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GridAPPS-D Evaluation Framework: A Systems Engineering Approach

March 2017

TF Sanquist
KP Schneider

U.S. DEPARTMENT OF
ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Richland, Washington 99352

Acronyms and Abbreviations

ADMS	advanced distribution management system
AMI	advanced metering infrastructure
DER	distributed energy resources
DERMS	distributed energy resource management system
DMS	distribution management system
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EIOC	Electricity Infrastructure Operations Center
EPRI	Electric Power Research Institute
HMI	human–machine interface
JTA	job task analysis
MDMS	meter data management system
NREL	National Renewable Energy Laboratory
OPF	optimal power flow
PMU	phasor measurement unit
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
SCADA	supervisory control and data acquisition
UF	University of Fairbanks
VVO	volt-var optimization
WSU	Washington State University

Contents

Figures

Tables

1.0 Introduction

GridAPPS-D is a software development platform that will enhance the ability of power systems application developers to design and implement software that easily integrates across diverse systems and provides end users, such as distribution control center operators, with enhanced operational capabilities. As described in the research project plan, a principal task of this effort is to develop and implement evaluation processes that will compare both user and system performance on new applications with more traditional distribution management applications. Evaluation guidelines will also be prepared for utilities and other potential end user organizations enabling them to assess applicability within their established operational environment. The end-product of the evaluation process will be a quantitative description of benefits provided by the applications developed within the GridAPPS-D platform, as demonstrated in realistic operational scenarios in the Pacific Northwest National Laboratory (PNNL) Electricity Infrastructure Operations Center (EIOC).

Evaluation is commonly considered as a process happening at or near the end of an engineering development. However, the GridAPPS-D program is applying a systems engineering process to both the testing platform and application development. In systems engineering, various types of testing and evaluation are embedded in the development process from program inception. Thus, in the early stages of identifying potential opportunities for application development, a *formative evaluation* process facilitates identification of requirements and potential operational performance criteria for later objective testing. Throughout the design and development phases, continual *developmental evaluation* addresses risks as they are identified. Finally, when functional application programs are completed, *operational evaluation* determines the extent to which the new capability matches or exceeds baseline performance. The relationship between evaluation processes and application development is shown in Figure 1.

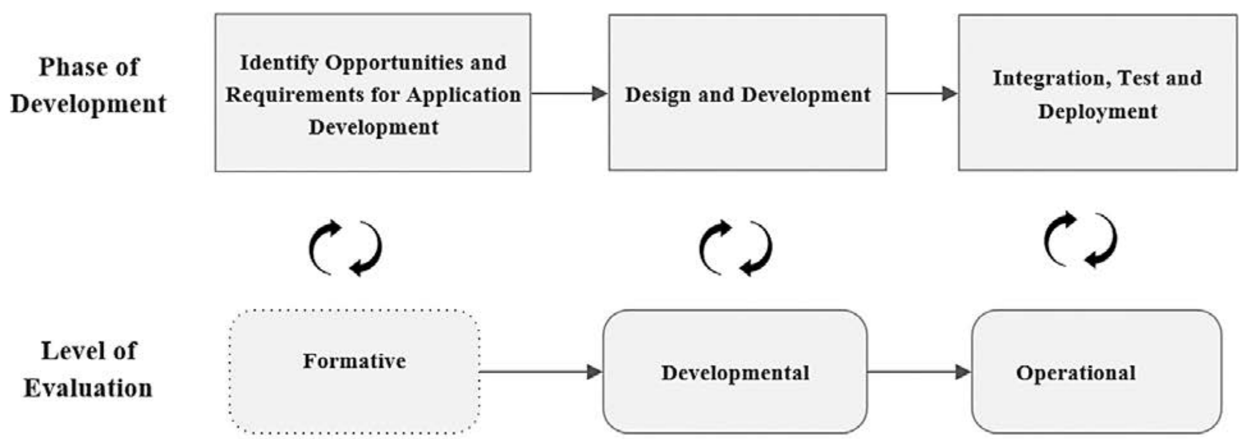

Figure 1. Levels of Evaluation in GridAPPS-D Systems Engineering Process

The systems engineering functions of evaluation and testing across the engineering life cycle are well characterized in the Department of Defense (DOD) Test and Evaluation Guide (2012). Evaluation is meant to “provide essential information to decision makers, verify and validate performance capabilities documented as requirements, assess attainment of technical performance parameters, and determine whether systems are operationally effective, suitable, survivable, and safe for intended use.” Further, “during the early phases of development, evaluation is conducted to demonstrate the feasibility of conceptual approaches, evaluate design risk, identify design alternatives, compare and analyze trade-offs, and estimate satisfaction of operational requirements.” As development proceeds, iterative evaluation becomes increasingly focused on specific performance criteria and demonstrating suitability for transition and integration with operational systems (DOD Test and Evaluation Guide, 2012).

This document outlines PNNL's evaluation framework and process for the GridAPPS-D program in the following sections:

- Section 2.0 discusses the general issues to be considered in evaluating new distribution management applications in an operational context.
- Section 3.0 describes formative evaluation process that will be used with developers to identify and select opportunities for specific application development.
- Section 4.0 describes general evaluation issues, including high-level scenarios to be addressed, and the architecture and physical structure of the operational evaluation system.
- Section 5.0 concludes with a plan for continued support of application development that will lead to operational testing in Year 3 of the program.
- The appendices provide early results from formative evaluation/requirements analysis for each of the application development team members.

2.0 Background

Developing credible evaluation scenarios requires an understanding of the operational context of distribution management operations. Software applications are generally embedded within a system-of-systems, comprising other software, databases, people, and organizations. This section summarizes the operational context of distribution management, to serve as a basis for developing realistic evaluation scenarios.

2.1 Distribution Management Functions in Context

Distribution management control centers were originally based in trouble-call management centers, where outages were handled. In this location, the distribution center personnel could interact directly with the field crew. Over time, distribution management control centers have become more integrated with centralized utility operations, with the preponderance of work focusing on clearance management and switching plans for planned outages. Less frequently, but still of prime importance, is facilitating the location of faults and restoration of service. Distribution management center operators tend to come from the ranks of field service crews, with whom they interact frequently during the management of switching and service restoration.

The principal functions of distribution management (whether performed by human operators, automated systems, or a combination of both) require:

- Knowing the grid conditions that impact forecasted and actual load
- Adjusting (via switching) to meet load demand, being cognizant of historical patterns, weather, distributed energy resources (DER) availability
- Planning, monitoring, and managing active and reactive flows to evaluate safety and reliability under normal and abnormal conditions
- Evaluating outage impacts
- Maintaining situational awareness for planned/unplanned outages, forecasted demand, resources available, and equipment status

Operations is often a department within a utility, while the *operational environment* includes all actors who participate in the day-to-day running of the system. Common groups include the core operations center, asset management, and external work management. These groups interact frequently by various means of communication. A prototype organizational system is shown in Figure 2, which also illustrates important linkages for generation, transmission, and customer systems.

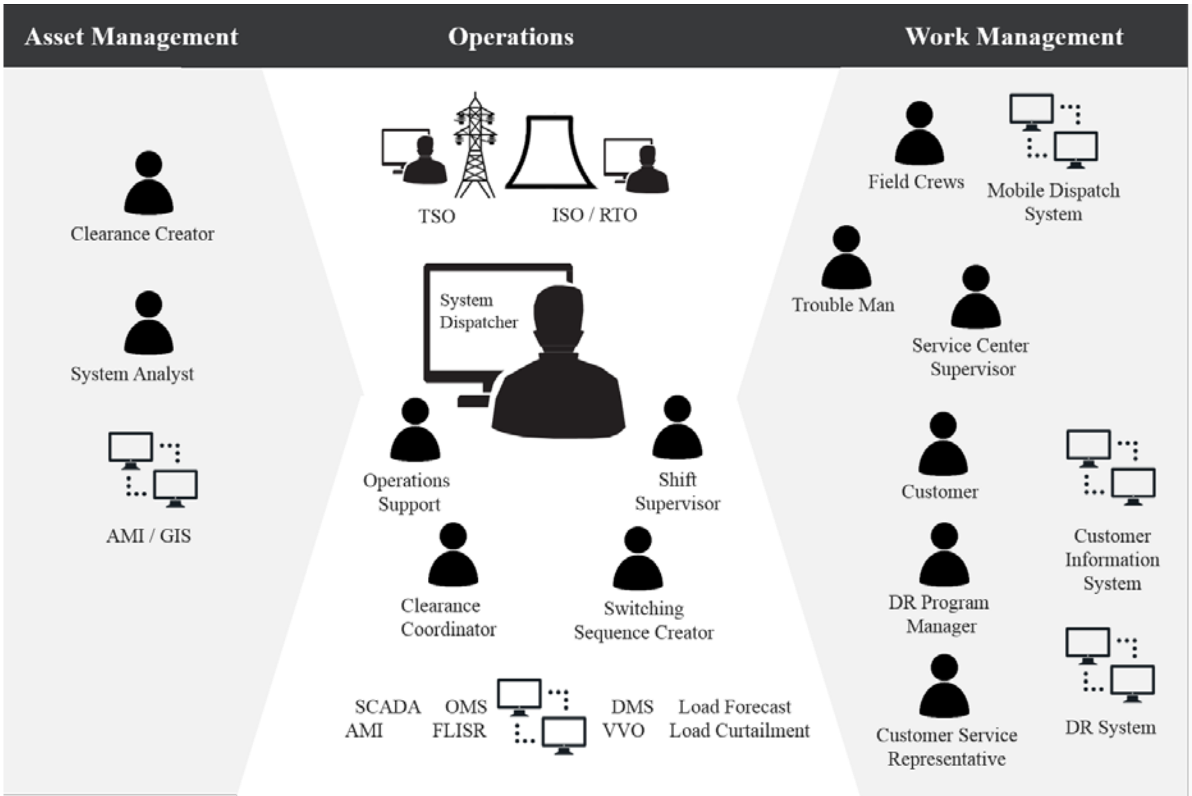

Figure 2. Component Systems within Distribution Management

Each of the organizations and individuals within them may have use for advanced applications developed within the GridAPPS-D program. Additionally, realistic evaluations of applications will require a substantial degree of operational fidelity, which will necessarily entail cross-organizational interactions and communications.

