A Real-World Demonstration of the Tactical Microgrid Standard on Legacy Distributed Energy Resources: A Case Study

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***Abstract*—The Tactical Microgrid Communications and Controls Standard (TMS), MIL-STD-3071 was developed by the Department of Defense (DoD) and gives a way for power devices to communicate through the Data Distribution Service (DDS). The standard utilizes DDS as a middleware between domain and device, where the devices may include generators, inverters, load banks, and energy storage systems. Devices developed before the standard do not use TMS, but instead use legacy protocols, such as Modbus and DNP3. To overcome this communication issue, a stack converter was developed to allow legacy devices to translate Modbus to TMS through DDS. This paper presents the research into developing TMS compliance of legacy Modbus power devices and how a working microgrid can implement the plug-and-play capabilities of these devices. Testing was done on an industry-grade microgrid at the Center for Microgrid Research (CMR) at the University of St. Thomas campus.**

***Index Terms* - Data Distribution Services (DDS), Distributed Energy Resources (DERs), Microgrid Communication, Modbus, Tactical Microgrid Communications and Controls Standard (TMS)**

I. Introduction

A Microgrid is a localized connection of distributed energy resources (DERs), storage systems, and load banks that can be controlled as a singular power system [1]. DERs allow microgrids to shift power production and load balancing between multiple devices as needs change. Microgrids that use renewable energy sources, such as a solar photovoltaic array (PV), along with an ESS, can have a higher stability and support sustainability [2]. Microgrids are implemented in multiple different environments such as Hospitals, Universities and neighborhoods [3]. Power outages within these environments could lead to the entire complex, and all those within it, losing power. In a critical case like this, the microgrid can switch into islanded-mode which allows power to keep flowing, but instead of from the grid, it gets power from the devices within the grid, like a generator [3].

Another type of critical environment that would benefit from the capabilities of a microgrid is a tactical environment. This type of environment requires a Tactical Microgrid (TMG) that can operate in an isolated area or battlefield. TMGs need to be reliable in their electrical performance and quality of power; they need to be secure and offer protection to the personnel and equipment on the grid [4]. Something that sets TMGs apart from a traditional microgrid is that the devices within the TMG need to be compliant within the Tactical Microgrid Communication and Controls Standard (TMS), MIL-STD-3071.

Within a microgrid, devices can communicate through multiple different protocols, such as CAN bus, DNP3, and Modbus. One of the most supported communication protocols used within distributed power systems is Modbus [5]. Since Modbus is widely supported, it is easier to implement across different types of devices and can also transfer to different serial communication standards like RS-232 and RS-485. It comes from an open-source protocol and has a simple connection structure for users to understand [6]. Even though Modbus has a high popularity, it still has its own shortcomings.

From a microgrid perspective, using Modbus is done on a request-response basis, for example, a microgrid controller (MC) sends a request to a device and must wait for a response or acknowledgment back. This follows a polling format and when new information is needed, the device must be polled each time by the MC. TMS introduces the Data Distribution Service (DDS) which will lessen the effect of this polling behavior. Through DDS, devices will follow a publish-subscribe protocol which will allow data to be published at different intervals without waiting for a request. One way, for example, is data will be updated every time it changes, which

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will keep data reliable [7]. These are a few of the behaviors and requirements that need to be checked during testing of DERs that are developed to be compliant with the MIL-STD-3071.

The primary contributions of this paper are:

1) Implementation of TMS device types on legacy non-TMS compliant devices
2) Demonstration through real-world testing of device communication over DDS that follow MIL-STD-3071 requirements on an industry-grade microgrid
3) Addressing challenges associated with transitioning communication to DDS and meeting timing guidelines for certain DDS topics

II. Introduction to the MIL-STD-3071

TMS offers microgrids an additional design layer with device communication to go through DDS. Within DDS, a singular domain is created where all of the authorized devices on the grid can connect and communicate with each other. Within the domain and defined in TMS, there are topics where devices can publish their data for other devices to then subscribe to the topic and be able to see that data. This way of communication gives a Microgrid Controller (MC) an easy way to gain an in-depth view of the behavior of the microgrid and the individual devices on it, while keeping data secure.

