Case Study: State-of-the-Art Microgrid Control System for Avista's Clean Energy Fund Project

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Presented at the
Power and Energy Automation Conference
Spokane, Washington
March 6–7, 2018

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***Abstract*—This paper describes the authors' vision and goal in designing a scalable, micro transactive grid that can be used as a platform to share the investment and return of distributed energy resources (DERs) with a community. The paper explores and defines the goals of a shared energy economy model. It also explains the design aspects of a microgrid control system (MGCS) which include high-speed protection and control; automation; cybersecurity; wired and wireless networks with DNP3, IEC 61850 Generic Object-Oriented Substation Event (GOOSE) and OpenFMB™ protocols; and a historian with oscillography events and Sequence of Events (SOE) monitoring. This unique design integrates various DERs, intelligent electronic devices (IEDs), meters, Avista Corporation's distribution management system (DMS) and economic forecast and DER optimization servers, and building energy management systems—all on a common, secure network. This powerful MGCS serves as the control and monitoring layer for all assets within the extent of the microgrid, providing several different modes of successful microgrid implementation: high-speed island detection and decoupling, grid-connected optimization mode, islanded mode, and automatic synchronization to the grid.**

I. Introduction

The Washington State Department of Commerce's vision to promote clean energy via a grant to Avista Corporation is leading to innovative work on electric microgrid projects. Avista's pilot project of a micro transactive grid using a shared energy economy model focuses on demonstrating how distributed energy resources (DERs) can benefit consumers, prosumers, and the distribution system by orchestrating the operation of groups of assets based on system conditions and economic signals. The project and its studies will aim to develop use cases for efficient and reliable sharing of resources while maintaining grid resiliency.

A shared energy economy model can best be explained with an example from the transportation industry. To start a taxi company a decade ago one would've needed a fleet of cars, a staff of drivers, and the resources required for a dispatch center. The individual or an entity owned the resources and required customers to pay for the services. Today the industry is built on a shared economy model where anyone who owns a vehicle can share it to provide a service to a group connected though the Internet. Multiple individuals bound by a common set of taxi service rules now participate in a common market to share the cost and benefits. What would the shared economy model or the participation model mean for the energy industry?

Microgrids are small electrical grids capable of islanded operation separate from the main utility grid. These grids include high percentages of distributed power electronic energy sources including photovoltaic (PV) and battery energy storage systems (BESS) sources. The fault ride-through capacities of these energy sources are smaller than those of conventional rotating energy sources. In addition, these sources do not provide inertial contribution to the power system, which causes instantaneous frequency changes and leads to blackouts [1]. A microgrid control system (MGCS) such as the one discussed in this paper is used to address these inherent problems in a microgrid. The primary role of a MGCS is to improve grid resiliency. Another objective of this project is to design an advanced, scalable, powerful, yet economical MGCS solution that can be easily repeated by utilities as DERs become more prevalent. This MGCS facilitates the sharing and optimization of DERs to improve building efficiency, renewable integration, grid coordination, and transactive energy use.

This paper shares the goals and objectives of Avista's transactive microgrid pilot project. The preliminary design and optimization goals of the MGCS are also discussed. In addition to improving grid resiliency, a MGCS facilitates economic value exchange by sharing and optimizing the DERs and allows transactive energy use while operating in parallel with the utility.

II. Microgrid Functionality Overview

Site selection for the pilot project implementation was an important step. To demonstrate the shared energy economy model, the pilot site required a small power system with DERs, controllable loads, and a utility tie. Washington State University's Spokane campus was chosen for the pilot microgrid for several reasons, one of which was the switching abilities of the existing infrastructure. Fig. 1 shows an overview map of the microgrid power system and the point of interconnection with the utility.

The point of common coupling (PCC) between the microgrid and utility includes an automatic transfer switch (ATS). The ATS includes a voltage-based automatic transfer scheme programed in an intelligent electronic device (IED) to switch between the two available utility sources. The site includes campus building loads. The building energy management system (BEMS) will be integrated into the MGCS. The site is strategically located so the project partners can collaborate on future research. The microgrid power system consists of two islands (north and south) with interconnection capabilities through a smart switchgear. The smart switchgear also includes the capabilities of an automatic source transfer described above. The microgrid island south of the smart