2.2 Operational Issues in Distribution Management

Typically, distribution management applications focus on activities within a control center. However, distribution management applications can exist in numerous forms and the following issues must be considered:

- Real-time vs. off-line planning
- Automated vs. manual
- Scope of interaction with human and non-human “actors” across organizations

In this setting, the term “application” is commonly thought of as a control center real-time tool. However, this is not necessary and we will consider applications that will be developed for the future data and control-rich environment that can replace existing manual workflows in addition to replacing automated systems. For example, a data analytics applications could be running in real-time to collect information, with the results sent to the planning department. These applications would not need to interact with the control room dispatcher. Figure 3 illustrates potential applications within the “space” of off-line to real-time, and fully manual to fully automated. As shown in Figure 3, various functions can be implemented in different ways within this operational space.

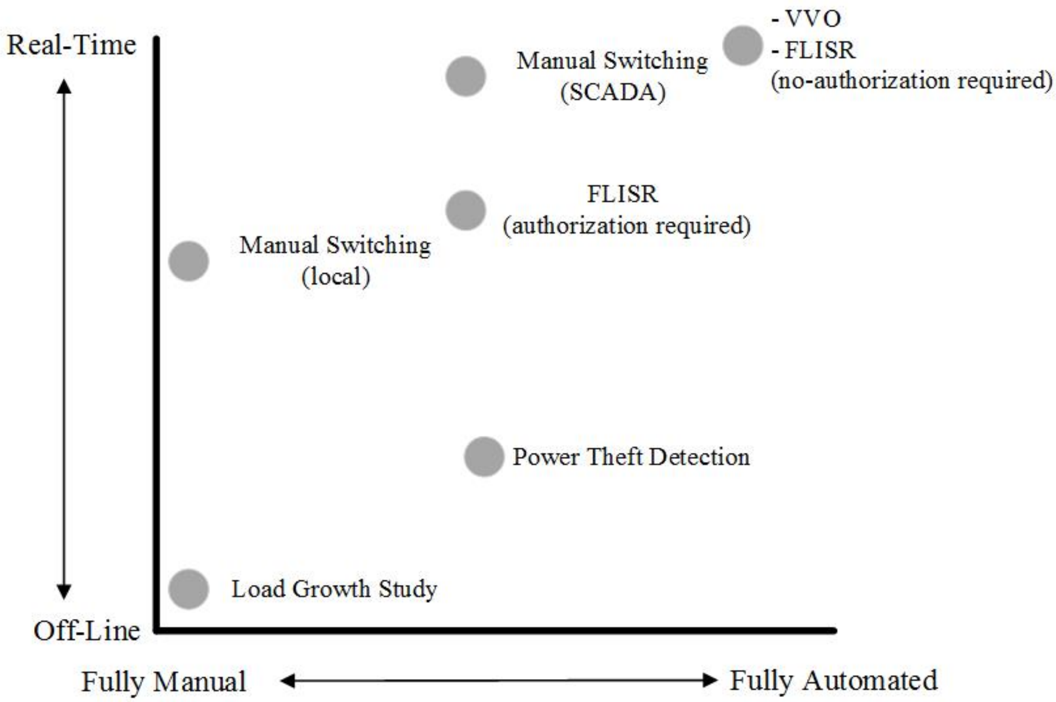

Figure 3. Operational "Space" of Potential Distribution Management Applications

Automation also needs to be considered in terms of supporting an overall workflow in distribution management. Operations tend to involve a cycle of acquiring and analyzing data, deciding what to do, and implementing an action. Thus, application automation may conceivably support some or all of these aspects of the work process, such as:

- **Data acquisition**: Is all data collected automatically (e.g., supervisory control and data acquisition (SCADA)) or is there a manual component (e.g., dispatcher talking to line crew)?
- **Analysis**: Is the data automatically analyzed or archived for human analysis?
- **Decision selection**: Are decision options generated via applications or constructed by a human?
- **Action implementation**: Are actions automated, human approved or authorized, or some combination of the two?

Figure 4 illustrates how three hypothetical software systems can vary in levels of automation across the various workflow functions that occur in distribution management. These variations will be important to consider in designing evaluation scenarios and measures. The beneficial value of a new application may not necessarily be evident in power system performance measures but may represent a substantial advance in terms of supporting the day-to-day operational workflow, such as the specific tasks necessary to dispatch a field crew.

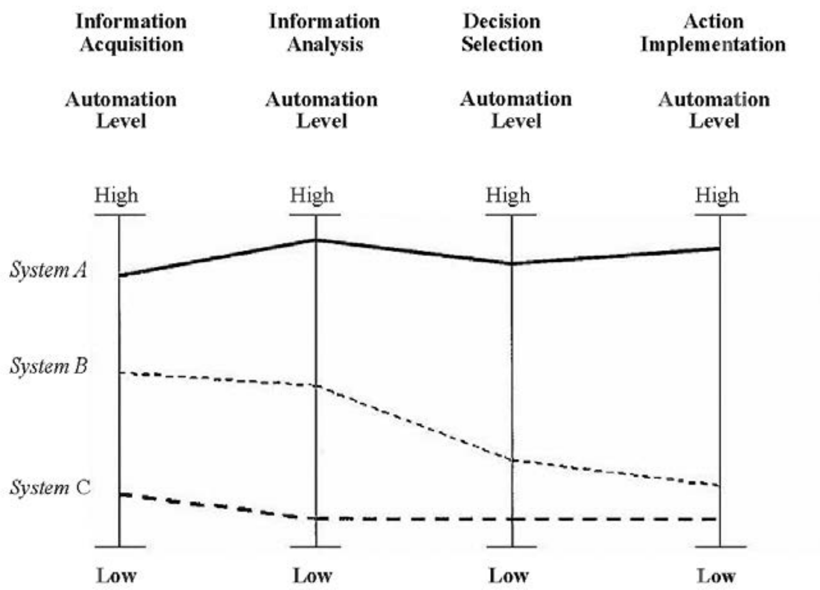

Figure 4. Hypothetical Levels of Automation for Three Different Systems across Workflow Activities (Parasuraman, 2000).

The generic information processing functions shown in Figure 4 are the elements of the operational work cycle in distribution management—whether they occur in a completely automated fashion or as an interactive process between human operator and software/data systems. These general functions need to be addressed in evaluation—how are they done now? How will they be done with new applications? How do the new applications change these functions for operational personnel in terms of increased or decreased workload, situational awareness, and trust in system performance?

3.0 Formative and Developmental Evaluation: Supporting Application Development

To support the early stages of application development, fundamental issues must be addressed related to conceptual designs, potential alternatives and trade-offs, and the criteria for eventual operational performance. We are approaching this phase of the project in terms of identifying opportunities for design that will enhance current approaches to distribution management tasks, and also be able to take full advantage of the GridAPPS-D platform for development.

To start this process, we developed an "application package" of basic requirements analysis questions for developers to consider in selecting potential applications for further work. Addressing these questions at this stage of the design process will

- provide a basis for selection specific applications to pursue, and subsequent design, development, and evaluation;
- explain the utility of the GridAPPS-D platform for developing the proposed application; and
- initiate a dialogue between the application developers and the project personnel focused on user-centered design and evaluation.

We conducted one design-focused workshop with the development team to introduce these requirements analysis questions, and generally agreed that they comprise a useful framework for early design concepts. Table 1 lists the ten requirements analysis questions, along with the rationale and utility for the development process.

Table 1. Application Requirements Analysis Questions to Aid Design and Development

Formative Evaluation Requirements Analysis Questions	**Rationale and Utility**
1. What is the primary function of the proposed application? Specifically, what problem does it solve?	• The application must address a known, or potential future, need. • Applications do not have to be operational dispatcher centric tools.
2. How is the function of this application currently achieved?	• For most commonly proposed applications, the function is currently performed in some manner at utilities. • Even if the process is fully manual, a workflow exists to achieve the desired outcome. • The execution of a function includes both the immediate actions, the interfaces, and data exchanges.
3. What is the organizational "home" of the proposed application (e.g., distribution operations center, other utility-specific system, transmission-level, third party)?	• Identifying the location of the application is necessary to properly identify all interactions and interfaces. • Applications can reside in a number of locations.

Formative Evaluation Requirements Analysis Questions	Rationale and Utility
	• Locations include, but are not limited to – DMS/ADMS[(a)] – Substation – Meter – Back office – Decentralized
4. Is the proposed application an interactive operational tool, or is it meant to run as a "background" process?	Applications do not have to be operational dispatcher centric tools.
5. If the application is a background process: a) How will the application be monitored for situational awareness and by whom? b) Does it feed data into another application which in turn interacts with one of the "actors" listed above? c) Is there a need to "phase-in" the operation of the autonomous application to develop trust among system personnel?	• For a background process there are two categories: – Operational – Non-operational • An operational background process runs continually but does not execute any action without human interaction. • A non-operational background process would typically be used by a group other than operations.
6. If the application is an operational tool, how is it intended to provide parameter display and control to an end user such as the distribution control center dispatcher? a) What is the job role of the intended end user or users (e.g., control center dispatcher, engineering analyst, field maintenance crew)? b) What parameters will be displayed and what parameters are controlled? c) What is the update rate of displayed parameters and what is the anticipated monitoring and control frequency? d) Will the tasks performed with the proposed application involve communication (verbal or other) with other people, either co-located or elsewhere? e) How will out-of-bounds system parameters (alarms) be displayed and annunciated? f) How will feedback be provided to the operator on control actions that they implement? g) How will erroneous operator input be addressed?	• Defining these complex interactions is what differentiates a transitional application and an applications built in a GridAPPS-D type environment. • It is necessary to define the inputs, outputs, and interconnections with other systems. • An operational application is far more complicated than the simple examples that are commonly cited in the literature.
7. Is the proposed application meant to address existing "system metrics" such as SAIDI, SAIFI, losses, or percent penetration of renewables	• For the applications performance to highlight the utility of the platform, there must be quantifiable metrics.

