR application to make switching decisions that result in optimal operation.

The presence of DERs brings both new opportunities and challenges for FLISR applications [4], [18]. Specifically, some DERs can help service restoration by acting as backup generation sources through appropriate switching actions and efficient algorithms are available [19], [20] to utilize the DERs for service restoration. However, the bidirectional power flow resulting from DERs might require dynamic changes to protective devices' fault current settings, and thus the FLISR application will need to dynamically adjust its operations in coordination with the dynamic protection settings [21], [22]. Also, some FLISR applications make their service restoration decisions and close tie-switches based on predefined rules that might no longer be appropriate in the presence of DERs because of their impact on net loads on the feeder network.

For this use case, the project team will use the FLISR application of the SurvalentONE ADMS operating on a hardware-in-the-loop (HIL) simulation of a feeder from Central Georgia EMC, a cooperative electric utility. The utility's specific interest is in the impact of different DER locations, tie-switch transfer limits, fault locations and DER trip settings on the performance of the SurvalentONE's FLISR application. The ADMS test bed project team developed a set of test scenarios to address these questions, and these are described in the next section.

These partners are also interested in how DERs, especially those with black-start and grid-forming capabilities, can be used to improve system restoration performance, and there is the potential for this use case to act as a starting point for such a study in the future. The test setup could also be used in the future to study the impact of locked or damaged switches.

B. Test Scenarios

The objective of this use case is to evaluate the performance of a commercially-available ADMS FLISR application (centralized, model-based) under different test scenarios, which consist of different combinations of DER locations, tie-switch transfer limits, fault locations, and DER trip settings.

The different DER locations that will be evaluated are illustrated in Fig. 2 for a feeder with a primary source, SRC0, and a secondary source, SRC1. The latter is connected to the feeder under study through a normally-open tie-switch, TIE1. Location options (b) and (c) also have another secondary source, SRC2, downstream of a second tie switch, TIE2. The amount of power that can be supplied by the secondary sources through the tie switches is limited, referred to here as tie-switch transfer limits. The feeder has two remotely controlled, normally-closed line switches. The first, SW1, is located upstream of TIE1, and the second, SW2, is located downstream of TIE1. The feeder is rural, with a peak load of 9.75 MW, a total length of 15 miles, and with 2,475 customers (approximately 90% residential and 10% small commercial). There are some rooftop PV systems, but at a low penetration, so they are not considered in the study.

Location option (a) has a utility-scale PV system and battery energy storage system (BESS) (PV+BESS) at a single, end-of-line location that is representative of a planned PV+BESS deployment on this Central Georgia feeder.

Location option (b) considers that same utility-scale PV+BESS deployment, but it is located at a single, mid-feeder location, upstream of TIE1.

Location option (c) has multiple utility-scale and behind-the-meter DERs—either PV systems or BESS—at multiple mid-feeder locations, both upstream and downstream of TIE1.

For DER location options (a) and (b), the BESS will be modeled as a grid-forming inverter-based source. For option (c), a mix of grid-forming and grid-following BESS inverters will be modeled. All PV systems will be modeled with grid-following inverters.

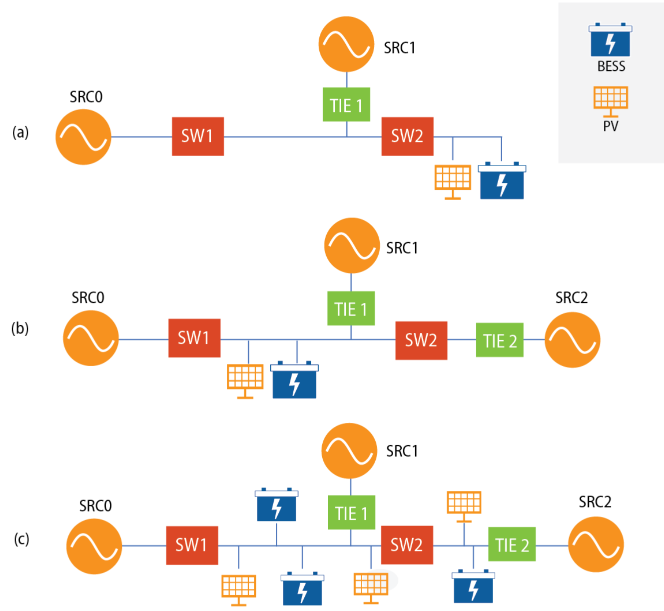

Fig. 2. DER location options (a) at the top, (b) in the middle, and (c) at the bottom. Network loads are not shown.