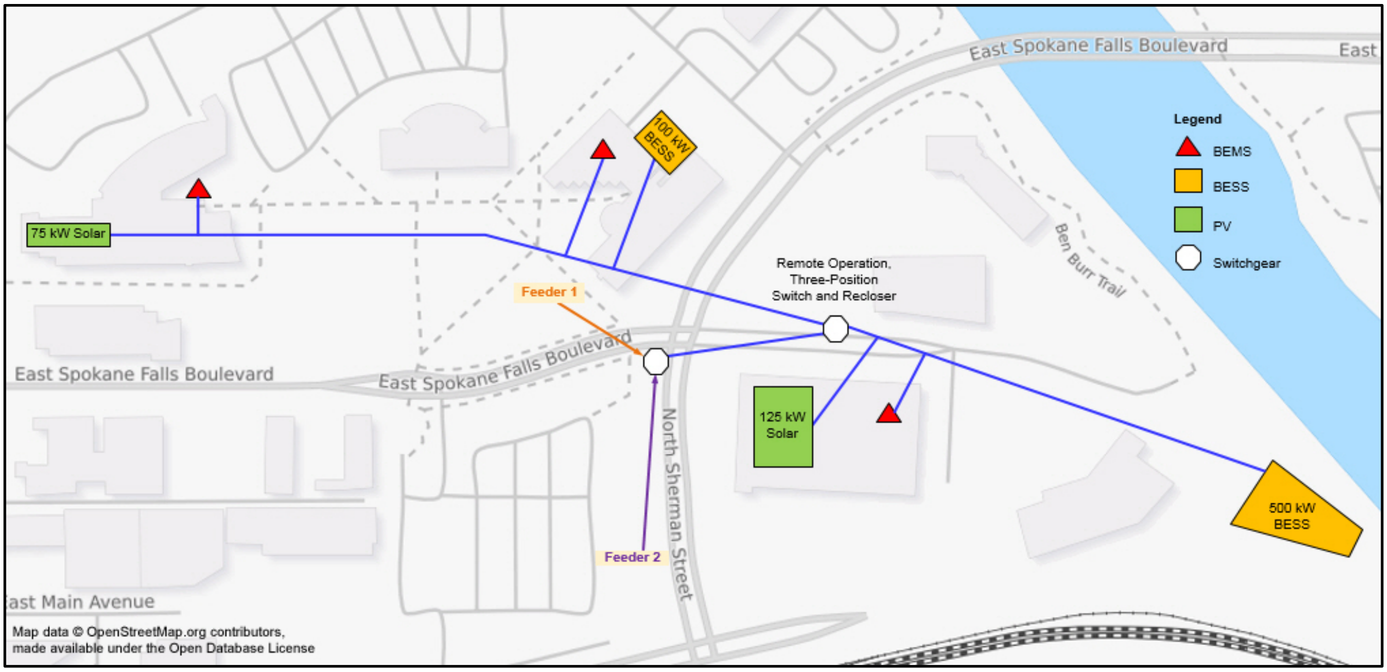

Fig. 1. Microgrid power system overview map

switchgear is controlled by the MGCS. It comprises one array of approximately 125 kW PV generation, one BESS with an approximate capacity of 500 kW, and controllable building loads. Each electrical load has a BEMS and revenue meters for metering installed.

The microgrid island north of the smart switchgear is a smaller version of the south island. There are no rotational energy sources such as diesel generation connected to either microgrid island. The proposed MGCS has the capability to simultaneously control both microgrid islands in islanded mode or in interconnected mode. The MGCS also facilitates the transition between the two modes of operation based on power system events.

Fig. 2 shows the simplified one-line diagram of the proposed microgrid.

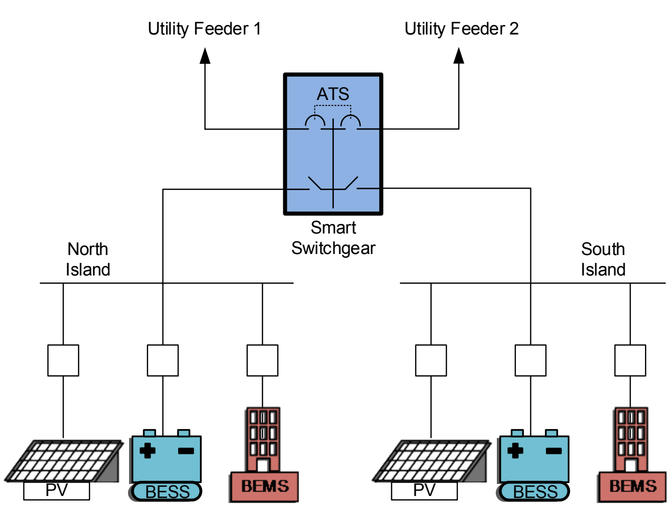

Fig. 2. Simplified one-line diagram of proposed microgrid

To demonstrate the benefits of a shared energy economy model, the microgrid's performance will be tested in four different operational concepts: grid service, DER optimization, building fleet optimization, and critical resiliency. The microgrid's performance will also be evaluated while operating in a combination of concepts. For example, a combination of DER optimization and building fleet optimization concepts can be used to measure the efficiency and resiliency of the microgrid. Based on test results, analysis will be performed to understand the relative financial values in various scenarios. The outcome will inform future regulatory and service model possibilities for microgrids. The definitions of the microgrid operational concepts are explained in the following subsections.