TMS defines seven different device roles, each with their own compartmentalized functionality. A device is assigned its specific role based on its capabilities and how those translate to TMS. The following are the TMS devices roles and what kind of power device or control device falls within that role:

- Source (SRC): Power devices categorized as a source device produce power for the microgrid to use. Generators, solar panels, and wind turbines would fall into this device role.
- Storage (STOR): Power devices categorized as storage devices have the ability to store power that is produced on the grid, from a source device or the utility. It can also discharge this stored power to other devices or back to the utility. Chargeable batteries fall into this device role.
- Load (LOAD): Power devices categorized as a load device use the power that is generated by SRC and STOR devices that are also on the grid. Load banks fall within this device role.
- Distribution (DIST): Power devices categorized as distribution devices have the ability to direct power between other power devices on the grid. Circuit breakers and switch gears fall within this device role.
- Conversion (CONV): Power devices categorized as conversion devices have the ability to change the power output of different forms of electrical energy, such as converting current from AC to DC. Inverters and transformers fall within this device role.
- Microgrid Controller (MC): Control devices categorized as microgrid controllers oversee all the power devices on the grid. It is aware of what each device is doing and will send requests to correct power usage and production.
- Microgrid Dashboard (MD): Control devices categorized as microgrid dashboards can display a human-readable status output of the grid. This is where warnings and diagnostic readings would appear.
- Monitor (MON): Control devices categorized as monitor devices keep track of all communication happening on the grid between devices. These devices do not have active capabilities but are aware of data and information passing over the network.

Devices within the domain also need to follow Quality of Service (QoS) policies. These can be seen as guidelines for the devices to follow, and if they are missed, then something may be congesting the network, or a device may be responding too slowly [8]. An example would be the QoS policy deadline, which is the expected time that the subscriber will receive a message from the publisher. The publisher needs to keep up with this deadline for each message published to the respective topic. For certain topics within TMS, there is an expectation for the devices to continuously publish their data on a set interval, for example, the topic *tms::AcMeasurementUpdate* requires new data to be published every 1 second and for the subscriber to receive that data by the deadline, in this case, 3 seconds [4]. For a TMG, there may be more states of urgency where the devices need to communicate quickly and reliably to avoid any grid disturbances.

III. The University of St. Thomas Center for Microgrid Research Industry-Grade Microgrid

A. CMR Microgrid: Modbus Devices

Shown in Fig. 1 is the University of St. Thomas (UST) microgrid that is a real-world industry-grade facility that students and faculty at the Center for Microgrid Research (CMR) have full working access to [9]. The UST microgrid can function in grid-connected mode which can receive power from the Xcel Energy feeder, and it can function in islanded-mode with power coming from the diesel genset, batteries, and solar panels. The following power devices make up the CMR

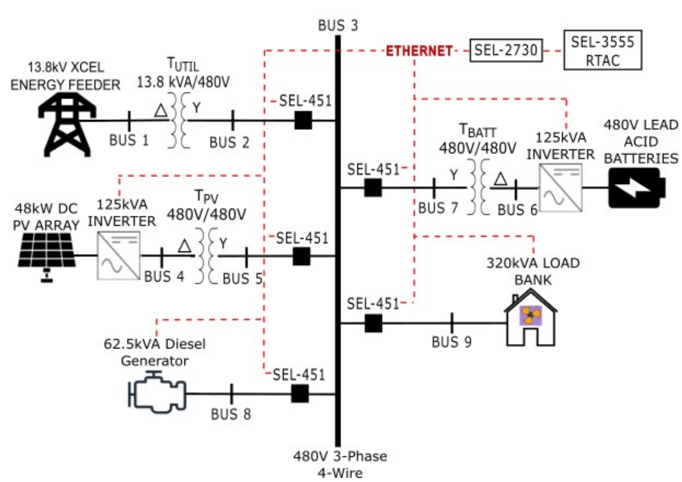

Fig. 1. Diagram of the microgrid at the Center for Microgrid Research.

