

Implementation of a Publish-Subscribe Protocol in Microgrid Islanding and Resynchronization With Self-Discovery

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Abstract—Communications systems and protocols are becoming second nature to utilities operating distribution systems. Traditionally, centralized communication approaches are often used, while recently in microgrid applications, distributed communication, and control schema emerge offering several advantages such as improved system reliability, plug-and-play operation, and distributed intelligence. Still, operation and control of microgrids including distributed communication schema have been less of a discussion in the literature. To address the challenge of multiple-inverter microgrid synchronization, a publish-subscribe protocol based, data distribution service, communication schema for microgrids is proposed. The communication schema is discussed in details for individual devices such as generators, photovoltaic systems, energy storage systems, microgrid point of common coupling switch, and supporting applications. Finally, islanding and resynchronization of a microgrid are demonstrated on a test-bed utilizing this schema.

Index Terms—Microgrid communications, islanding, resynchronization, publish-subscribe.

I. INTRODUCTION

TODAY, advancements in electric distribution system intelligence are occurring rapidly with the emerging Internet of Things technologies. Many of these advancements are being spawned by the available data and information that is collected and distributed to various utility management systems, such as the distribution management system. This ability to obtain data and communicate to various devices and components in power systems is altogether changing the way utilities do business [1].

Communications in power systems have been in development for many years and are highly instrumental in systems such as system automation [2]. For example, through a peer-to-peer communication scheme, the Electric Power Board of Chattanooga has shown the ability to intertie protection settings for their fault interrupting devices, thereby producing dynamic protection mechanisms [3].

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Typically distribution system communication systems are broken down into sub systems, including a main high speed communication backbone network and a last mile connectivity [1], [2], [4], [5]. At the lowest level, communications to buildings through technologies such as the Advanced Metering Infrastructure (AMI) are typically done wirelessly. In more complicated systems such as microgrids, multiple tier communication systems have been adopted to interface neighborhood area networks and microgrids [5].

In many publications on microgrid communications, research has primarily focused on the higher-level architectures and is demonstrated through simulation. For example, Shukla *et al.* [6] utilize a simulation tool called OPNETTM to investigate the impacts of packet losses and latency, specifically on wireless communications for microgrids. The authors show a network architecture to support transmitting different types of traffic. Ci *et al.* [7] utilize MATLAB/Simulink models to demonstrate the communication delay associated with wireless technology and the impact on load sharing type control. Another discussion on wireless communications for microgrids focused on islanding and utilized SimpliciTI [8].

To a large extent, the choice of communication architecture and protocols is determined by the microgrid control structure and required functions. The general practice in microgrid communications appears to be master-slave type of communication architectures using Modbus, DNP3, and IEC 61850 [9]. In [10], the IEC 61850 protocol is discussed for implementation within a microgrid with a description of the messaging structure and communication model described. In [11], a microgrid communications strategy that utilizes the agent communication language (ACL) is developed and discussed. This work has the agents operate and control the various distributed generation assets and load. The authors also discuss an operational scheme to island utilizing this agent-based communication approach.

The Data Distribution Service (DDS) is a networking middleware and machine-to-machine communication standard for real-time systems. Using publish-subscribe pattern, DDS enables scalable and interoperable data exchanges, which are desired for real-time microgrid applications, and simplifies complex network programming. Cintuglu *et al.* [12] utilize DDS and IEC 61850 to examine a framework for supporting agent-based control and communications on a microgrid and demonstrate functionality through a hardware-in-the-loop platform. This is further discussed in [13]. Shi *et al.* [14]

implement DDS for basic smart grid system monitoring and demonstrate the functionality by utilizing wind turbines and a dSPACE MATLAB/Simulink environment. Youssef *et al.* [15] performed a similar exercise utilizing MATLAB/Simulink on their testbed [16]. The authors review a developed topics list and schema for implementation onto DDS, as well as provide several high-level control diagrams to support the discussion of the development.

Although different microgrid control and monitoring functions have been explored using DDS communications, so far an effective solution is still yet to be found for microgrid reconnect and synchronization to grid and multiple inverter control coordination during transition, which requires fast communications for corresponding control mode changes. This paper is intended to address this technical challenge by deploying and implementing the DDS publish-subscribe communication scheme. Specifically, in this paper, a DDS protocol will be discussed in detail for the development of the second generation of the Complete System-Level Efficient and Interoperable Solution for Microgrid Integrated Control (CSEISMIC), an open-source microgrid controller funded by Department of Energy [17]. The communications are demonstrated on a physical microgrid testbed at Oak Ridge National Laboratory (ORNL) known as the Distributed Energy Communications and Controls (DECC) Laboratory. One of the key aspects of this controller is the ability to self-discover devices interconnected to the system without preexisting knowledge of the devices. This provides avenues for devices or even applications such as load forecasting, weather forecasting, and utility pricing to share information to the system without significant setup. More information regarding this type of system is presented in the following sections.