A. Grid Service

The goal of the grid service concept is to demonstrate that a combination of DER and building assets coordinated by a grid controller can be aggregated to respond to grid demands more effectively than a single asset. The combination of assets is referred to as a DER integration node, or simply a node. Microgrid performance evaluation can be based on measurements at the distribution feeder level (e.g., voltage control) or at the bulk system level (e.g., frequency response). Some of the operational targets that will be used to evaluate the microgrid operation include load shaping, frequency response, load balancing, and power quality. Load shaping can be quantified based on the ability of the aggregated assets to efficiently and economically dispatch generation and impact load on the power system. Actual node performance and flexibility can then be compared to predicted performance to understand the capabilities. The frequency response of four-quadrant smart inverters will be quantified continuously during all use cases to understand the overall availability of the service. Power factor control and reactive power control of the node will be tested during hunting and low-power conditions to avoid excessive control adjustments. Balancing capability at each node can be demonstrated using the aggregated rate-of-change of power in and out at each interconnected node. This helps the operators understand the changes in ramping and balancing required to meet load variations. The ability of the DER node to influence the local voltage and power factor will also be explored.

B. DER Optimization

The goal of the DER optimization concept is to demonstrate that a collection of DERs and other assets can be optimized to more effectively create value than individual DERs. Examples include operating buildings to use excess local PV generation when available and optimizing battery storage for local needs. Solar optimization includes proactively operating buildings to predict and respond to available solar generation, which allows for system efficiencies and better long-term economics for solar energy. Strategies within the buildings, such as precooling or controlling processes that are not time-dependent, will be explored.

The BESS can be used for local optimization of the microgrid in the grid-connected mode. For example, the battery can benefit a building operator while it is grid connected by discharging during peak building loads to offset demand charges. The battery can also be charged while solar output is high, supplementing the ability of the building to shape its load to match solar output.

C. Building Fleet Optimization

The project will verify and test the operation of the building fleet optimization concept by attempting to demonstrate the coordinated operation of a fleet of buildings, resulting in reduced feeder demand peaks without negatively impacting building occupants.

The MGCS calculates the total demand on a campus by communicating with multiple meters. This information can be used to create a financial incentive, allowing for demand charge reductions. The building load coordination required to achieve the aggregated demand reduction is within the purview of the building operator. The buildings participating in the shared energy economy model represent a predictable amount of load curtailment. This can be achieved by assigning priorities and set points to individual building loads or to an aggregated group of loads. These priorities can be time-dependent and can vary based on the use cases and transactive energy negotiations. The smart meters provide the data visibility to the BEMS operator for generating the optimization use cases. The MGCS can provide aggregate demand control signals to the building operators to reduce demand during system events or peaks.

D. Critical Resiliency

During grid outages, the goal of the critical resiliency concept is to demonstrate that a shared resource model can offset the cost of investment while improving the economics of renewable generation and storage and achieving resiliency. The microgrid can provide energy to critical loads while islanded. The voltage ride-through capacity and the frequency support capabilities of the DERs will be used as indices to test and measure grid resiliency. The noncritical loads will participate in a peer-to-peer transactive energy experiment to use any excess energy within the islanded system.

By providing operational flexibility for DERs, enabling them to participate in numerous services for the four concepts described in this section, the project can illustrate the potential benefits of applying a shared economy model to the energy industry. The MGCS designed for this project must be robust to demonstrate the performance of the four concepts.

III. MICROGRID CONTROL SYSTEM

All hardware devices chosen for the MGCS are protection-class substation-hardened equipment with extended temperature range, shock resistance, electromagnetic immunity, and static discharge capabilities. There is a small chance of equipment failure because of dust accumulation, so there are no fans or spinning hard drives in any of the devices. Fig. 3 shows the MGCS architecture using a layered and segmented representation. This architecture provides a logical representation of the MGCS and is used to identify and define the security controls and patterns of the network design.