For each DER location option, we will generate at least 10 test scenarios to simulate based on a combination of tie-switch transfer limits, faults, and DER trip settings, listed in Table I. We will also simulate some baseline scenarios with no DERs on the system.

TABLE I
TEST SCENARIO INPUTS

Transfer Limits	Faults	DER Trip Settings
No transfer limit at TIE1	Between SRC0 and SW1	All generation rides through event (transient fault)
Transfer limit at TIE1	Between SW1 and SW2	All generation trips offline at first source trip
No transfer limit at TIE2	Between SW2 and TIE2—only for locations (b) and (c)	All generation trips offline at second source trip
Transfer limit at TIE2		All generation trips offline at source lockout
Source limit at SRC0 (feeder rating)		Mix of trip settings listed above—only for location (c)

Transfer limits can be applied to TIE1 and/or TIE2. We might also implement a source limit equal to the feeder rating for SRC0. Faults will be simulated in one of three locations, and faults may be transient or permanent. Different DER trip settings will be investigated. A specific combination of DER location, transfer limit, DER trip settings, and fault location and duration will comprise one test scenario.

The study will be repeated for 3 days with heavy, light, and shoulder load, respectively, to capture different operating conditions. We will also evaluate whether the initial state of charge and/or whether the BESS is charging or discharging at the time of the event has a significant impact on FLISR decisions. If this is found to be the case, then the state of charge and/or charging status might be added as additional test scenario inputs.

IV. Test Setup

The simulations will be carried out using the ADMS test bed at NREL's Energy Systems Integration Facility (ESIF). The ADMS test bed enables utilities, vendors, and researchers to evaluate existing and future ADMS applications in a laboratory setting that provides a realistic representation of a power distribution system using software and hardware elements [7], [10]. These software and hardware components of the test bed are interfaced with an ADMS or other utility management system using industry-standard communications protocols. Fig. 3 shows the test bed setup for this use case.

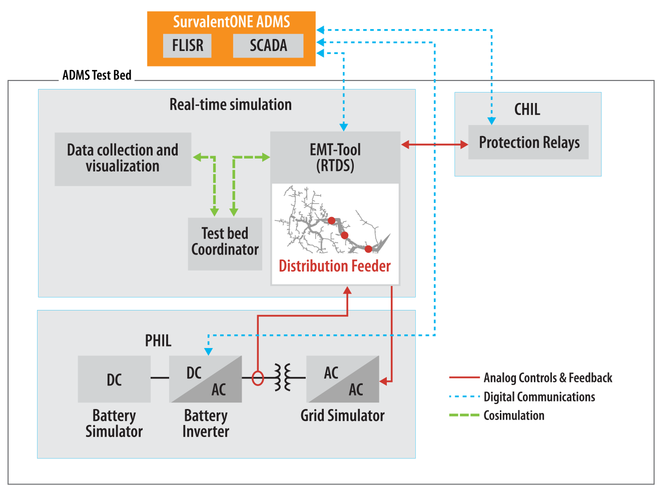

Fig. 3. ADMS test bed setup for the use case.

The test bed performs a real-time simulation of the distribution feeder, and the test bed can use different types of simulators [7], [10]. For this use case, we will simulate a reduced-order model of the feeder using electromagnetic transient (EMT) simulations. This will allow us to capture the dynamic and transient behaviors of the distribution network during and after faults. We will use a specialized digital real-time simulator from RTDS Technologies and model the feeder using their RSCAD software. We will use an average inverter model to simulate the PV inverters as well as the battery inverters for DER location option (c).

The test bed coordinator software will manage the execution of the simulation with the selected load and solar insolation profiles, fault locations, transfer limits and DER trip settings, as well as data collection and real-time visualization [23].