Formative Evaluation Requirements Analysis Questions	Rationale and Utility
supported? Or will new metrics be used to evaluate performance?	• Evaluation team will work with application developer to determine relevant measures. • The evaluation team will use the metrics when performing tests in the EIOC.
8. With which other subsystems will the proposed application be integrated?	• An application that only requires access to SCADA would not highlight the utility of the platform as effectively as one that interacted with a DMS, EMS, AMI,[(b)] and data warehouse. Suitable applications will require complex data sets that cannot be obtained from a single system.
9. Is the proposed application based on a familiar method of distribution operation, or is it based on future concepts?	• This question is designed to have the developer consider where the proposed application resides with respect to current applications. • Is it a small incremental improvement from existing applications? • Is it an advanced concept that will operate in a future environment that is not fully understood? • The program needs a range of applications.
10. What assumptions are made by the application on data and model quality?	An application that only requires access to SCADA would not highlight the utility of the platform as effectively as one that interacted with a DMS, EMS, AMI,
(a) DMS is distribution management system; ADMS is advanced distribution management system (b) AMI is advanced metering infrastructure	

Each member of the application development team provided responses to these questions for three candidate applications being considered for selection by their teams, including the following:

- PNNL
  - Volt-var optimization (VVO) with robust switching
  - State estimation with varying data quality
  - Transactive control
  - Model validation
- Washington State University (WSU):
  - Resilient distribution restoration with high-level DER penetration
  - VVO with integrated control of legacy and new devices (optimal power flow (OPF) formulation)
  - Automated DER interconnection

- National Renewable Energy Laboratory (NREL)
  - Data-driven real-time state forecasting
  - Online distribution OPF for real-time set point dispatch
  - Data-driven day-ahead forecasting
- University of Fairbanks (UF)
  - Fault tolerant distributed microgrid control

Each development team member provided initial answers to these questions, which are compiled in Appendixes A, B, C, and D. We anticipate that facilitated discussions among the team members will lead to selections for further development that are based on individual team member strengths, utility of the GridAPPS-D platform, and relative levels of innovation in design.

To facilitate addressing the application requirements analysis questions, the PNNL team will conduct focused job-task analysis of distribution management tasks that are currently performed in operations centers. This will serve two functions: (1) it will provide a baseline of current operational practice for designers to address in application selection and development, and (2) it will provide a task basis for developing operational scenario scripts and measures to be used in evaluation. Section 1.0 provides further description of the approach to job-task analysis.

4.0 Operational Evaluation Considerations

4.1 Scope

The project work plan calls for evaluation of newly developed applications by experienced distribution management system operators.

4.2 Experimental Design and Measurement

The basic approach to be used for evaluation is a direct comparison of how distribution management tasks are performed with traditional tools (baseline) with performance using new applications developed with the GridAPPS-D platform. The tasks will be performed under varying conditions of operational complexity, such as normal operations on a "blue-sky day," and in moderate storm and extreme storm conditions. These conditions are intended to exercise the newly developed applications to determine their resilience under increasingly difficult operating parameters. Table 2 portrays the general design of the evaluation framework.

Most of the work in distribution management system operations centers revolves around switching. As shown in Table 2, the increasingly complex scenarios involve switching for planned outages, isolation of feeder sections, and entire feeders being out of service. As applications are developed within the program, developers and evaluation specialists will define more specific tasks and workflows for assessing operational performance. General metric classes are shown in Table 2, including grid-performance measures (e.g., SAIDI, SAIFI), as well as more qualitative operator-focused measures such as operational workflow. System-specific measures can be calculated based on scaled event data (number of outages in an area, time-to-restoration); measures such as workflow will focus more on *how* work is performed. This will entail structured de-briefings of operators as either during or after activities such as switching operations, and potentially stopping a scenario to probe for situational awareness (perception of the elements in the immediate environment, such as grid operational parameters, understanding what those parameters mean, and planning for the next actions to be taken).

A key issue for the evaluation process is the extent to which the applications developed under this program actually required *observable operator activity* (i.e., responses to alarms, physical interaction with control systems, and communications with service personnel). It is likely that some—perhaps the majority of applications—will reduce the need of operators to execute such actions. At this point in the planning process, these circumstances are likely to occur and will prepare to address the issue of performance scenarios and metrics as specific applications are selected for development. A key part of developmental evaluation during Year 2 is working with the application teams to define specific metrics and scenarios for demonstrating performance and assessing changes from baseline. The metric "Operator Actions Avoided" may be a specific measure defined to reflect the increased level of automation provided by new applications. Similarly, "Operator Trust" may be a specific measure defined to calibrate the degree to which experienced operators are likely to permit a new application to run autonomously—such as a complex restoration switching scheme.

Table 2. Framework for Experimental Design of Application Evaluation

<table>
<tr><th>Condition</th><th>Operational Characteristics</th><th>Traditional Capability</th><th>New App Capability</th><th>Classes of Potential Measures</th></tr>
<tr><td>Scenario 1:
Blue-Sky Day</td><td>Feeders normally operating
Communications normal
Limited switching to support new load connection</td><td>Baseline</td><td>Comparison</td><td rowspan="3">Alarm logs
Response time
Workflow
Situational Awareness
Trust
SAIDI
SAIFI
CAIDI</td></tr>
<tr><td>Scenario 2:
Moderate Storm</td><td>Feeders abnormal
Momentary communication loss
Portion of feeder transferred to aid fault isolation</td><td>Baseline</td><td>Comparison</td></tr>
<tr><td>Scenario 3:
Extreme Storm</td><td>Feeder in abnormal operating condition
Persistent communications disruptions and outages
Portion of feeder out of service (includes end-of-line measurements)</td><td>Baseline</td><td>Comparison</td></tr>
</table>

4.3 Evaluation System Architecture and Physical Platform

We intend to perform the evaluations in a realistic simulation of a distribution management operations center, using the PNNL EIOC. This system is a re-configurable space consisting of external hardware typically seen in operations centers, such as workstations and wall-board video displays, and simulator functional elements to provide technical data, as shown in Figure 5. The EIOC is further divided into a control room environment space where operators perform tasks, and an evaluator/instructor space, where the evaluation scripts and communications are controlled.

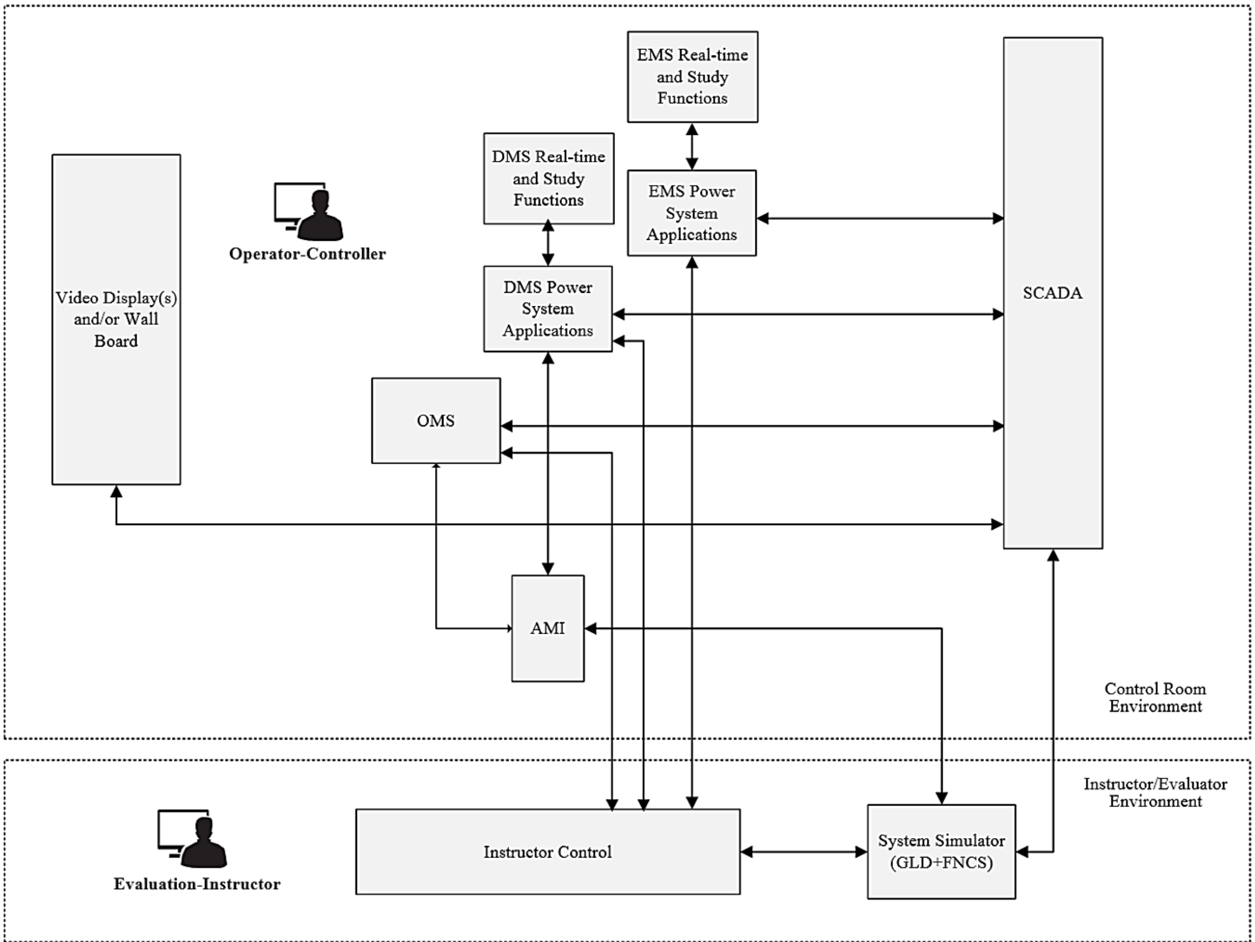

Figure 5. Basic Elements of the EIOC Evaluation System

Figure 6 shows the EIOC through the one-way mirror window used by the evaluation controller/instructor.

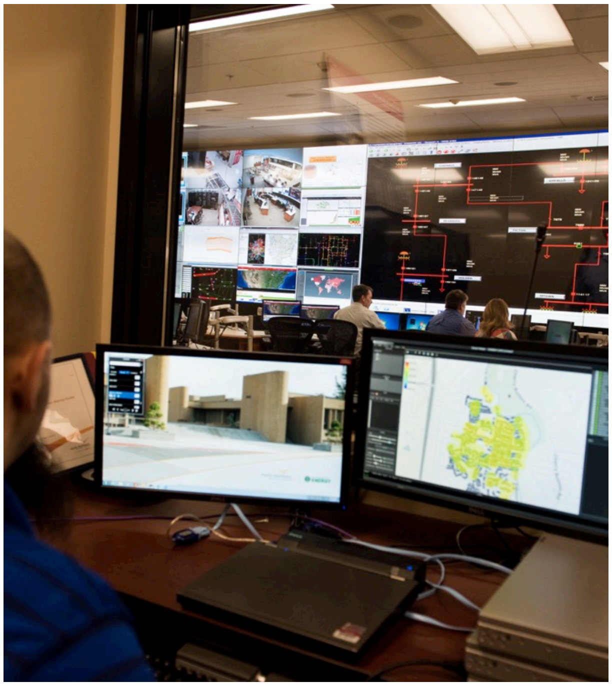

Figure 6. View of Operational Section of EIOC through Evaluation Controller One-Way Mirror.