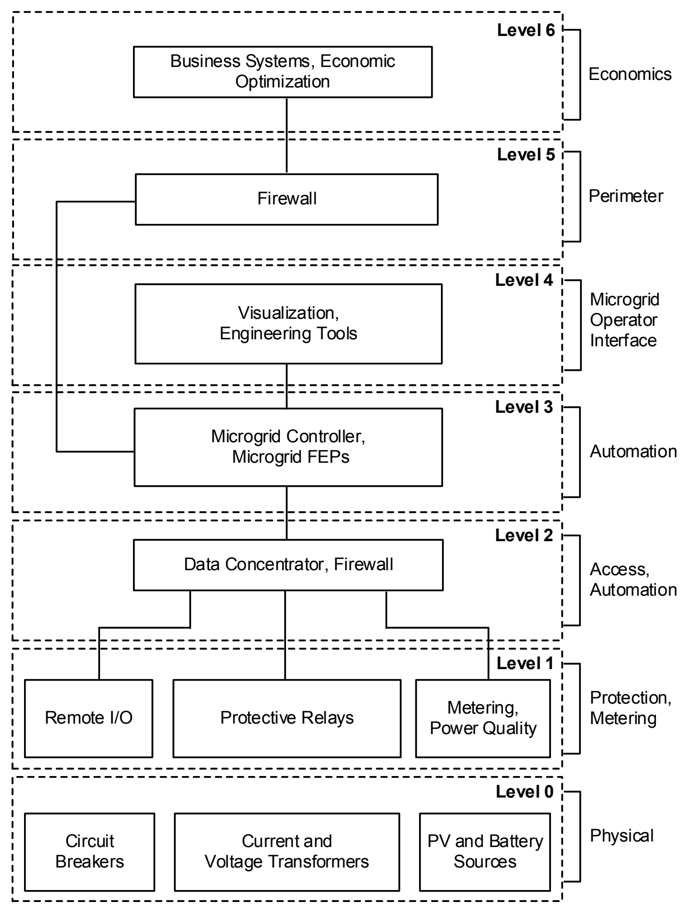

Fig. 3. Segmented MGCS architecture

Level 0 comprises equipment within the microgrid power system. This equipment includes the circuit breakers, switchgears, instrument transformers, and energy sources. The devices at Level 0 integrate into the MGCS via the devices in Level 1, which include protective relays, remote input/output (I/O) modules, and metering devices. The protective relays are required to protect the power system assets from damages during a power system fault. These protective devices are typically located at each PV site, BESS site, and the PCC between the utility and the microgrid. Apart from overcurrent protection, the protective relay at the PCC is also capable of localized controls such as automatic transfer scheme or a synchronism-check element (25). Automatic synchronization schemes programmed in protective relays (A25A) adjust slip and voltage differences by sending raise or lower signals to a single DER. The meters at the electrical load center provide information about the electrical loads.

Level 2 of the MGCS includes a data concentrator (D-CON) that collects data from the protective devices, meters, and I/O modules and passes the information on to the devices in the upper levels. These data concentrators also serve as protocol translators and communicate securely with the devices at Level 2 using a standard set of protocols. This design allows the processing burden associated with the protocol translation to be limited to Level 2 devices. The stateful deny-by-default firewall (FW) at this level improves system awareness and provides the network segmentation explained later in this section.

Front-end processors (FEPs) provide great flexibility for the microgrid scalability. They serve as the primary communications interfaces for all devices. The FEPs at Level 3 communicate with the data concentrators at Level 2 and collect information pertaining to the power system topology, load statuses, and DER statuses. The FEPs also communicate with external control systems, such as the distribution management system (DMS) and distributed energy resource management system (DERMS) at Level 6, to provide MGCS visibility for operators. In certain cases, the FEPs also receive DER optimization control signals from the DERMS. It is important to maintain a single point of communications and control interface between the different control systems and the DERs in the field. The FEP in Level 3 serves as the data bus or the single point of communications integrating the different control systems. The MGCS is always aware of the present state of the power system topology, fault conditions, and overall health of the DERs. Regardless of its mode of operation, the MGCS continuously communicates the status of the power system and the DERs to the DERMS and the DMS. The DMS has the capability to shut down the MGCS if required. Section IV of this paper explains the different modes of operation of the MGCS. The microgrid controller (MGC) at Level 3 is the brain of the MGCS. It runs algorithms that make decisions and sends commands back to devices at Level 1.

Level 4 equipment includes a human-machine interface (HMI) that provides graphical system representations, access to real-time data, the ability to override points in a system, an interface with external management systems, and access to all supervisory monitoring and control functions. These visualization systems properly collect, manipulate, and present power system data as usable information. Other equipment at this level includes engineering workstation (EWS) and historian (HIS) devices. These systems enable operators, maintenance staff, and engineering staff to operate and manage the microgrid system and diagnose system events, predict equipment failures, and minimize unnecessary maintenance. The HIS collects oscillography events and Sequence of Events (SOE) records from the microgrid controller and each protective relay. An electric power engineer can use these data for post-event analysis or fault diagnostics. This node also deploys a Structured Query Language (SQL)-based HIS to collect data from protective relays, DERs, and the microgrid controller. These data archived in the HIS can be retrieved by any SQL client or SQL queries for business analysis. Level 5 is the security perimeter that allows the MGCS to communicate with other control systems such as the DMS and the DERMS in Level 6. The MGCS is designed such that any failure of equipment in Level 5 or Level 6 has no effect on the functionality of the microgrid.

A. MGCS Network Architecture

Extreme care must be taken in designing a network for a critical infrastructure such as an MGCS. Designs involving a flat network reduce the number of switches and routers on the network, but they have drawbacks including poor security and lack of scalability. A segmented network approach was followed in designing the network for the MGCS in this project. In a flat network, any device on the network can see and send messages to any other device on the network. It is best to segment a network that follows the basic security principle that devices should communicate only with other devices that have a need to share data. Flat networks are more prone to data storms and cyberattacks and have poor network resiliency.