II. OVERALL VISION AND MICROGRID COMMUNICATION STRUCTURE

A vision that the microgrid community is striving to achieve is that of an automatically deployable and interoperable microgrid. Today, this is met with a number of barriers. As mentioned in literature, many devices are typically interfaced through communications such as Modbus that do not have strict adherence to addressing or data types to support intercommunication [9]–[11]. Instead, unique schemas and configurations have to be embedded into the communication architecture of the microgrid controller in order to interface with each specific device. IEC 61850 attempted to mitigate this challenge by addressing all the different data types and required communication interfaces. However, the communications still require configuration files and device communication setup based on a foreknowledge of the physical topology of the microgrid. Another group, the Smart Grid Interoperability Panel (SGIP), has been working on a standard communication called the Open Field Message Bus (OpenFMB) to provide a framework that allows for discovery and eliminates the requirement of pre-existing knowledge of microgrid topology [18]. At the time of this writing, the standards are still in progress and are not practical for the initial

TABLE I
SAMPLE MICROGRID COMMUNICATION SCHEMAS

Schema	Protocols	Domain
IEC 61850	MMS, GOOSE & GSSE	Substation
OpenADR	HTTP & XMPP	Price-based
		Demand Response
OpenFMB	AMQP, DDS, MQTT, etc.	Grid Edge

TABLE II
EXAMPLE COMMUNICATION PROTOCOLS

Protocol	Message Based	Peer to Peer	Native Security	Discovery
AMQP	X	X	X	X
DDS	X	X	X	X
DNP3			X	
GSE	X	X		
HTTP			X	
MMS				
Modbus				
MQTT	X	X		X
XMPP	X		X	
ZeroMQ	X	X	X	X

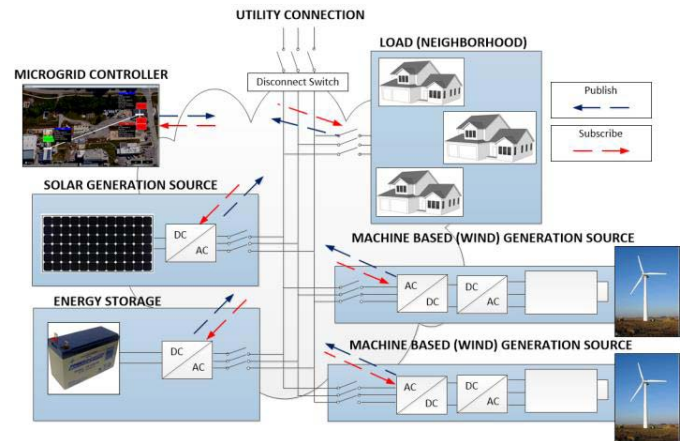


Fig. 1. Diagram representing concept of the communications.

development of the communication schema utilized here. Some example microgrid communication standards are shown in TABLE I [22]–[24].

The communications system for CSEISMIC utilizes DDS as the communication protocol. Several protocols were considered before the decision to adopt DDS was made (see TABLE II [20], [24]–[36]). Only two communication protocols supported easy messaging, peer-to-peer capability, native security, and discovery, DDS and AMQP. DDS was chosen since adapters had become available in LabVIEW.

The DDS protocol is based on a publish-subscribe framework and supports the direct application of peer-to-peer communications or device-to-device communications within a microgrid [19]. In this protocol, devices publish topic information by broadcasting information onto a communication medium such as Ethernet. All of the information is automatically collected on the devices and filtered to topics of interest. A depiction of this communication is shown in Figure 1. Peer-to-peer communications with a publish-subscribe protocol

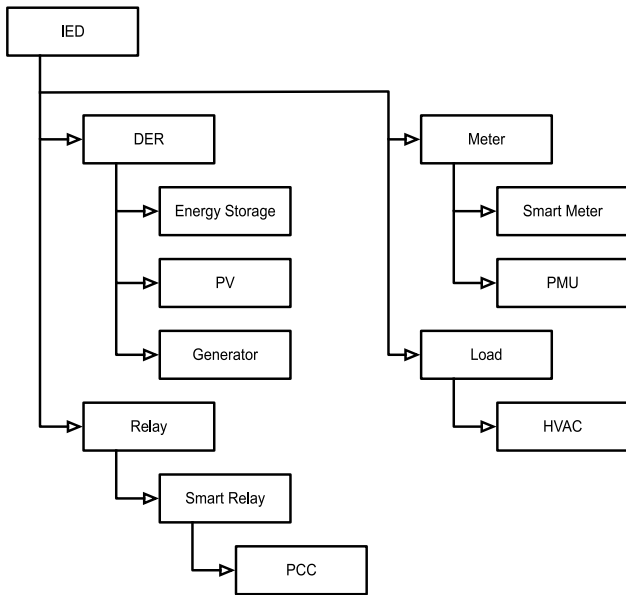


Fig. 2. Class architecture supporting communications.

allows for devices to communicate directly, without the added complexity and latency of communicating through the master controller.

The CSEISMIC microgrid controller subscribes to different data sets being published by all the devices within the microgrid. This includes any forecasting applications that provide guidance on load and potential renewable generation such as photovoltaic (PV). The forecast data is utilized by the optimization portion of CSEISMIC to determine the optimal dispatch of the generation to meet cost objectives. The devices subscribe to the dispatch requests of the master controller and modulate output to achieve these targets. More sophisticated interconnects on the communications can be also included, as is the case with islanding and resynchronization. The details on the communications schema and discussion on islanding and resynchronization of a microgrid are provided in the following sections.