4.4 Evaluation Scenarios – General Measurement Considerations

The application evaluation will use scenarios that accurately reflect current, and future anticipated, practices. Multiple observations of performance are desired but may not always be possible. Ideally five similar problems would be solved with each application. Problem scenarios must have defined indications of problem solution, which might include the following:

- Faulty feeder correctly identified
- Faulty feeder properly isolated
- Power re-routed via switching
- Critical loads maintained/non-essential loads shed during maintenance

Experienced dispatchers will be recruited to serve as test subjects in the EIOC.

Development of evaluation scenarios will be a joint effort between PNNL, Incremental Systems (evaluation consultant), and the application developers. The evaluation scenarios will be compared using traditional tools and enhanced with GridAPPS-D tools to assess performance improvements. Scenario scripts will be developed and administered by a test controller who observes and provides external communication content when necessary. Performance measures will involve both technical parameters reflecting power system health and status as described above, and operator parameters such as time-to-problem solution, alarm response, situational awareness, and workload ratings. More specificity of these measures will be the result of the joint process of evaluation scenario development.

Prior evaluations in the EIOC (e.g., Greitzer, et al., 2009, page 20) used the following approaches:

- Pre-scenario survey/interview
- Video and Audio capture for each experiment, focused on the participant
- Screen capture for each experiment – workstation software can capture the screens and actions that the participant views and takes.
- Running explanation of actions and thoughts – the participant is asked to explain their thoughts and actions out loud for the duration of the experiment.
- PowerSimulator log-messages – the PowerSimulator log captures and include all control actions taken with time stamps.
- Stopwatch – each experiment records the time the participant takes in reaching each major milestone relative to the scenario start time. This information is logged by the facilitator during the experiment (assuming it is available; otherwise log is updated after experiment).
- Post scenario interview – a human factors expert conducts an interview immediately after the experiment. Questions clarify and focus on determining what actions were taken, at what times, and why.
- Post scenario review – a subject matter expert reviews the actions taken by participants to determine the validity of the actions.

We intend to employ most of these approaches in the GridAPPS-D evaluations of specific applications.

5.0 Evaluation Project Plan, Years 2 and 3

The foregoing discussion emphasizes the developmental nature of evaluation planning. Defining specific application scenarios and metrics will be an iterative process, in collaboration with the software team members. This process needs to start with defining a core set of baseline operational tasks currently performed in distribution management operations centers. These core tasks will provide the baseline scenarios for which various classes of measures will be developed and serve as the benchmarks for comparison with similar functions as executed by new GridAPPS-D applications. Year 2 will entail developing a detailed understanding of how operational distribution management control centers work currently: tasks performed frequently, the workflow involved, specific vendor or homegrown systems used, displays, controls, and communications. Year 3 will entail translating these findings into executable evaluation scenario scripts and carrying out the evaluation. The following discussion focuses primarily on Year 2, as the work during this period will enable the selection of distribution management tasks for evaluation, and translating those into tractable scenarios.

5.1 Job/Task Analysis of Distribution Management Operations (Project Year 2)

To develop executable evaluation scenarios and specific measures of performance, it is necessary to perform focused job/task analyses (JTA) of distribution management operator tasks. Human work activity can be considered as comprising four basic functions (as shown in Figure 7): sensing, storing, processing/deciding, and acting. These activities can be carried out in myriad ways either by individuals, teams, or collective organizations. Description and analysis of how these functions are carried out is the essence of analyzing jobs and tasks.

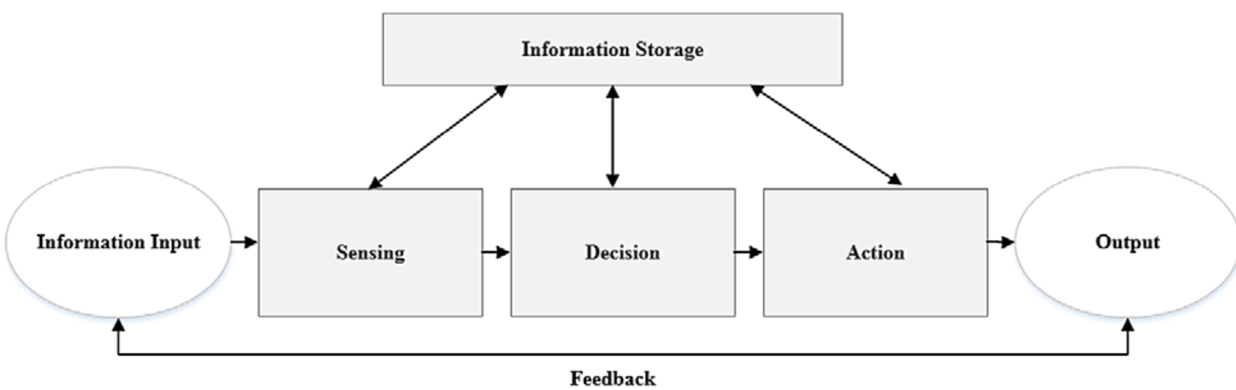

Figure 7. Four Basic Functions in all Human Work (McCormick, 1979).

The terminology used in the study of work is quite variable depending on the specific investigation purposes and the researcher's theoretical orientation. At a high level, *job* and *task* analysis can be distinguished as follows:

- *Job* analysis is generally considered a more macro-level description and analysis of a "group of positions which are identical with respect to their major or significant tasks" (McCormick, 1979, p. 19). Job analysis tends to be used for purposes such as personnel recruiting, selection, and evaluation, as well as establishing training programs and working conditions, setting compensation, manpower forecasting, and organizational planning.

- *Task* analysis is more focused on discrete work activities carried out by an individual or small team; tasks are combined to result in overall job performance, which is often influenced by higher level variables affecting the job (e.g. seniority, seasonal work, organizational biases). For the purposes of this research, we consider titles such as "Distribution Management Control Center Operator," "Field Service Technician," or "Operations Engineering Support" to be job categories. In contrast, "implement switching plan" would be considered a function or task with multiple sub-elements. Task analysis is focused on designing equipment, reducing errors, developing procedural training, and improving safety.

Since our evaluation in the EIOC focuses on control center activities, most of our analyses will involve the operators—those individuals who sit at workstations in a centralized facility, and coordinate activity with field crew and engineering/asset management (see Figure 2). Figure 8 shows a sequential functional task flow for the control room actions necessary to support switching in hot-line work (EPRI, 2002). Each of the task blocks illustrated in this figure can be further broken down into specific software systems displays that are used to access data and develop plans, and control actions and communications that are performed to implement those plans.

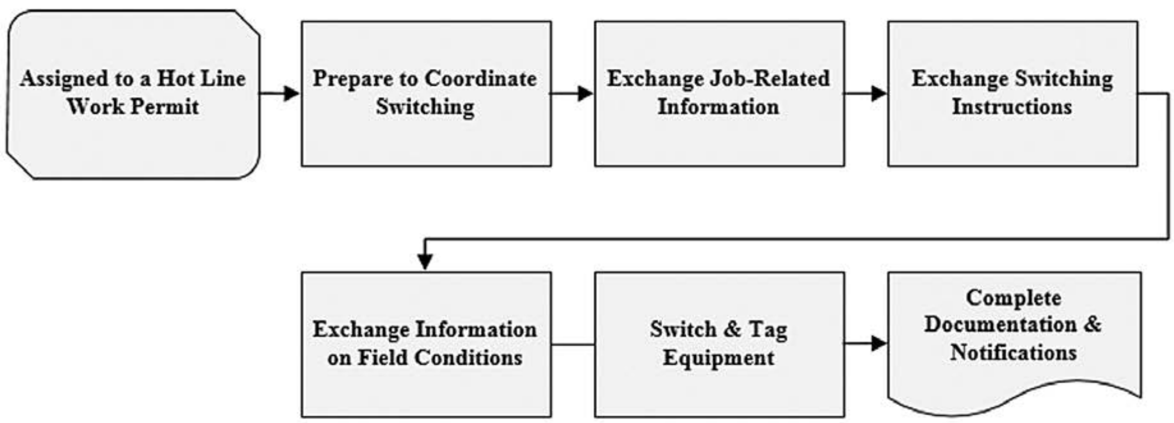

Figure 8. Control Room Actions to Support Hot Line Work Switching (EPRI, 2002).

We conducted preliminary JTA observations at one utility distribution management control room in October, 2016. The results of these observations suggest that more detailed knowledge acquisition is necessary to understand the specific task elements of the work cycle shown in Figure 8. In particular, the following questions need to be addressed:

- What are the most frequent functions/tasks performed by the operational personnel?
  - How frequently is the function/task performed?
- For each function or task, what specific software programs and displays are used to acquire information?
- For each specific function or task, what specific control actions and/or communications are made?
- Are there critical decisions that occur in the process?
- How are specific application functions and/or data such as SCADA, AMI, OMS, FLISR, DMS, VVO, Load Forecast, and Load Curtailment currently handled?
- What criteria are used to determine that a function or task is properly completed?

The optimal way to conduct JTAs for purposes of this project is to draw on the experience and contacts of consultants who have been extensively engaged with a variety of utilities in their work. The PNNL team members meeting this requirement are Modern Grid Solutions and Incremental Systems, Inc. Both have considerable experience conducting JTAs for various aspects of electric grid operations, and industry contacts who will facilitate access to operational control centers for observations and interviews. PNNL human factors evaluation experts will work with Modern Grid Solutions and Incremental Systems, Inc. to develop the protocols for knowledge acquisition, and documentation of results.

At present, utility visits are arranged for introductory purposes, to establish contact, observe the varieties of distribution management operations centers and their software tools, and to gather data based on the protocol described above. Where available, we will obtain JTA documentation from utility partners. JTA is an iterative activity involving progressive refinement of work decomposition until the goal of the analysis is met—in this case, the ability to specify and script executable evaluation scenarios.