In a flat network, all communicating devices have a logical connection to all other devices. Devices receive all broadcast traffic on the network. If the network traffic is not carefully managed and filtered, a data storm is created in which multicast or broadcast traffic floods the network. This can burden all network devices, disable network devices, or create bottlenecks in the network. It is much easier to filter out multicast traffic in a segmented network. Network segmentation allows for fewer endpoints in a subnet, making it easier to set up endpoints for each type of multicast traffic. In addition, any broadcast traffic that is not filtered is much easier for devices to handle in a segmented network.

An intruder who gains access to a flat network can communicate with all devices on the network. On a segmented network, an intruder has access only to a portion of the network and is required to also gain access to individual subnets to cause significant damage.

Network management is more simple and efficient when the network is segmented. Misconfigurations or device failures on a flat network are harder to detect, isolate, and fix. By segmenting the network into smaller, more manageable sections, the design implemented for the MGCS can provide better security, resiliency, and control. A segmented network design also provides the distinct advantage of network scalability. Additional devices can be easily integrated into the network by extending the existing subnet with new device addresses or by adding a unique subnet for the new devices.

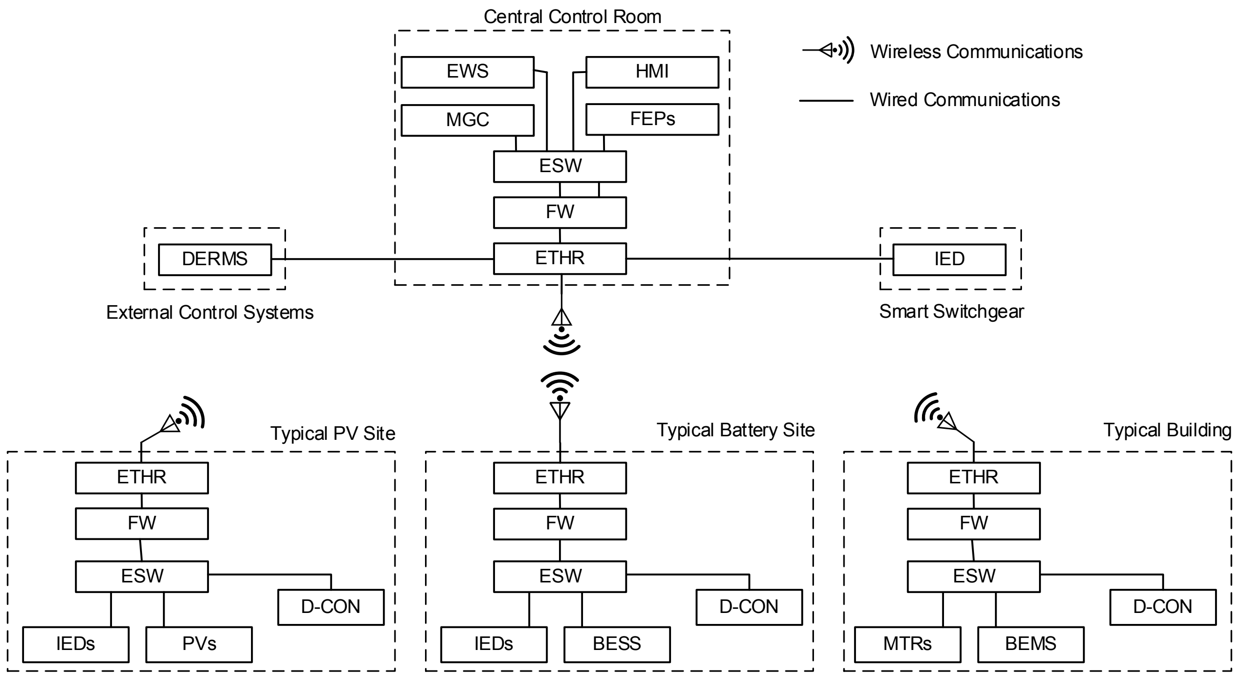

Fig. 4. Overall MGCS network architecture

Fig. 4 shows the overall architecture of the MGCS and how typical DER assets and loads integrate with the central controllers. A typical PV, battery, and building site include Level 0, Level 1, and Level 2 devices. The FW device at Level 2 can be used to establish network segmentation between the different physical locations. The central control room (CCR) includes Level 3 and Level 4 devices. The FW at the CCR is the Level 5 FW that can be used to establish the MGCS security perimeter. Ethernet radios (ETHRs) are the communications medium between field devices and the FEP and microgrid controller in the CCR because of the unavailability of dedicated fiber backbone for communication. Each ETHR is equipped with two 10/100BASE-T Ethernet ports that allow connection to a managed Ethernet switch (ESW). The ETHRs communicate in the 900 Mhz, license-free industrial, scientific, and medical (ISM) frequency band. The ETHRs support Advanced Encryption Standard (AES) 128-bit encryption for secure data transfer. They also support protocols such as User Datagram Protocol (UDP) and IEC 61850 Layer 2, both increasingly used in critical infrastructure applications for their smaller payloads and high-speed communication capabilities. Relays in the smart switchgear and the external control system have dedicated fiber links to the microgrid CCR. The FWs at the ingress and egress points of each subnet allow rules to be established where multicast traffic within a subnet is contained within that portion of the network, reducing device load caused by this type of network traffic. For example, rules can be generated on the segmented network to allow certain types of traffic to flow from the PV site to the CCR and not between the PV site and the battery site.