III. DDS SCHEMA/TOPICS

In the implementation of a DDS schema, a class based structure was utilized as shown in Figure 2. This schema was developed to support necessary microgrid use cases (such as islanding and resynchronization) and optimization. At the highest level, all system devices fall into the class intelligent electronic devices (IED). All generation resources are classified as distributed energy resources (DER) and include potential generation assets such as energy storage, PV, and generators.

The relay class contains all the devices able to break connection in the grid, including more modern relays that are able to provide measurement data via the communications system and those that provide synchronization capabilities (PCC). Other device types including metering and load are defined in separate classes.

TABLE III
IED COMMUNICATIONS DATA

Topic	Information	Data Type
PROPERTIES		
IED_Status	DeviceID	STR
	MicrogridID	U8
	Active	BOOL
	Inactive	BOOL
	Error	I32
	Fault	BOOL
	ErrorString	STR
METHODS		
IED_setMicrogridID	DeviceID	STR
	MicrogridID	U8
IED_watchdogReset	MicrogridID	U8

In general, the topics defined in the schema follow a classification as either a property of the device or as a method. Properties are data sets that are published for information purposes. This includes information data such as measurements performed by the device, characteristics of the device such as efficiency or power rating, and current control modes or states of the device. This information is often subscribed to by the microgrid master controller. Methods are published data that provide actionable information to the devices such as target dispatch setpoints for the device, activation and deactivation commands, and change in control mode. This data can come from the master controller or other devices in the network. More details regarding the information for each class is presented in the following sections.

A. Intelligent Electronic Device

The IED class has the basic device related information including the assigned microgrid (MicrogridID), device identification code (DeviceID), and other information as shown in TABLE III. This is information that all devices are required to publish to support the microgrid control and the self-discovery capability of the system. Figure 3 shows the general state-machine for each device. Upon starting the device or commissioning the device, the device performs self-checks and confirms full functionality before reaching the checkID state. At this stage, the device publishes a MicrogridID of zero and the DeviceID to a dedicated DDS domain used by the controller to generate a list of available devices. A MicrogridID of zero signifies that this device has not been claimed by a controller and is considered a free agent for adoption into a microgrid. The user of the microgrid controller is presented with a graphical interface screen that allows them to choose the devices to incorporate into their microgrid and the controller subsequently publishes a change in the MicrogridID to the chosen devices. No configuration or code change is required on either the device or the controller, regardless of the microgrid being assigned, thereby providing true plug-and-play functionality. However, the device selection is also capable of being automated with preconfigured configuration files that specify which devices are to be automatically assigned to explicit microgrids for situations where headless deployment is desired.

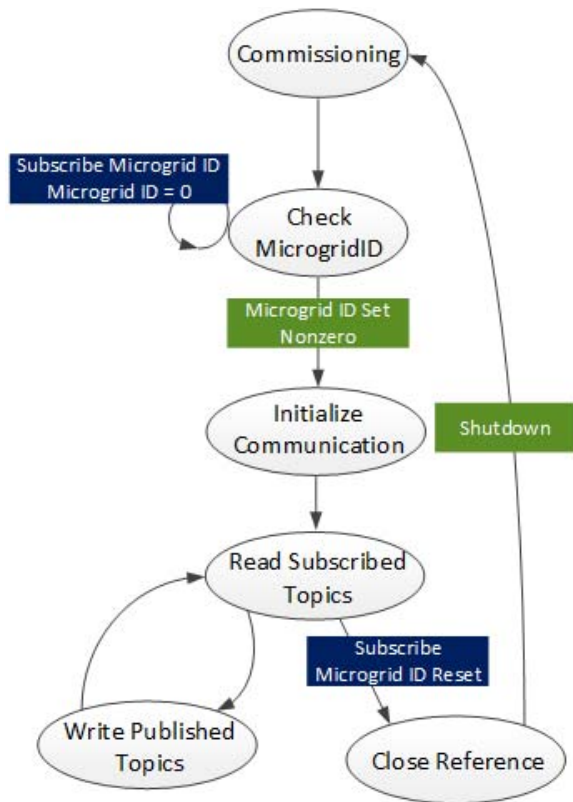


Fig. 3. High level device communications interface.

The devices at this stage initialize communications and begin subscribing (reading) and publishing (writing) data as defined by the schema. In the following sections, details on subclasses of distributed resources and relays are provided to give insight into the islanding functionality.

B. Distributed Energy Resource

All generation and energy storage assets are classified as DER in this schema. These include PV, energy storage, and generators such as diesel or microturbine types.

The corresponding DER device based state machine is represented in Figure 4. Upon commissioning, the device operates in a standby mode and awaits a change in the MicrogridID before transitioning to an active state. The DER topics and schema are presented in TABLE IV. The schema allows for microgrid communications that support single master operation and integration of an optimization actor [20]. While on grid, generation assets can be dispatched utilizing the DER_SetPointP and DER_SetPointQ to meet optimization objectives such as peak reduction while staying within constraints on voltage and microgrid power factor. The LineConfig provides information regarding the phasing of the interconnection of the resource such as A/B/C or C/A/B to ensure that the optimization has the correct information.