We anticipate that the full range of distribution management activities will be observed, including

- Maintain Situational Awareness about Assigned Service Area
- Handling a Planned Outage
- Unplanned Outage Management
- Fault Localization and Isolation
- Service Restoration.

For each of these tasks, the analyst will try to understand the following:

- Who actually does the task – the individual you are talking? If not, who does?
- How frequently is the task performed? Many times per day? Only a few times per day? Try to get a sense of how often it is done.
- How is the task performed? What software programs, displays, and communications to others are made? What is the workflow among the subtasks—what do you do to start? What comes next? After that? (e.g., until the cycle is completed). Pictures of display screens are desirable. This is the information from which operational sequences and scenarios can be constructed.
- How do you know the task is finished?
- What critical decisions are made during the task? What are the contingencies? How does this process vary depending on weather and load conditions?
- How are specific application functions and/or data such as SCADA, AMI, OMS, FLISR, DMS, VVO, Load Forecast, and Load Curtailment currently handled?
- Impediments to getting the task done – What gets in the way? What could make this better?
- Things that make the task easier to perform. What are they?

5.1.1 Task Timing

The JTAs will be carried out during the April-June, 2017 time period. Site visits to partner utility control rooms will be made during this period for observations, interviews, and collection and/or review of specific operational JTAs that may already have been done.

5.2 Documentation of Job/Task Analysis Data (Project Year 2)

The observations and interviews made by the PNNL team during utility visits will be documented in a form similar to that presented by the Electric Power Research Institute (EPRI) and used as a general standard in developing training material and exercises. An extract from the EPRI (2002) report conveys the level of detail that will be necessary (along with the specific displays and controls used) to develop realistic evaluation scenarios. In addition to the focus on job/task sequence and current operational systems employed, the analysis will address questions concerning the *cognitive* content of the jobs; this often overlooked in strictly procedural approaches to JTA. The following are subtasks involved in exchanging job-related information for switching between control center and field crew (EPRI, 2002):

- Verify that the Field Crew Leader (the person executing the physical switching operation) receiving the instructions is the person who was designated to receive the instructions.
- Confirm communication tool to use (phone number, radio channel).
- Confirm possession of a copy of the Hot Line Work Request and/or associated Switching Instructions.
- Review the purpose of the Hot Line Work Request.
- Verify work location(s) including the name and location of recruits or equipment involved.
- Verify the time of the activity.
- Review any abnormal situations that may impact the work to be accomplished.
- Review the sequence of switching against maps and one-lines.
- Verify equipment to be removed from service or reconfigured and associated tags.
- If not already done, verify that the personnel who will do switching are “Qualified.”

5.2.1 Task Timing

The results of the JTAs will be documented on a continuing basis, with a preliminary report in early May 2017, and a final report on June 30, 2017.

5.3 Facilitation with Application Development Team (Project Year 2)

In parallel with the JTAs, each application development team will be working toward defining application scenarios and metrics that are specifically tailored to their anticipated products. This process has already been started by addressing the initial formative evaluation requirements analysis questions. As further design detail is developed, a better understanding of exactly what and how to evaluate for each application will established.

Application-specific evaluation scenarios and metrics will be developed through an iterative process involving co-facilitation of application and evaluation issue identification. We envision this process as involving workshops structured around the fundamental evaluation issues of how specific application functions are performed today and how they will be performed with new suites of software. One of the main tools during this phase of development will be structured walkthroughs of operational tasks, based on evolving application design specifications, to address the “how” of such core operational activities as switching, unplanned outage management, fault isolation, and localization, etc. The result of these facilitated workshops will be sets of scenarios and metrics that can be further developed for evaluation scenarios in the EIOC.

5.3.1 Task Timing

The task and product timing for this task, and integration with the JTA work, is as follows:

Task	Tentative Date
Preliminary list of evaluation scenarios and metrics provided by application developers	May 15, 2017
Workshop with application developers and JTA consultants to refine evaluation scenarios and metrics	June 9, 2017
Draft evaluation process (all apps, scenarios, and metrics)	December 31, 2017
Final evaluation process (all apps, scenarios, and metrics)	March 31, 2018

5.4 Scripting of Evaluation Scenarios and Implementation in EIOC (Project Year 3)

The activities of Year 2 will result in a highly specific set of evaluation scenarios and metrics that can be used to program scripts for comparison of baseline and new application capability in the EIOC.

5.4.1 Task Timing

Task	Date
Start formal application evaluations in EIOC	9/30/2018
Finalized application evaluations (Report and Publications)	3/31/2018

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Appendix A

PNNL Applications

This appendix contains the formative and developmental evaluation answers for the three applications that PNNL will be developing.

A.1 PNNL Application 1: VVO

PNNL: VVO Application	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
1. What is the primary function of the proposed application? Specifically, what problem does it solve?	The primary function of the VVO application is to control the operation of voltage regulators, shunt capacitors, transformer taps, and photovoltaic (PV) inverters to reduce annual energy consumption. The specific set points are based on AMI or SCADA measurements.
2. How is the function of this application currently achieved?	The majority of utilities currently use voltage regulators and/or capacitors operating based on local set points. For utilities that have implemented true VVO, these systems operate the regulators and/or capacitors based on centralized logic informed by end of lines sensors. During abnormal operations and/or topologies these systems are typically removed from service. This system will use the data and control-rich environment to remain in operation during abnormal conditions.
3. What is the organizational “home” of the proposed application (e.g., distribution operations center, other utility-specific system, transmission-level, third party)?	This application would be located either at the distribution control center or at a substation, depending on the architecture of the supporting systems. In either case, the system would be monitored/operated by the dispatcher at the control center.
4. Is the proposed application an interactive operational tool, or is it meant to run as a “background” process?	This is designed to be an operational tool that runs in the control center and is monitored by the dispatcher. The system is automated and the dispatcher provides supervisory oversight, and does not need to take regular actions.
5. If the application is a background process: a) How will the application be monitored for situational awareness and by whom? b) Does it feed data into another application which in turn interacts with one of the “actors” listed above?	The primary function of the VVO application is to control the operation of voltage regulators, shunt capacitors, transformer taps, and PV inverters to reduce annual energy consumption. The specific set points are based on AMI or SCADA measurements.

PNNL: VVO Application	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
c) Is there a need to "phase-in" the operation of the autonomous application in order to develop trust among system personnel?	
6. If the application is an operational tool, how is it intended to provide parameter display and control to an end user such as the distribution control center dispatcher? a) What is the job role of the intended end user or users (e.g., control center dispatcher, engineering analyst, field maintenance crew, etc.)? b) What parameters will be displayed and what parameters are controlled? c) What is the update rate of displayed parameters and what is the anticipated monitoring and control frequency? d) Will the tasks performed with the proposed application involve communication (verbal or other) with other people, either co-located or elsewhere? e) How will out-of-bounds system parameters (alarms) be displayed and annunciated? f) How will feedback be provided to the operator on control actions that they implement? g) How will erroneous operator input be addressed?	a) The distribution operator has the ability to turn the system on, turn the system off, and change set points. Under normal operations, the system requires no input from the operator. The operator performs a supervisory role and determines if the system should be on or off. b) The human–machine interface (HMI) will display the current state of regulators and capacitors, and the statistics of PV inverters. The PV inverter values will indicate the minimum, maximum, and average PV inverter output. End-of-line measurements will be displays as well as minimum, maximum, and average voltage magnitudes from AMI and the PV inverters. The HMI will also display the estimated current energy reduction being achieved. c) The HMI display values will be updated once a minute, with some AMI values being updated every 15 minutes. Control signals are generated and sent to the various devices once a minute. Updated PV inverter set points are set out once every 24 hours if necessary. d) Under normal operation there is no need for external communications. In situations where there are system faults, it may be necessary to coordinate with the dispatcher for adjacent regions within the utility if the feeder is on a bounty between two regions. This would only occur if the utility has multiple distribution dispatchers in their service territory. e) High and low voltage levels are the primary concern and they will be identified in two ways. First, a flashing warning message indicating the occurrence of an out of range value. Second, all alarms will be logged for future analysis. There will be no audible

PNNL: VVO Application	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
	alarm because of the large number of alarms that can occur during switching and outages. f) When an operator turns on, turns off, or changes set points, the system will provide confirmation messages and log the event. g) The system will have hard limits that will prevent an operator from entering set points that will result in an out of range value. For example, it will not be possible to set the system to regulate to 85 V.
7. Is the proposed application meant to address existing "system metrics" such as SAIDI, SAIFI, losses, or percent penetration of renewables supported? Or will new metrics be used to evaluate performance?	The system will use a combination of metrics. The first will be the standard calculations to estimate the reduction in annual energy consumption achieved by the system, and the number of operations for voltage regulators and shunt capacitors. Second, metrics will be developed to quantify the level of participation of each PV inverter. Specifically, how much reactive power each inverter sources or sinks, and how this compares to other units. This will allow for a determination of which inverters are providing the greatest level of voltage support to the system. Finally, metrics will be developed to evaluate how robust the VVO system is to losses of data, changes in system topology, and other unplanned events.
8. With which other subsystems will the proposed application be integrated?	This system will be a module within the existing DMS and it will also have access to the AMI data provides through the meter data management system (MDMS). In addition to meter data, a connection will be made to the third party aggregator, which coordinates the operation of the PV inverters with the utility customers. The connection to the aggregator is an external connection to the utility. Other sources of data will be used as available; e.g. inputs from AMI and OMS.
9. Is the proposed application based on a familiar method of distribution operation, or is it based on future concepts?	This application is based on well-established VVO system, but with additional data inputs and outputs. To be successful it will require a level of data and control integration that does not currently exist.

PNNL: VVO Application	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
10. What assumptions are made by the application on data and model quality?	The system will require an accuracy "as built" system model. Performance will be increased with an accurate "as operated" model, but is designed to operate effectively in the presence of parameter and topology errors.

A.2 PNNL Application 2: State Estimation and Model Validation

PNNL: State Estimation and Model Validation	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
1. What is the primary function of the proposed application? Specifically, what problem does it solve?	Distribution level network models often contain a number of errors due to a combination of incorrectly entered data, variations in equipment parameters, and missing information. This application will use all available data to identify errors in the network model and to estimate what the correct values should be.
2. How is the function of this application currently achieved?	Currently models are maintained by either the operations or the planning group and changes are only made when gross errors are identified, or new equipment is installed. A data-rich environment will allow for the application to use data from SCADA, AMI, DERMS,[a] any other available sources to identify potential errors in the model. At the transmission level, this process is referred to as parameter error identification. Once potential errors are identified the application will develop a best estimate for the parameter value.
3. What is the organizational "home" of the proposed application (e.g., distribution operations center, other utility-specific system, transmission-level, third party)?	While this application will be in continuous operation with real-time data as inputs, it will reside with the organization that maintains the operational/planning models. (Ideally, there will only be a single model in the future.) While this application is primarily an off-line tool that is not used in the control center, data from its output will update the system that are used on the control room.
4. Is the proposed application an interactive operational tool, or is it meant to run as a "background" process?	This is a background application that will not normally interact with operational personnel.