B. Data Flow Diagram

Data required for the operation of the MGCS are collected from Level 1 equipment. The MGCS also communicates certain important information with other control systems in Level 6. These data can be classified into high-speed data and low-speed data categories. Contingency signals such as loss of a power source or loss of the utility tie are detected at high speeds. Metering information such as real power, load status, power factor, and voltage values required for calculating the actions are not necessary at high speeds. Collecting all data at high speeds would require wide communication bandwidth, demanding additional communication infrastructure. In addition, the segregation of data into high speeds and low speeds has been proven to yield better performance on both large-scale and small-scale projects [2] [3] [4]. All digital and analog data used by the MGCS for calculations are based on speed and reliability. The MGCS monitors the communications for failure at different levels of the network and selects the best data available. The final data used in the controller algorithms are chosen based on data quality. Data validation is accomplished by comparing the two sets of data and ensuring that neither is outside a given threshold from the other.

Data required for the operation of the MGCS are collected from field devices using two different protocols. One protocol will be a traditional open-source protocol that operates on a client-server-based architecture. The client requests the server for data and the server responds to the request with the data. Both the client and server follow predefined, agreed-upon request and response patterns and schedules for establishing communications. The second protocol is an Internet of Things (IoT) standard publish/subscribe (PUB/SUB) protocol such as Data Distribution Service (DDS). The DDS protocol is subscribing to the Open Field Message Bus (OpenFMB™) architecture and framework.

Fig. 5 shows the communications data flow diagram of the concept MGCS. Communications between the data concentrators in the field and the FEPs in the CCR will include both high-speed and low-speed data. The Network Global Variable List (NGVL) protocol is used as the primary protocol. Data over the DDS protocol subscribing to OpenFMB framework is used as the secondary protocol. The NGVL protocol allows data to be transmitted in a peer-to-peer format, using a configurable and flexible cyclic transmission interval between the D-CONs and the FEPs. Message confirmations from remote devices using peer-to-peer protocols are required for the communications integrity. This can be achieved by establishing a data echo signal to ensure successful transmission. Network bandwidth allocations and timing of echo response signals should be taken into consideration while designing the data flow between devices using peer-to-peer protocols.

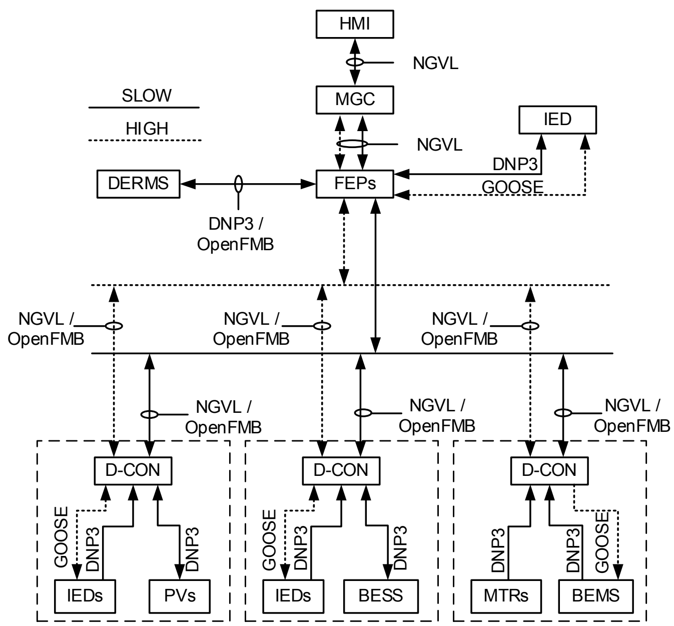

Fig. 5. Communications data flow diagram

The pilot project administrators will implement and investigate the OpenFMB framework in the design to integrate DERs and share data with central systems such as the MGCS and DERMS. The OpenFMB framework was established to move away from centralized intelligence requirements for DERs, to leverage peer-to-peer communication, and to establish distributed intelligence concepts. This model fits and facilitates the establishment of a transactive energy marketplace wherein the market and grid conditions affect one another in a tight closed loop.

The OpenFMB framework can be explained with the help of a three-layered architecture including an application layer, an interface layer, and a PUB/SUB layer. The application layer hosts client-server adapters for communications to field devices using traditional open-source and other proprietary protocols. The interface layer includes unique, semantic data models such as a database to serve as the common interface for messages to be exchanged between field devices. This layer uses data profiles based on the IEC 61970 Common Information Model (CIM). This layer also hosts unique configurations and security patterns. The PUB/SUB layer uses IoT protocols such as DDS, Message Queuing Telemetry Transport (MQTT), Advanced Message Queueing Protocol (AMQP), and other PUB/SUB clients to represent the data in the interface layer to other field devices in a peer-to-peer format.