Within this set of topics is DER_VF. This identifies the specific device designated as a voltage-frequency control asset or the single master. The master controller decides on this device and publishes DER_VF, to which the DER devices subscribe.

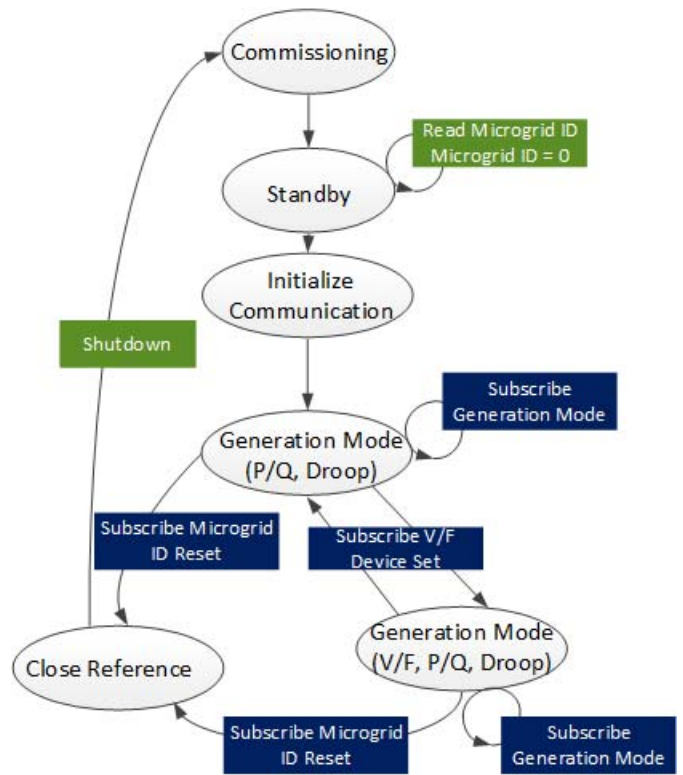


Fig. 4. Generation source communications.

In this particular case, the PCC switch also subscribes to this topic. This is described further in the following sections.

Beyond the typical dispatch information associated with DERs, the subclasses associated with the DER class (e.g., energy storage and PV) also have specific information associated with the class, generally of the Properties type. For energy storage systems, TABLE V provides the topics and data sets utilized to distribute information. This data includes information measurements that are not typical of a DER, but pertinent to an energy storage system such as State of Charge (SOC), minimum and maximum allowable SOC, and charging and discharging efficiency.

The generator class has no additional measurements beyond those supported by the DER class. However, information for properties associated with the optimization is included, such as fuel cost, startup cost, and efficiency as shown in TABLE VI.

C. Supporting Applications

There are a number of applications that share intelligence of system wide operations within the microgrid, including forecasting and pricing information. Historically, these applications have been directly interconnected to the energy management system (EMS) and provided the information directly to it without interaction with other devices. With the implementation of the DDS-based communications schema, the applications are able to reside independently of the EMS and publish data relevant to optimization and other system hardware. In many cases, these applications are only information providers and do not utilize any of the information within the system.

TABLE IV
DER COMMUNICATIONS DATA

Topic	Information	Data Type
PROPERTIES		
DER_Measurement	DeviceID	STR
	Voltage	DBL[3]
	Current	DBL[3]
	RealPower	DBL[3]
	ReactivePower	DBL[3]
	LineConfig	U8[3]
DER_Info	DeviceID	STR
	VFCControl	BOOL
	PControl	BOOL
	QControl	BOOL
	PFCControl	BOOL
	PVControl	BOOL
	Droop	BOOL
	Unbalanced	BOOL
DER_Status	DeviceID	STR
	VFCControl	BOOL
	PControl	BOOL
	QControl	BOOL
	PFCControl	BOOL
	PVControl	BOOL
	Droop	BOOL
	Unbalanced	BOOL
DER_Control	DeviceID	STR
	Activate	BOOL
	Deactivate	BOOL
DER_setGeneratiopn Mode	DeviceID	STR
	Mode	Enum32
DER_SetPointP	DeviceID	STR
	RealPower(kW)	DBL[3]
DER_SetPointQ	DeviceID	STR
	ReactivePower(kVAR)	DBL[3]
DER_SetPointVF	DeviceID	STR
	Voltage(V)	DBL
	Frequency(Hz)	DBL
DER_VF	DeviceID	STR

TABLE V
ES COMMUNICATIONS DATA

Topic	Information	Data Type
PROPERTIES		
ES_Measurement	DeviceID	STR
	SOC	DBL
ES_Info	DeviceID	STR
	BusID	U16
	PowerRating(kVA)	DBL
	EnergyRating(kWh)	DBL
	RampRate(kW/s)	DBL
	MaxPowerFactorLeading	DBL
	MaxPowerFactorLagging	DBL
	ChargingEfficiencyCurve	Cluster
	DischargingEfficiencyCurve	Cluster
	MinSOC	DBL
	MaxSOC	DBL

For performing optimization, forecast data such as that of both load and renewable generation is needed. TABLE VII shows the schema for forecasting. The schema is the same for all types of forecasting and the TargetID identifies the device associated with the specific forecast. For example, if