The RTDS will also allow us to integrate actual power system equipment, either controller or power hardware, with the simulation through HIL techniques. For this use case, we will interface protection relays through controller HIL (CHIL) and a grid-forming battery inverter through power HIL (PHIL). The battery inverter will be powered by a bidirectional power amplifier (grid simulator) at its AC terminals and by a battery simulator at its DC terminals. The ADMS will interface with both real and simulated devices using standard industrial protocols such as DNP3 and Modbus. The RTDS supports both these protocols to enable communications between the ADMS and simulated devices [7].

We will simulate power system faults and the resulting simulated currents and voltages may result in responses of some of the simulated devices that trigger the ADMS FLISR application. The simulated voltages and currents will be converted to analog signals—through the digital-to-analog signal interface of the RTDS—and provided to the relays and battery inverter hardware. These hardware may also respond in ways that trigger the FLISR application by providing feedback to the ADMS through its communications interfaces as shown in Fig. 3. A flow chart of the proposed methodology is shown in Fig. 4.

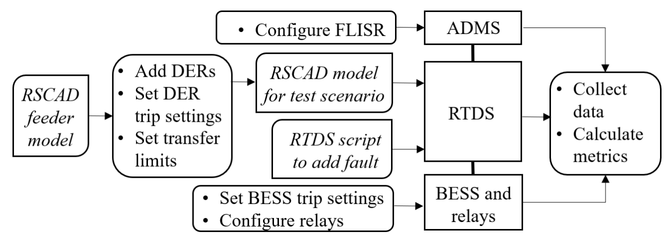

Fig. 4. Flowchart illustrating the proposed methodology.

V. Test Metrics

During testing, voltage and current waveforms and power measurements will be collected from the RTDS, relays (to capture the switching decisions implemented by the FLISR), the battery inverter, and the ADMS. The ADMS can provide statistical information on the number of affected customers, the FLISR response time, and the total energy delivered and not delivered.

Two metrics that are commonly used for evaluating FLISR performance are the System Average Interruption Frequency Index (SAIFI) and the System Average Interruption Duration Index (SAIDI). These are typically calculated over longer time periods (several weeks to 1 year), so they are not applicable to the relatively short ($<$ 1 day) simulation time that we will use.

The DOE Solar Energy Technologies Office published a list of criteria that can be used to evaluate grid resilience [24]. We will use some of these criteria, summarized in Table II, for evaluation. The test metrics will be calculated for each test scenario described. This will allow us to determine the impact of the different test scenario inputs on the FLISR performance, e.g., how a less sensitive trip setting influences the time to recovery.

VI. Conclusions

Utility adoption of ADMS has the potential to accelerate grid modernization through the deployment of advanced applications such as VVO and FLISR. The DOE Office of

TABLE II
TEST METRICS AND MEASUREMENTS

Test Metric	Description
FLISR response time	The response time of FLISR to detect and isolate faults
Time to recovery	Time between fault and all loads restored to power and all DERs restored to full generation capacity
Cumulative customer-hours of outages	Total number of customer-hours that load is not served
Cumulative customer energy demand not served	Total energy that is not served to customer loads
Number of customer outages	Average number (or percentage) of customers experiencing an outage during a specified time period
Cumulative critical customer-hours of outages	Total number of critical customer-hours that load is not served
Critical customer energy demand not served	Total energy that is not served to critical customer loads
Number of critical customer outages	Average number (or percentage) of critical customers experiencing an outage during a specified time period
Voltage excursions	Number of voltage excursions (beyond the acceptable range from 0.95–1.05 p.u.)

Electricity has established an ADMS test bed at NREL that can be used by utilities and vendors to evaluate the performance of such advanced applications and to understand their potential benefits for a specific utility. This is done through defining use cases that address specific questions. The use case presented in this paper is about the operation of a commercially-available FLISR application and its performance on a feeder of an electric cooperative with DERs. After completing the experiments, the results from this use case will be disseminated to the electric utility and research communities to improve understanding of the challenges and benefits that DERs present to ADMS applications and the operation of a modernized grid.

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