Fig. 6 shows an example OpenFMB framework model and how different end nodes that subscribe to the model communicate. Each IoT domain participant (communicating device) can publish and/or subscribe to a topic. Each message sent on a topic is called a sample. Unlike traditional methods of applying security at the transport layer, information is secured in every topic like it is secured for database systems. IoT provides great flexibility over how data are managed and shared on a peer-to-peer network. Topics are keyed so that each publisher of a topic can be distinguished as publishing a unique instance of the topic by using a unique key. This way, a participant can receive or ignore samples and receive only samples from certain publishing entities. This model reduces latency and introduces distributed intelligence opportunities.

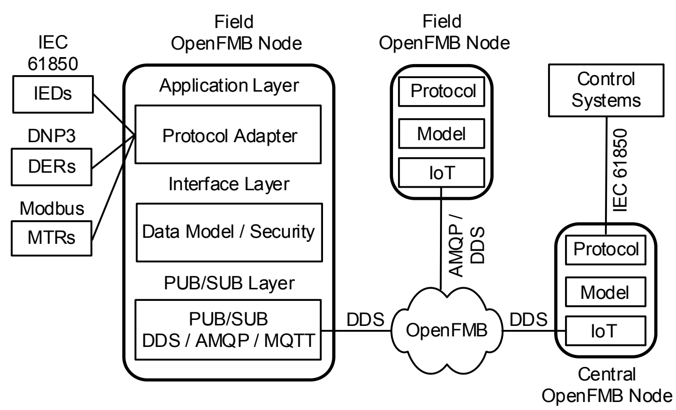

Fig. 6. Example OpenFMB framework model

IV. Microgrid Controller Operation

The microgrid power system is capable of operating in parallel with the utility in grid-connected mode and operating completely independent of the utility in islanded mode. The primary role of the MGCS is to maintain power system stability whether operating in islanded mode or in grid-connected mode. It maintains the power system within the stability boundaries or the boundary conditions set by the operator.

A. Grid-Connected Mode

Though this project will have only one PCC, the MGCS is capable of simultaneous management of several PCCs to the adjacent utility grid. The MGCS can provide support to the utility when operating in this mode. During grid-connected operation, the MGCS passes on commands from the DERMS server based on DER optimization and economic operation decisions. The FEPs communicate the present state of the power system topology and overall health of the DERs to the DERMS. Careful consideration is required in designing and designating the control signal exchanges between the two control systems. The MGCS includes several algorithms that control an individual DER asset or coordinate the operation of a group of assets. An automatic generation control (AGC) algorithm dispatches the power output of a single asset or a group of assets to maintain power interchange at the PCCs within predetermined limits. The MGCS continuously monitors and tracks the status of PV generation and present loading and load-status information. Based on the predicted solar generation available for a predefined window of time, the MGCS sends control signals to the BEMS to proactively operate building and individual loads using the excess local PV generation. Because the MGCS continuously monitors the topology of the power system, dispatch control signals are dynamically recalculated under all system bus configurations.

The MGCS charges the BESS during grid-connected mode. BESS charging can be implemented using two different strategies [5]. Strategy 1 ensures that a minimum BESS charge is maintained regardless of the PV power output status. Strategy 2 charges the BESS proportionately to the PV power output. Strategy 2 is implemented using techniques such as peak shaving, where the MGCS controls energy resources such as battery discharge during peak usage while charging is accomplished during minimal usage.

B. *Islanded Mode*

One of the most important reasons why automatic and intentional islanding is preferred is safety. The microgrid is intentionally islanded from the utility to prevent backfeeding from the microgrid when the breaker upstream of the PCC is opened to clear a fault. The MGCS communicates with the smart switchgear to collect breaker status indications, disconnect switch statuses, voltage measurements, and current measurements to detect the loss of utility tie. The present design of the project calls for allowing the microgrid to pass through a brief blackout period during the loss of utility tie. Seamless islanding of a microgrid is possible and more effective when the microgrid contains conventional sources of power generation. The microgrid steps during the islanded mode of operation are shown in Fig. 7. Automatic decoupling schemes using frequency, rate-of-change of frequency, and directional power elements will be investigated and tested in future stages of this project. These types of decoupling schemes are required to prevent damage to the microgrid components during a fault on the main utility grid.

After a microgrid island is formed, the MGCS modifies the mode and dispatch of islanded generation and loads to keep the microgrid stable. The system keeps the frequency and voltage within allowable parameters for any number of islands. A load-shedding action is performed to disconnect loads in the microgrid after the formation of an island. This is required to black-start the microgrid using the BESS. The charged BESS provides the voltage set-point reference for the PV sources to start exporting power to the islanded microgrid. The MGCS energizes all critical loads. Following critical load restoration, the MGCS dispatches any excess energy in the islanded system to the noncritical loads based on the results of the economic transaction signals. The transactive economic model for load restoration to noncritical loads and use cases will be studied in this pilot project.