TABLE VI
GEN COMMUNICATIONS DATA

Topic	Information	Data Type
PROPERTIES		
GEN_Info	DeviceID	STR
	BusID	U16
	PowerRating(kVA)	DBL
	MinimumPower(kVA)	DBL
	RampRate(kW/s)	DBL
	MaxPowerFactorLeading	DBL
	MaxPowerFactorLagging	DBL
	EfficiencyCurve	Cluster
	StartCost	DBL
	FuelCost	DBL

TABLE VII
LOAD AND PV FORECAST COMMUNICATIONS DATA

Topic	Information	Data Type
PROPERTIES		
ForecastData_Long	DeviceID	STR
	TargetID	STR
	t0	DBL
	dt	DBL
	Power(kW)	DBL[2880]

TABLE VIII
REAL TIME PRICE COMMUNICATIONS DATA

Topic	Information	Data Type
PROPERTIES		
PriceData_RealTime	DeviceID	STR
	t0	DBL
	dt	DBL
	Price	DBL[2880]

a PV system is interconnected to the microgrid, a separate PV forecast application with the TargetID of that PV system will provide the needed forecast for the PV system.

A separate set of pricing information is also needed to support the needs of the microgrid objective. In this case, a real-time price structure has been developed as shown in TABLE VIII. Other schema can be added to support demand charge and energy based rate structure systems.

D. Relay

For islanding operations and load shedding, relays and breakers are needed to break the electrical connection, but are also valuable assets for system data. The relay represents the highest class within this structure. The relay control topic provides the ability of the device to be activated (closed) and deactivated (opened) as shown in TABLE IX. Since not all relays will necessarily have data available, a subclass described as a smart relay provides measurement information. This information can be linked to a load forecast and provide valuable real-time readings on current load consumption. The topics for this are presented in TABLE X.

Devices of particular interest to microgrids are those that provide a resynchronization capability. These are devices that

TABLE IX
RELAY COMMUNICATIONS DATA

Topic	Information	Data Type
METHOD		
Relay_Control	Device ID	STR
	Activate	BOOL
	Deactivate	BOOL

TABLE X
SMART RELAY COMMUNICATIONS DATA

Topic	Information	Data Type
PROPERTIES		
SmartRelay_Info	Device ID	STR
	LineConfig	U8[3]
	NominalVoltage(V)	DBL
SmartRelay_Measuremet	Device ID	STR
	PrimaryVoltage(V)	DBL [3]
	SecondaryVoltage(V)	DBL [3]
	Current	DBL [3]
	RealPower	DBL [3]
	ReactivePower	DBL [3]

TABLE XI
PCC SWITCH COMMUNICATIONS DATA

Topic	Information	Data Type
METHODS		
PCC_Transition	Device ID	STR
	Island	BOOL
	Resynchronize	BOOL

measure the voltage waveforms on both sides of the device and wait until the voltage magnitude and phase are aligned before closing. In the class structure, these have been designated as PCC switches. The topics for this device are islanding and resynchronization as shown in TABLE XI.

The state machine for the PCC switch with DDS schema is shown in Figure 5. As in the case with DER, the device commissions and stays in standby until a change in MicrogridID is received from the master controller. At this stage, the communications are initialized and the device confirms the current state 'open' or 'closed.' As previously noted, the master controller publishes the DeviceID for the voltage/frequency control through DER_VF and the PCC switch is a subscriber to this topic. An internal reference to this device is stored by the PCC and utilized to publish the need for a change in device control state of the designated VF device when islanding and resynchronization occur. An example of this is shown in Figure 6.

The PCC switch also subscribes to the topic PCC_Transition and monitors for an islanding or resynchronization request. Upon receiving PCC_Transition, the device either performs the resync operation or islanding operation. Once islanding or resynchronization is confirmed, the PCC switch publishes DER_setGenerationMode to the stored device performing voltage real/reactive control for an on-grid transition or voltage/frequency for an off-grid transition.

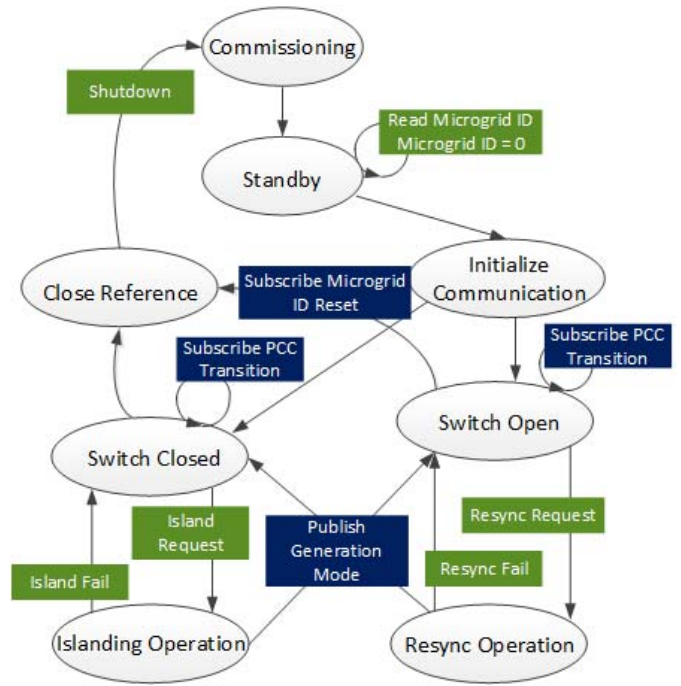


Fig. 5. PCC Switch state machine.