PNNL: State Estimation and Model Validation	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
5. If the application is a background process: a) How will the application be monitored for situational awareness and by whom? b) Does it feed data into another application which in turn interacts with one of the “actors” listed above? c) Is there a need to “phase-in” the operation of the autonomous application in order to develop trust among system personnel?	a) The application will be monitored by the organization that maintains the operational and/or planning models. The output will be a list of parameters and confidence values that are continually updated and can be queried at any time. It will be up to the engineer to determine if a manual change in the network model(s) needs to be made. Later versions could automate the pushing of updated parameter values. b) While the application will not directly feed into other tools or applications, the models that it informs are used by other tools and applications. c) Yes. To verify that the application is accurate it will be necessary to have a process to verify that it is generating reliable updated values.
6. If the application is an operational tool, how is it intended to provide parameter display and control to an end user such as the distribution control center dispatcher? a) What is the job role of the intended end user or users (e.g., control center dispatcher, engineering analyst, field maintenance crew, etc.)? b) What parameters will be displayed and what parameters are controlled? c) What is the update rate of displayed parameters and what is the anticipated monitoring and control frequency? d) Will the tasks performed with the proposed application involve communication (verbal or other) with other people, either co-located or elsewhere? e) How will out-of-bounds system parameters (alarms) be displayed and annunciated? f) How will feedback be provided to the operator on control actions that they implement? g) How will erroneous operator input be addressed?	N/A

PNNL: State Estimation and Model Validation	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
7. Is the proposed application meant to address existing "system metrics" such as SAIDI, SAIFI, losses, or percent penetration of renewables supported? Or will new metrics be used to evaluate performance?	Metrics will need to be developed for the following items: • Threshold for identifying that a potential parameter error has been identified and needs to be examined by an engineer. • Threshold for identifying that a parameter needs to be updated. • Metric for overall model accuracy as determined by available data. • Ability of the application to identify parameter errors, and estimate new values, as the number of data sources is reduced.
8. With which other subsystems will the proposed application be integrated?	While this will be an off-line system, it should interface with a number of operational systems. These include: • SCADA • OMS • MDMS • AMI • DERMS • Any third part connections • Historian(s)
9. Is the proposed application based on a familiar method of distribution operation, or is it based on future concepts?	This application is based on technologies that have existed at the transmission level but have not been widely applied to distribution systems. This will be replacing a completely manual, or non-existent, manual workflow at current utilities.
10. What is the applications reliance on data from communications system and/or data bases? How robust is the application to the loss of these inputs?	This application is heavily dependent on information from other operational data sources as well as historical data. As the number of data sources is reduced, so is the accuracy of the system.
(a) DERMS is distributed energy resource management system	

A.3 PNNL Application 3: Transactive

PNNL: Transactive	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
1. What is the primary function of the proposed application? Specifically, what problem does it solve?	A transactive application will implement a distribution system market mechanism enabling the convergence of economics and control for

PNNL: Transactive	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
	distributed optimization in support of system operations. Optimization is achieved via distributed decision making based on concepts such as local greed where in each distributed participant makes decisions about optimizing their local economic position within the constraints of control system convergence and stability.
2. How is the function of this application currently achieved?	Currently markets are not used in distribution systems. Optimization is achieved through central calculations and dispatch. With increasing numbers of active distributed elements and with increased availability of data decision making can be decentralized. The local optimization features of a transactive system are required when the number of elements to be optimized becomes large enough that central optimization cannot succeed and when including active assets that are not owned by the energy service provider. In this case the asset owner needs to be enabled to make incentivized decisions contributing to overall optimization.
3. What is the organizational "home" of the proposed application (e.g., distribution operations center, other utility-specific system, transmission-level, third party)?	A transactive applications will need distributed elements to support the participation in the market place by active elements of the system. A common architecture is required and the ability for individual elements (nodes) to be recognized, to register, and to participate. Even if the market is distributed, some form of auditing and oversight is required along with an accounting mechanism. This may be centralized or distributed—in the latter case, possibly using technology such as block-chains and/or "smart contracts."
4. Is the proposed application an interactive operational tool, or is it meant to run as a "background" process?	This type of application will primarily be autonomous. An ability to have situational awareness, auditing, and status information will be required. In addition, the transactive application will require interfaces to assets, e.g., batteries, PV, and system such as home or building energy management systems.
5. If the application is a background process: a) How will the application be monitored for situational awareness and by whom? b) Does it feed data into another application which in turn interacts with one of the "actors" listed above?	a) A transactive system application will need monitoring and situational awareness from an operations perspective (are the assets responding and what are the forecast responses) and a business perspective (are asset owners'

PNNL: Transactive	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
c) Is there a need to "phase-in" the operation of the autonomous application in order to develop trust among system personnel?	transactions being properly accounted for, etc.) b) A transactive system may feed into other applications and may receive data from other applications. c) Extensive testing of such an application will be needed to confirm operational performance.
6. If the application is an operational tool, how is it intended to provide parameter display and control to an end user such as the distribution control center dispatcher? a) What is the job role of the intended end user or users (e.g., control center dispatcher, engineering analyst, field maintenance crew, etc.)? b) What parameters will be displayed and what parameters are controlled? c) What is the update rate of displayed parameters and what is the anticipated monitoring and control frequency? d) Will the tasks performed with the proposed application involve communication (verbal or other) with other people, either co-located or elsewhere? e) How will out-of-bounds system parameters (alarms) be displayed and annunciated? f) How will feedback be provided to the operator on control actions that they implement? g) How will erroneous operator input be addressed?	--- N/A for now. The specific details will depend on the nature of the transactive system and how it is being applied operationally.
7. Is the proposed application meant to address existing "system metrics" such as SAIDI, SAIFI, losses, or percent penetration of renewables supported? Or will new metrics be used to evaluate performance?	Transactive systems are a class of application that is intended to enable flexible assets to provide support for offsetting variability in the system. The specific use is intended to address multi-objective optimization by responding to need for "services" such as peak load management, fast regulation, etc. The specifics will depend on the operational objectives to be achieved by using a transactive system.
8. With which other subsystems will the proposed application be integrated?	A transactive system as a distributed application will primarily interact with peers (other

PNNL: Transactive	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
	transactive nodes) and local assets (e.g., a battery). More broadly, as an active part of optimizing the distribution system, there may also be data exchanges with other elements such as • MDMS • AMI • DERMS (a transactive system may be thought of as a form of DERMS in some cases) • Possibly others
9. Is the proposed application based on a familiar method of distribution operation, or is it based on future concepts?	This is an advanced concept that has been demonstrated in pilot projects but that is not commonly used today.
10. What is the applications reliance on data from communications system and/or data bases? How robust is the application to the loss of these inputs?	As a distributed application there is a dependence on communications between the distributed elements and with centralized components providing functionality such as situational awareness of the activity of the distributed elements. Loss of communications must be tolerated for reasonable periods of time.

Appendix B

NREL Applications

This appendix contains the formative and developmental evaluation answers for the three applications that NREL will be developing.

B.1 NREL Application 1: Data-Driven Real-time State Forecasting

NREL: Data-Driven Real-time State Forecasting	
Formative Evaluation Requirements Analysis Questions	**Rationale and Utility**
1. What is the primary function of the proposed application? Specifically, what problem does it solve?	Using real-time measurements such as data from phasor measurement units (PMUs) and DMUs, perform system-state forecasting in short- to medium-term horizon (from seconds to hours) in multiphase distribution network. The input will be partial information on model, measurements (PMU, SCADA, smart meters, etc.), and historical data. The output of this application includes forecasting DER generation, load, bus voltages, currents, etc.
2. How is the function of this application currently achieved?	Existing methods are focused on devising real-time state-estimation methods that try to provide an accurate estimate of the current electrical state. Also, there are methods to forecast the output of individual components in the distribution networks, such as PV or wind plant power production. However, there is a need for unified and distributed approaches that provide accurate forecasts for different grid-related quantities in different time horizons (short, medium, long) and different grid scales (home, distribution, transmission). Also, there is lack of methods that can cope with missing data, outliers in data, and wrong/incomplete models.
3. What is the organizational "home" of the proposed application (e.g., distribution operations center, other utility-specific system, transmission-level, third party)?	This application would be located either at the distribution control center or at a substation, depending on the architecture of the supporting systems. At can also be implemented in a decentralized fashion.
4. Is the proposed application an interactive operational tool, or is it meant to run as a "background" process?	This will be an online background process that provides input to other applications (e.g., control and optimization procedures).
5. If the application is a background process:	The primary function of the application is to serve as input to other operational tools that require

NREL: Data-Driven Real-time State Forecasting	
Formative Evaluation Requirements Analysis Questions	**Rationale and Utility**
a) How will the application be monitored for situational awareness and by whom? b) Does it feed data into another application which in turn interacts with one of the "actors" listed above? c) Is there a need to "phase-in" the operation of the autonomous application in order to develop trust among system personnel?	accurate knowledge of system states in a given time period. The system will be monitored by system operator through a using operational tool, and it will need to "phase-in" to develop trust.
6. If the application is an operational tool, how is it intended to provide parameter display and control to an end user, such as the distribution control center dispatcher? a) What is the job role of the intended end user or users (e.g., control center dispatcher, engineering analyst, field maintenance crew,)? b) What parameters will be displayed and what parameters are controlled? c) What is the update rate of displayed parameters and what is the anticipated monitoring and control frequency? d) Will the tasks performed with the proposed application involve communication (verbal or other) with other people, either co-located or elsewhere? e) How will out-of-bounds system parameters (alarms) be displayed and annunciated? f) How will feedback be provided to the operator on control actions that they implement? g) How will erroneous operator input be addressed?	
7. Is the proposed application meant to address existing "system metrics" such as SAIDI, SAIFI, losses, or percent penetration of renewables supported? Or will new metrics be used to evaluate performance?	Metrics will be developed to quantify the accuracy of the forecasters. For example, accuracy will be measured in hindsight by comparing the forecasted voltages with the actually realized voltages. Also, existing metrics can be evaluated based on running operational tool that take input from this app.
8. With which other subsystems will the proposed application be integrated?	This system will be a module within an existing ADMS and it will also have access to the AMI data. In addition, the system can have input from other sources of data, such as weather forecasts. The application output can serve as input to

NREL: Data-Driven Real-time State Forecasting	
Formative Evaluation Requirements Analysis Questions	**Rationale and Utility**
	several other application, such visualization, control app, etc.
9. Is the proposed application based on a familiar method of distribution operation, or is it based on future concepts?	The application will be a new concept which will build upon the conventional state-estimation application by using novel machine learning methods to forecast the future states of the system.
10. What assumptions are made by the application on data and model quality?	The application is expected to perform well in face of missing data and data outliers, and will fill the gaps in data by using data-driven machine learning methods. As a result, it will also be able to overcome inaccuracies in the utilized system model. As a bi-product, the application will be able to improve the accuracy of the system model in an online fashion.