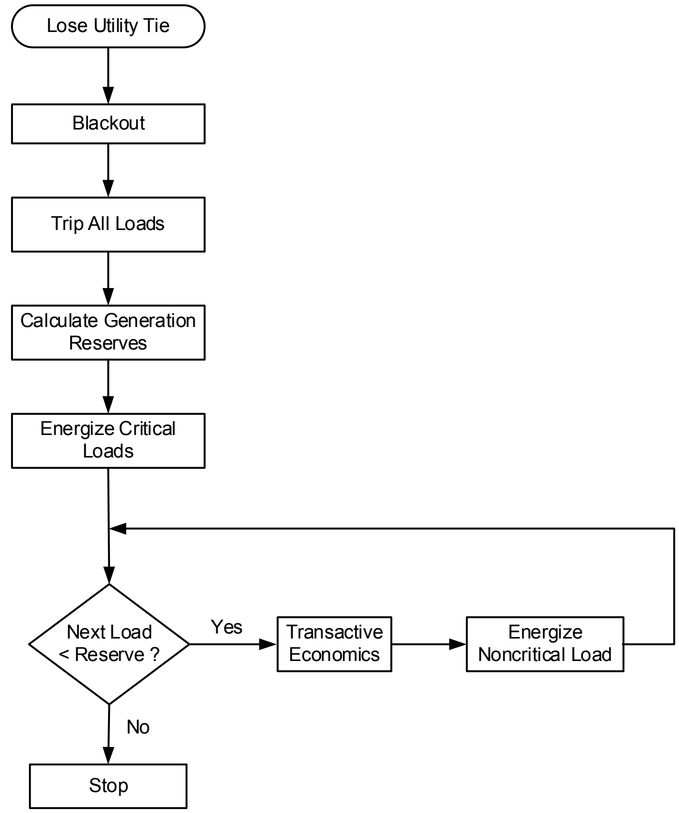

Fig. 7. Black-start sequence

The MGCS performs automatic load management to equalize the load with generation for grid stability. After the power is restored to the microgrid, a fast load-shedding system provides automatic load reduction in response to island events or loss of distributed power generation. Low-inertia microgrids require ultrafast load reductions to prevent cascading losses of distributed power generation. This scheme equalizes the system load and generation, typically within 70 ms. This system operates in every combination of system topology and bus configuration by dynamically tracking the system state.

When the utility source is healthy, the MGCS sends time-varying control signals to the group of DERs to bring the frequency, voltage, and angle difference across the PCC to within limits of synchronization. Advanced breaker-close logic, which is programmed in the relays protecting and monitoring the smart switchgear, sends a close signal to the PCC breaker to ensure a zero-angle close [5].

V. Hardware-in-the-Loop Testing

The main objective of real-time hardware-in-the-loop (HIL) testing of this concept microgrid is to analyze the combined performance of the microgrid controllers and other control systems such as DERMS or BEMS. A real-time simulator allows dynamic modeling of the microgrid and the utility power system interconnection with a simulated small-time step to test all closed-loop controls. The power system model built in the real-time simulator will represent the Level 0 equipment in the microgrid. The real-time simulator I/O module allows the dynamic model to interface with relays, meters, and other equipment in Level 1 and higher levels.

Significant time and effort will be devoted to configuring and testing the power converter models and communications interface between different components of the MGCS. Because the DERs do not contribute to the fault currents at levels that conventional generators do, the power system model will also be used to perform short-circuit studies. Results from these studies will be used to develop an adaptive protection system to mitigate any potential coordination problems between the grid-connected mode and the islanded mode. Several use cases will be developed and tested using the HIL testing methods to validate the combined performance of the protection and control system functionalities.

VI. Conclusion

Avista's Clean Energy Fund project seeks to demonstrate the benefits of a shared energy economy model for the control and optimization of DERs. The goal is to increase the use of the electric distribution system and DERs, benefiting consumers and the utility system. The MGCS design for this pilot project will focus on addressing and investigating the following:

- Experimenting with various modes of microgrid operation and determining their values in a real-world scenario.
- Verifying protection coordination in transitioning from grid-connected mode to islanded mode and vice-versa.
- Reviewing the application of OpenFMB framework and investigating the advantages of implementing it over traditional protocols.
- Investigating advantages, challenges, and use cases of a micro transactive grid.

The design proposed in this paper describes the MGCS functionality needed to achieve the project goals while providing safe and reliable energy service to customers within the microgrid, whether it is islanded or grid-connected. The micro transactive grid will serve as a platform for future research and experimentation related to distributed energy.

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VIII. Biographies

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20180123 • TP6862-01