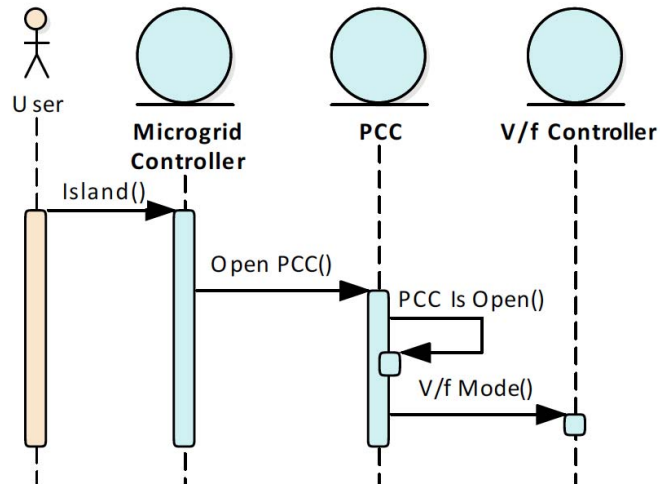


Fig. 6. Islanding operation with a Publish-Subscribe communications protocol.

Islanding with a master-slave architecture requires that the microgrid controller send a command to the PCC and await a state change that must be read from the PCC before issuing a state-change on the primary inverter source as shown in Figure 7. The master-slave architecture requires at least one additional communication of a message as the master controller must read a state change and communicate this to another device. This increases the communication traffic and round-trip latency of the communications [17].

E. Devices With Other Schemas

As this schema was developed independent of any standards and is purely DDS focused, device communication interface translators can be developed to convert the DDS schema to the

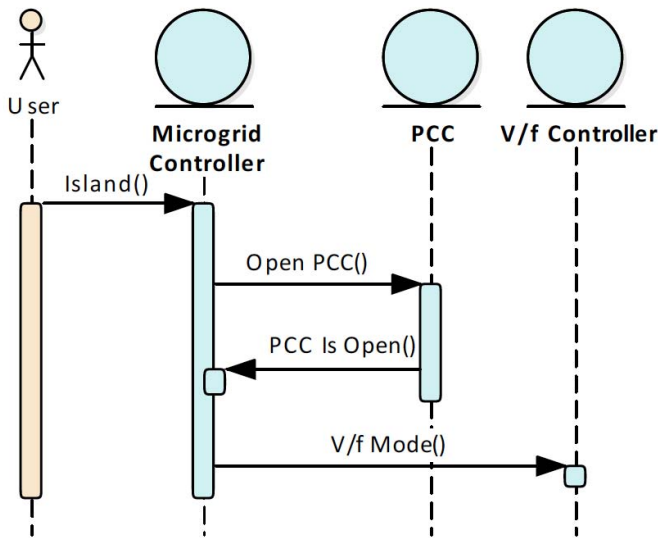


Fig. 7. Islanding operation with a Master-Slave communications protocol.

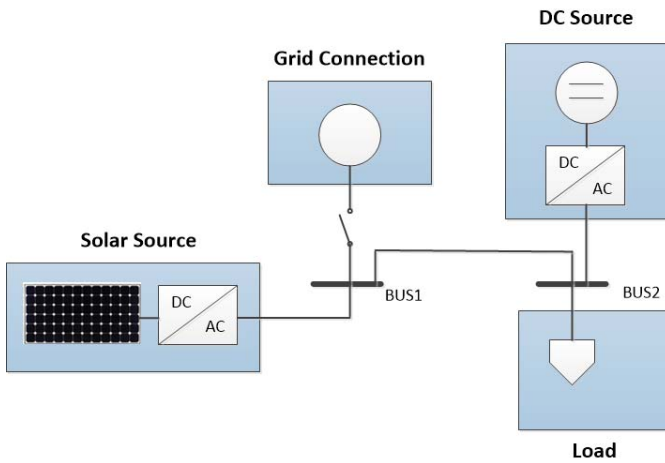


Fig. 8. Electrical model representation of test-bed.

device schema either on the device side with a low cost device or in the microgrid controller side with a software interface. The choice of the approach is governed by any communication latency concerns such as that between the generator source and PCC switch. An example of this conversion is described in the following section under the hardware implementation.

IV. ISLANDING AND RESYNCHRONIZATION HARDWARE

In this section the implementation of the schema on physical hardware is presented. In this case, the microgrid demonstration is implemented on the DECC facility and consists of two sources, a PV system and generator, a PCC switch, and load relay at 480V, three phase. The electrical representation of the system is shown Figure 8.

A. Generation Sources

The generator consists of ORNL-developed inverter-based control systems utilizing NI CompactRIOs. As an example, the generator main controller is an NI CompactRIO 9030 running



Fig. 9. Inverter Source.



Fig. 10. PV System.