B.2 NREL Application 2: Online Distribution OPF for Real-Time Set Point Dispatch

NREL: Online Distribution OPF for Real-Time Set Point Dispatch	
Formative Evaluation Requirements Analysis Questions	**Rationale and Utility**
1. What is the primary function of the proposed application? Specifically, what problem does it solve?	The application will address the problem of real-time control of distribution grids with high penetration of DERs. The control algorithms will be based on decentralized online optimization methodology, and will track the solution of a time-varying OPF problem with the objective of optimizing the different grid resources while providing good quality of service (in terms of voltages, currents, etc.) in real-time (second or even sub-second time scale).
2. How is the function of this application currently achieved?	Existing methods are mostly based on the well-known Volt/VAR local control, and are not based on optimization principles (typically, heuristics are used). Recently, several papers proposed centralized and decentralized real-time control methods; however, these methods have high communication requirements, are typically designed for balanced networks, and are applied to small “toy” problems. The proposed application will be scalable to big networks (more than 1,000 nodes), will require limited

NREL: Online Distribution OPF for Real-Time Set Point Dispatch	
Formative Evaluation Requirements Analysis Questions	**Rationale and Utility**
	communication infrastructure, and will be applicable to general multiphase networks to control devices behind the secondary of the distribution transformer.
3. What is the organizational "home" of the proposed application (e.g., distribution operations center, other utility-specific system, transmission-level, third party)?	This will be a decentralized application, with a certain function implemented at the distribution operation center and/or substation, and local control functions implemented at the resources and/or transformers.
4. Is the proposed application an interactive operational tool, or is it meant to run as a "background" process?	This will be an online background process that may also provide input to visualization and override tool. In its normal operation, it does not require any input from system operator.
5. If the application is a background process: a) How will the application be monitored for situational awareness and by whom? b) Does it feed data into another application which in turn interacts with one of the "actors" listed above? c) Is there a need to "phase-in" the operation of the autonomous application in order to develop trust among system personnel?	The primary function of the application is to serve as input to visualization and override tool. The system will be monitored by a system operator through a using operational tool, and it will need to "phase-in" to develop trust.
6. If the application is an operational tool, how is it intended to provide parameter display and control to an end user, such as the distribution control center dispatcher? a) What is the job role of the intended end user or users (e.g., control center dispatcher, engineering analyst, field maintenance crew,)? b) What parameters will be displayed and what parameters are controlled? c) What is the update rate of displayed parameters and what is the anticipated monitoring and control frequency? d) Will the tasks performed with the proposed application involve communication (verbal or other) with other people, either co-located or elsewhere? e) How will out-of-bounds system parameters (alarms) be displayed and annunciated? f) How will feedback be provided to the operator on control actions that they implement?	

NREL: Online Distribution OPF for Real-Time Set Point Dispatch	
Formative Evaluation Requirements Analysis Questions	**Rationale and Utility**
g) How will erroneous operator input be addressed?	
7. Is the proposed application meant to address existing “system metrics” such as SAIDI, SAIFI, losses, or percent penetration of renewables supported? Or will new metrics be used to evaluate performance?	Existing operational metrics can be evaluated such as voltage quality in the controlled grid. Additional metrics will be developed to quantify the accuracy the dispatched setpoints compared to the solution of the baseline OPF.
8. With which other subsystems will the proposed application be integrated?	This system will be a module within an existing ADMS and it will also have access to the AMI data. In addition, the system can have input from other applications such as state estimation and forecasting app. The application output can serve as input to several other applications, such visualization and manual override tool.
9. Is the proposed application based on a familiar method of distribution operation, or is it based on future concepts?	The application will be a new concept that will build upon the advances in online optimization and control.
10. What assumptions are made by the application on data and model quality?	The application is expected to perform well in face of missing data, data outliers, and inaccurate system model. In particular, it will use the output of the state forecasting app as an input, and will dispatch set points based on the accurate knowledge provided by that app.

B.3 NREL Application 3: Data-Driven Day-Ahead State Forecasting

NREL: Data-Driven Day-Ahead State Forecasting	
Formative Evaluation Requirements Analysis Questions	**Rationale and Utility**
1. What is the primary function of the proposed application? Specifically, what problem does it solve?	Using PMU measurements and available models, perform system-state forecasting day ahead for the purpose of operational planning, such as outage coordination and contingency analysis in multiphase distribution network. The input will be partial information on model, measurements (PMU, SCADA, smart meters, etc.), and historical data. The output of this application includes forecasting DER generation, load, bus voltages, currents, etc.
2. How is the function of this application currently achieved?	Existing methods are mostly manual and based on available system models, without the information on real state. Also, there is lack of methods that

NREL: Data-Driven Day-Ahead State Forecasting	
Formative Evaluation Requirements Analysis Questions	**Rationale and Utility**
	can cope with missing data, outliers in data, and wrong/incomplete models.
3. What is the organizational "home" of the proposed application (e.g., distribution operations center, other utility-specific system, transmission-level, third party)?	This application would be located either at the distribution control center or at a substation, depending on the architecture of the supporting systems.
4. Is the proposed application an interactive operational tool, or is it meant to run as a "background" process?	This will be an off-line background process that provides input to other applications. It will be used by operation engineers for operational planning and pro-active decision making. The output will be visualized.
5. If the application is a background process: a) How will the application be monitored for situational awareness and by whom? b) Does it feed data into another application which in turn interacts with one of the "actors" listed above? c) Is there a need to "phase-in" the operation of the autonomous application in order to develop trust among system personnel?	The primary function of the application is to serve as input to visualization tool that affects the operation engineers. The system will be monitored by operation engineer through a visualization and engineering analysis tool, and it will need to "phase-in" in order to develop trust.
6. If the application is an operational tool, how is it intended to provide parameter display and control to an end user such as the distribution control center dispatcher? a) What is the job role of the intended end user or users (e.g., control center dispatcher, engineering analyst, field maintenance crew)? b) What parameters will be displayed and what parameters are controlled? c) What is the update rate of displayed parameters and what is the anticipated monitoring and control frequency? d) Will the tasks performed with the proposed application involve communication (verbal or other) with other people, either co-located or elsewhere? e) How will out-of-bounds system parameters (alarms) be displayed and annunciated? f) How will feedback be provided to the operator on control actions that they implement? g) How will erroneous operator input be addressed?	

NREL: Data-Driven Day-Ahead State Forecasting	
Formative Evaluation Requirements Analysis Questions	**Rationale and Utility**
7. Is the proposed application meant to address existing “system metrics” such as SAIDI, SAIFI, losses, or percent penetration of renewables supported? Or will new metrics be used to evaluate performance?	Metrics will be developed to quantify the accuracy of the forecasters. For example, accuracy will be measured in hindsight by comparing the forecasted voltages with the actually realized voltages. Also, existing metrics can be evaluated based on the results of the operational planning that uses this tool.
8. With which other subsystems will the proposed application be integrated?	This system will be a module within an existing ADMS and it will have access to the AMI data. In addition, the system can have input from other sources of data, such as weather forecasts. The application output can serve as input to several other application, such visualization.
9. Is the proposed application based on a familiar method of distribution operation, or is it based on future concepts?	It is based on familiar concept, but we propose to automate it and deliver higher accuracy.
10. What assumptions are made by the application on data and model quality?	The application is expected to perform well in face of missing data and data outliers and will fill the gaps in data by using data-driven machine learning methods. As a result, it will also be able to overcome inaccuracies in the utilized system model.

Appendix C

WSU Applications

This appendix contains the formative and developmental evaluation answers for the three applications that WSU will be developing.

C.1 WSU Application 1: Resilient Distribution Restoration with High DER Penetration

WSU: Resilient Distribution Restoration with High DER Penetration	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
1. What is the primary function of the proposed application? Specifically, what problem does it solve?	In an environment of distribution systems with high DER penetration, traditional radial configurations are no longer practical. To conduct feeder restoration and reconfiguration with utility as well as DER resources and microgrid. Enhance resilience of distribution feeder in minor as well as major outage events.
2. How is the function of this application currently achieved?	Industry practice is largely manual, although remote control function has been improved through the smart grid efforts. The system used to do this study is FLISR. FLISR currently uses data from SCADA and fault indicators.
3. What is the organizational “home” of the proposed application (e.g., distribution operations center, other utility-specific system, transmission-level, third party)?	Distributed application among utilities, microgrids, and DER entities. This will not be a centralized application at the utility center.
4. Is the proposed application an interactive operational tool, or is it meant to run as a “background” process?	The application will be designed as an operational tool or decision support tool. As a background process, it will support reliability calculation process as the current tools do not include system restoration into the calculation of reliability indices. It will help evaluate the operational reliability of the system.
5. If the application is a background process: a) How will the application be monitored for situational awareness and by whom? b) Does it feed data into another application which in turn interacts with one of the “actors” listed above?	a) When used as a background process, this will be supporting reliability engineer in system assessment. b) No. c) Yes. System restoration involves personnel and equipment safety issue. So