LabVIEW 2016. There are three control modes for inverter-based DERs: active and reactive power control (P/Q), active power vs. frequency (P-f) droop control or reactive power vs. voltage (Q-V) droop control, and voltage and frequency secondary control (V/f).

In the current implementation of a source controller on DECC, a programmable inverter [21] is implemented as shown in Figure 9. A programmable DC supply is used to provide the DC link support for source testing.

B. PV System

A vendor-provided PV system is integrated and utilizes Modbus communications. A Modbus to DDS conversion was created on the software side of the master controller to provide automatic discovery and communication integration to the master controller. The PV system is shown in Figure 10. This type of conversion can be created for any number of devices that do not support the communication schema.

C. PCC Switch

The PCC switch is a 1200A-rated circuit breaker. A control interface for providing signaling of closing and opening has been developed utilizing an NI CompactRIO 9068 running LabVIEW 2016 as shown in Figure 11. An analog input module is used to obtain voltage and current signals on both grid and microgrid sides. The voltage, frequency, and phase angle of grid and microgrid sides are monitored and compared in the microgrid switch controller in order to make islanding and resynchronizing decisions. A digital output module is used



Fig. 11. PCC Switch.

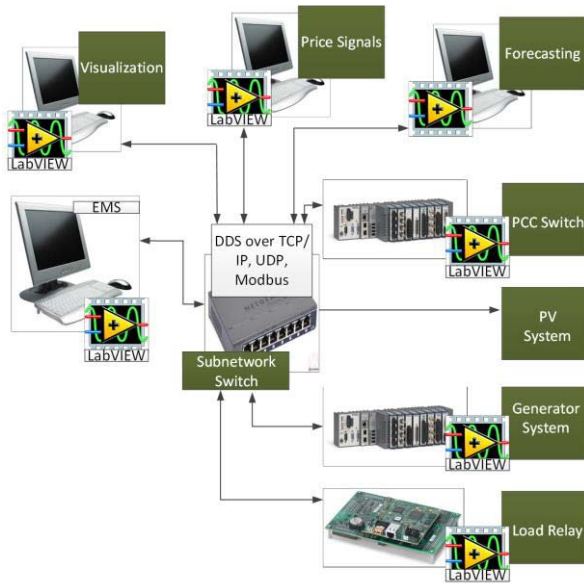


Fig. 12. Overall Communication and System Diagram.

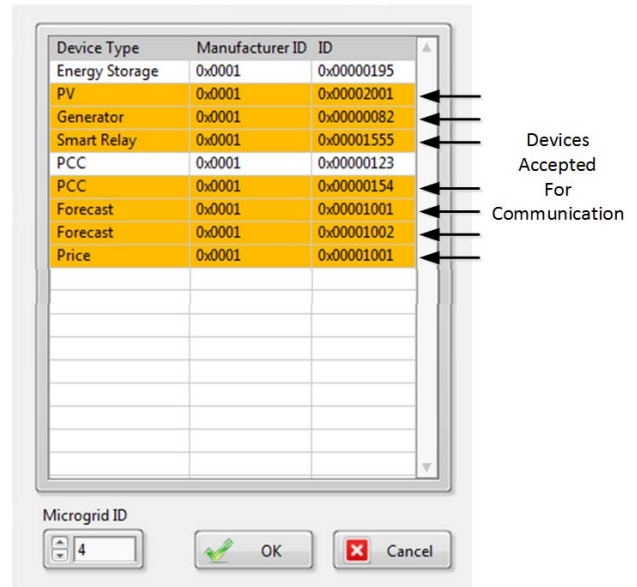
to send out the digital signal to open or close the microgrid switch.

D. Overall Integration

The overall interconnection of devices and applications is presented in Figure 12. The devices are primarily composed of LabVIEW controllers as mentioned previously. Applications were developed in LabVIEW that support visualization, price signals, and forecasting for 48 hours ahead of the current time interval.

V. RESULTS

Initial demonstration of the functionality of the new communications schema begins with the demonstration of the self-discovery capability. Figure 13 shows the window for a device search that looks at all the open devices that have not been assigned to a microgrid. The ID code represents a unique set of numbers that both identifies the device and also signifies



Devices Accepted For Communication

Fig. 13. Example of self-discovery.

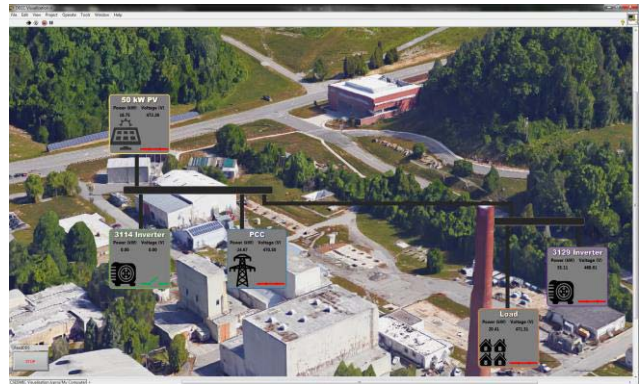


Fig. 14. Visualization of CSEISMIC.

the device type. The highlighted devices are those that the user has selected to incorporate to the microgrid. The microgrid ID at the bottom will be the new microgrid operating number for generation communications.

The initial launch of the communications pushes all devices into read/write states and initiates optimization and other functions of an energy management system (EMS). A separate application that is purely considered a spectator reads the data and performs the visualization. This is shown in Figure 14. As shown, PV, the generation asset labeled 3129 Inverter, and the microgrid switch (PCC) are interconnected to the microgrid and operating.

A user interface provides the user the ability to launch an islanding transition upon request (non-intentional islanding is also supported but is directly initiated by the PCC). Different optimization routines are utilized to support microgrid functionality. For example, in islanding the objective is to minimize the net real and reactive power flow through the microgrid switch to ensure a more stable transition to island.

An example result of the islanding transition is shown in Figure 15. The voltage waveform on the PCC is captured

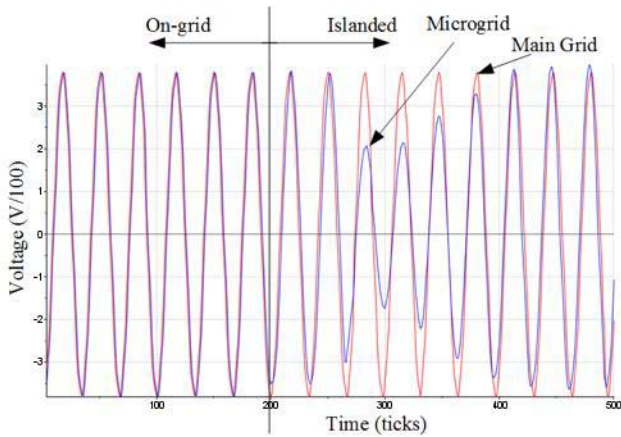


Fig. 15. Islanding (Voltage at PCC).

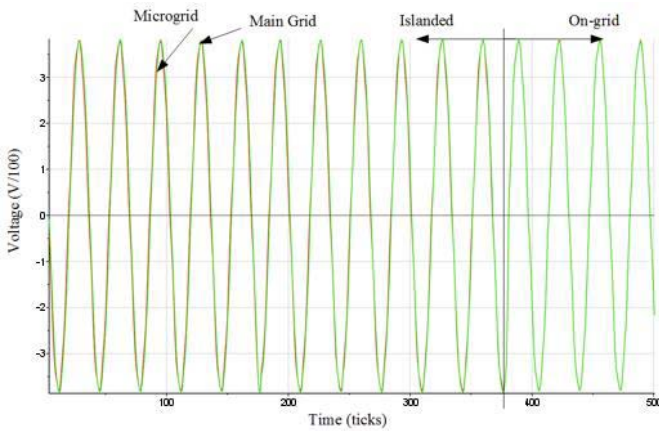


Fig. 16. Resynchronization (Voltage at PCC).

to demonstrate the recoverability of the system during an islanding transition. During an island, the master controller publishes a request to island. The PCC performs an open on the switch and publishes a generation mode change request (`DER_setGenerationMode`) to the designated V/f source (3129 Inverter). As seen, the communication delay associated with the peer to peer communications in this deployment is approximately 2 cycles, allowing for the controller to ensure stability of the system within the necessary voltage and frequency limits.

During resynchronization, the optimization objective is to minimize the voltage gap between the primary and secondary sides of the PCC. This is performed before publishing a resynchronization request. An example result of the resynchronization transition is shown in Figure 16. The voltage waveform on the PCC is captured to demonstrate the synchronization of the voltage waveforms of the microgrid and primary grid. After receiving the published message for resynchronization from the EMS, the PCC begins monitoring for an alignment in the phase of the microgrid and primary grid before initiating a closing of the switch. Upon closing, the PCC publishes a generation mode change request (`DER_setGenerationMode`) to the designated V/f source (3129 Inverter).

Finally, the islanding and resynchronization process has been repeated numerous times and compared to [17]. In [17],

TABLE XII
COMMUNICATION ROUNDTrip DELAY

Delay Causing Entity	Master-Slave	Peer-to-Peer
Request from User /OpenPCC	N/A	N/A
Process and Issue Open on Hardware	Less than a cycle	Less than a cycle
Read by Master	3-4-cycle	N/A
Issue Reuest for State Change	3-4-cycle	3-4-cycle
Total	7-9 Cycles	3-5 Cycles

a master-slave type communications architecture was implemented and the communication delays recorded. In this work, the communication was able to reduce the communication delay by almost a factor of 2 as shown in TABLE XII.

VI. CONCLUSION

This paper proposed using a DDS communication schema for microgrid operations that provides mechanisms for islanding and resynchronization. The utilization of DDS provides peer-to-peer communications of devices while enforcing a communication schema that allows a microgrid switch to directly coordinate with a power electronics based generation asset on the control modes independent of the microgrid controller. The communication schema also provides device discovery mode, which provides a direct plug-and-play type feature for integration of the devices with a microgrid controller. This is a key feature on promoting interoperability of devices on the smart grid. The proposed communication approach has been implemented on a real 480V microgrid hardware with PV, generator, microgrid switch, and load. The results of measured data from an islanding and resynchronization are presented as well as the differences between master-slave type communication and peer-to-peer communication on a 480V test-bed.

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Authors' photographs and biographies not available at the time of publication.