<table>
<tr><th colspan="2">WSU: Resilient Distribution Restoration with High DER Penetration</th></tr>
<tr><th>Formative Evaluation
Requirements Analysis Questions</th><th>Design Considerations</th></tr>
<tr><td>c) Is there a need to “phase-in” the operation of the autonomous application to develop trust among system personnel?</td><td>the confidence has to build up before application can be close-loop.</td></tr>
<tr><td>6. If the application is an operational tool, how is it intended to provide parameter display and control to an end user such as the distribution control center dispatcher?
a) What is the job role of the intended end user or users (e.g., control center dispatcher, engineering analyst, field maintenance crew,)?
b) What parameters will be displayed and what parameters are controlled?
c) What is the update rate of displayed parameters and what is the anticipated monitoring and control frequency?
d) Will the tasks performed with the proposed application involve communication (verbal or other) with other people, either co-located or elsewhere?
e) How will out-of-bounds system parameters (alarms) be displayed and annunciated?
f) How will feedback be provided to the operator on control actions that they implement?
g) How will erroneous operator input be addressed?</td><td>To provide parameter display, the application will be integrated with the DMS.
a) This is a decision support system. So the end user has to approve/revise the control actions.
b) Switching actions to reconfigure the feeders and restore service with DERs.
c) This is an event dependent applications. So the parameters will be displayed in post-fault situation when restorative actions are called for.
d) Yes. Field crew, microgrid operator, and DER entities.
e) Using SCADA system and fault indicators.
f) This app automatically does that given it is a decision support system.
g) System will continuously monitor grid conditions and provide decision support weather or not operator actions are erroneous.</td></tr>
<tr><td>7. Is the proposed application meant to address existing “system metrics” such as SAIDI, SAIFI, losses, or percent penetration of renewables supported? Or will new metrics be used to evaluate performance?</td><td>The proposed application will include traditional metrics including SAIDI, SAIFI, and loses.
A comparative metric to demonstrate the reliability improvement with DER and microgrid will be developed.</td></tr>
<tr><td>8. With which other subsystems will the proposed application be integrated?</td><td>Distribution system condition - DMS, OMS, RTUs
DER/Microgrid availability - Microgrid management system, DERMS
Load estimation – smart meter data</td></tr>
<tr><td>9. Is the proposed application based on a familiar method of distribution operation, or is it based on future concepts?</td><td>The two major advancements are
• Distributed operation as opposed to centralized system
• Use of DERs and microgrids
The use of DERs and microgrids require complex system stability analysis and reconnection and synchronization study. These</td></tr>
</table>

WSU: Resilient Distribution Restoration with High DER Penetration	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
	new technical challenges arise due to the high penetration of DERs and microgrid and also their advanced applications.
10. What assumptions are made by the application on data and model quality?	

C.2 WSU Application 2: VVO with Integrated Control of Legacy and New Devices (OPF Formulation)

WSU: VVO with Integrated Control of Legacy and New Devices (OPF formulation)	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
1. What is the primary function of the proposed application? Specifically, what problem does it solve?	The primary function of VVO is to control feeder's voltage control devices in order to 1) reduce energy consumption, 2) reduce system losses, and 3) regulate feeder voltages. The proposed application will develop OPF formulations to coordinate legacy devices - voltage regulators, load-tap changers, capacitor banks and new device – DER smart inverters to achieve system-level goals. We propose a two-level framework: • Level-1: 15-min schedule for legacy devices and DER reactive power demand set points to minimize active and reactive power demand from the substation. • Level 2: real-time control of DERs to meet system-level objective while including DER variability. This two-level framework minimizes the voltage regulator and capacitor switching operations and meet the system goals using reactive power support from DERs.
2. How is the function of this application currently achieved?	Currently, the VVO application used by the utilities are based on centralized logic for controlling capacitor banks and voltage regulators. The control is achieved using feeder-end data either through sensors or approximated using feeder-head measurements.
3. What is the organizational "home" of the proposed application (e.g., distribution operations center, other utility-specific system, transmission-level, third party)?	This will be a distributed application located at the distribution control center, microgrids, and DER entities.

WSU: VVO with Integrated Control of Legacy and New Devices (OPF formulation)	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
	The 15-min control schedule will be implemented using centralized control located at distribution control center. The real-time DER dispatch will be a decentralized control logic based on local and neighboring DER data.
4. Is the proposed application an interactive operational tool, or is it meant to run as a "background" process?	The application will be designed as an operational tool or decision support tool. As a background process, it will support reliability calculation process as the current tools do not include system restorative actions into the calculation of reliability indices. It will help evaluate the operational reliability of the system.
5. If the application is a background process: a) How will the application be monitored for situational awareness and by whom? b) Does it feed data into another application which in turn interacts with one of the "actors" listed above? c) Is there a need to "phase-in" the operation of the autonomous application to develop trust among system personnel?	When used as a background process, this will be supporting reliability engineer in system assessment. It does not feed another application. System restoration involves personnel and equipment safety issues. So the confidence has to be established before the application becomes closed-loop.
6. If the application is an operational tool, how is it intended to provide parameter display and control to an end user such as the distribution control center dispatcher? a) What is the job role of the intended end user or users (e.g., control center dispatcher, engineering analyst, field maintenance crew)? b) What parameters will be displayed and what parameters are controlled? c) What is the update rate of displayed parameters and what is the anticipated monitoring and control frequency? d) Will the tasks performed with the proposed application involve communication (verbal or other) with other people, either co-located or elsewhere? e) How will out-of-bounds system parameters (alarms) be displayed and annunciated?	In order to provide parameter display, the application will be integrated with the DMS. a) This is a decision support system. So the end user has to approve/revise the control actions. b) Switching actions to reconfigure the feeders and restore service with DERs. c) This is an event dependent applications. So the parameters will be displayed in post-fault situations when restorative actions are called for. d) Yes. Field crew, microgrid operator, and DER entities. e) Using SCADA system and fault indicators. f) This app automatically does that given that it is a decision support system. g) System will continuously monitor grid conditions and provide decision support whether or not operator actions are erroneous.

WSU: VVO with Integrated Control of Legacy and New Devices (OPF formulation)	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
f) How will feedback be provided to the operator on control actions that they implement? g) How will erroneous operator input be addressed?	
7. Is the proposed application meant to address existing "system metrics" such as SAIDI, SAIFI, losses, or percent penetration of renewables supported? Or will new metrics be used to evaluate performance?	The proposed application will include traditional metrics including SAIDI, SAIFI, and losses. A comparative metric to demonstrate the reliability improvement with DER and microgrid will be developed.
8. With which other subsystems will the proposed application be integrated?	Distribution system condition - DMS, OMS, RTUs DER/Microgrid availability - Microgrid management system, DERMS Load estimation – smart
9. Is the proposed application based on a familiar method of distribution operation, or is it based on future concepts?	The two major advancements are Distributed operation as opposed to centralized system Use of DERs and microgrids The use of DERs and microgrids require complex system stability analysis and reconnection and synchronization study. These new technical challenges arise due to the high penetration of DERs and microgrid and also their advanced applications.
10. What assumptions are made by the application on data and model quality?	This application heavily depends upon communication and data during the fault condition. In the event of a loss of communication, only partial restoration may be possible. In the event of data corruption, the robustness of the restoration plan will decrease.

C.3 WSU Application 3: Automated DER Interconnection Process

WSU: Automated DER Interconnection Process	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
1. What is the primary function of the proposed application? Specifically, what problem does it solve?	Develop an automated framework to conduct DER integration analysis. Automate the DER interconnection request while running multiple impact studies on the feeder.

WSU: Automated DER Interconnection Process	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
	This application will be significant for utilities receiving thousands of interconnection request.
2. How is the function of this application currently achieved?	Currently, the interconnection assessment process is largely manual. Each interconnection request is individually evaluates and approved, which is time-consuming. This application will require available network and load data to estimate system impacts of requested DER connection.
3. What is the organizational "home" of the proposed application (e.g., distribution operations center, other utility-specific system, transmission-level, third party)?	This is primarily a planning application. Therefore, the application will be placed within the organization maintaining the system planning models.
4. Is the proposed application an interactive operational tool, or is it meant to run as a "background" process?	This application will not interact with operational personnel. This application will supplement the system planning studies while including DERs into the existing planning framework.
5. If the application is a background process: a) How will the application be monitored for situational awareness and by whom? b) Does it feed data into another application which in turn interacts with one of the "actors" listed above? c) Is there a need to "phase-in" the operation of the autonomous application to develop trust among system personnel?	The application will be monitored by personnel responsible for processing and approving DER interconnection requests. Based on the output of this application, the DER interconnection will be approved or denied or alternate locations will be suggested. The application requires input from network model and system load data to do a planning study. Yes. Verification is needed to show that the proposed automated interconnection study is accurate and takes into account all possible cases.
6. If the application is an operational tool, how is it intended to provide parameter display and control to an end user such as the distribution control center dispatcher? a) What is the job role of the intended end user or users (e.g., control center dispatcher, engineering analyst, field maintenance crew)? b) What parameters will be displayed and what parameters are controlled? c) What is the update rate of displayed parameters and what is the anticipated monitoring and control frequency? d) Will the tasks performed with the proposed application involve communication (verbal or other) with	NA

WSU: Automated DER Interconnection Process	
Formative Evaluation Requirements Analysis Questions	**Design Considerations**
other people, either co-located or elsewhere? e) How will out-of-bounds system parameters (alarms) be displayed and annunciated? f) How will feedback be provided to the operator on control actions that they implement? g) How will erroneous operator input be addressed?	
7. Is the proposed application meant to address existing "system metrics" such as SAIDI, SAIFI, losses, or percent penetration of renewables supported? Or will new metrics be used to evaluate performance?	The existing metrics used in the interconnection study will be used. These include evaluating DER interconnection for voltage impacts, thermal impacts, reverse power flow, increase in capacitor and regulator tap operations, and impacts on system protection.
8. With which other subsystems will the proposed application be integrated?	This is an off-line application. This needs to be interfaced with the following systems: System logging the DER connect request Updated network models Load models and load data (MDMS)
9. Is the proposed application based on a familiar method of distribution operation, or is it based on future concepts?	Based on the existing concepts of distribution system studies. Includes load flow, short-circuit, and protection studies The main challenge is to automate the process for thousands of request while solving the real-world three-phase unbalanced distribution system models.
10. What assumptions are made by the application on data and model quality?	The application requires the following critical information: 1. DER interconnection request. 2. Accurate network models 3. Accurate load models Since this is a planning application, temporary loss of communication is not a major problem.

Appendix D

UF Applications

This appendix contains the formative and developmental evaluation answers for the application(s) that the University of Fairbanks (UF) will be developing. UF will not officially joint the team until October, so this section is a placeholder.

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902 Battelle Boulevard
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