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microgrid and describe how their device role is assigned based on TMS:

- 62.5 kVA Cummins Diesel Genset (DiG): This is a 3-phase diesel genset with a Woodward easYgen-3000XT control unit. Under TMS, this device is viewed as a SRC device.
- 320 kVA Avtron 6000 series Load Bank: This is a 3-phase load bank with a Sigma 2 controller that communicates through a Modbus-RTU (Remote Terminal Unit) to a monitoring application. Through this application, resistive and inductive loads can be applied to the microgrid. This changes the flow of real power and reactive power on the microgrid, respectively. Under TMS, this device is viewed as a LOAD device.
- 480 V Lead Acid Battery Storage System: This energy storage system is connected to the grid by a 3-phase bi-directional Princeton Power GTIB-125 inverter. Even though inverters are considered a CONV device under TMS, this type of connection of inverter to ESS categorizes as a STOR device. This device can also operate in grid-following and grid-forming depending upon if the UST grid, as a whole, is in grid-connected or islanded-mode.
- 48 kW Solar Photovoltaic Array (PV): This PV array is also connected to a 3-phase Princeton Power GTIB-125 inverter. The inverter converts the DC energy produced by the PV array into AC, which can then be used by the microgrid. This type of device connection of inverter to PV array categorizes this set up as a SRC device under TMS.
- Schweitzer Engineering Laboratories (SEL) 451 Relays: There are five SEL-451 relays that connect each of the power devices mentioned above, along with one connecting the grid to the Xcel Energy feeder. Each relay controls a 3-phase circuit breaker which can be opened to cut off the devices' connection to the grid or closed to connect it to the grid.

Each power device in the CMR microgrid communicates over Ethernet using Modbus TCP. These devices are also connected to the SEL-3555 Real-Time Automation Controller (RTAC) where an engineer can manually send requests and see real-time power readings of each device. A few of these power devices can be seen in Fig. 2.

B. Microgrid with DDS to Enable TMS Compliance

The design for TMS implementation starts with each of the power devices communication ports being connected to a Raspberry Pi single-board computer (SBC) which runs Raspbian as the Linux operating system and functions as a stack converter. The SBC holds two connections; 1) a Modbus connection to the device itself and 2) a Cyclone Data Distribution System that the MC will get information about the device through. All devices on the microgrid will have access to the same DDS domain where each of the TMS topics will be. The MC uses these topics to send the power devices requests and to see the current states of those devices. This

Fig. 2. Legacy power devices at the CMR Microgrid: SEL relays, PV array inverter, Battery inverter, and a Diesel Generator. Cited from Fig. 3. [10]

process follows a publish-subscribe model and an example of data captured over DDS can be seen in Fig. 4.

Seen in Fig. 3, on each of the SBCs, there is DDS middleware which allows communication to the DDS domain for each device. For example, when a device comes onto the network, it will need to publish its device information to the topic *tms::DeviceInfo* within the domain [4]. The MC of the grid can then subscribe to this topic and see the devices info. Once the MC is aware of the device, it can become that devices active MC through the topic *tms::ActiveMicrogridControllerState*

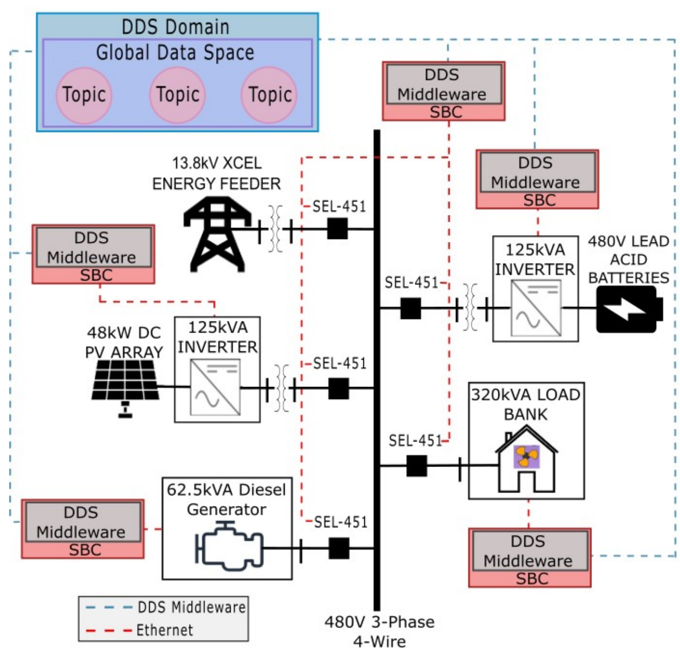

Fig. 3. A Diagram of the CMR Microgrid following the Tactical Microgrid Standard with the implementation of DDS.

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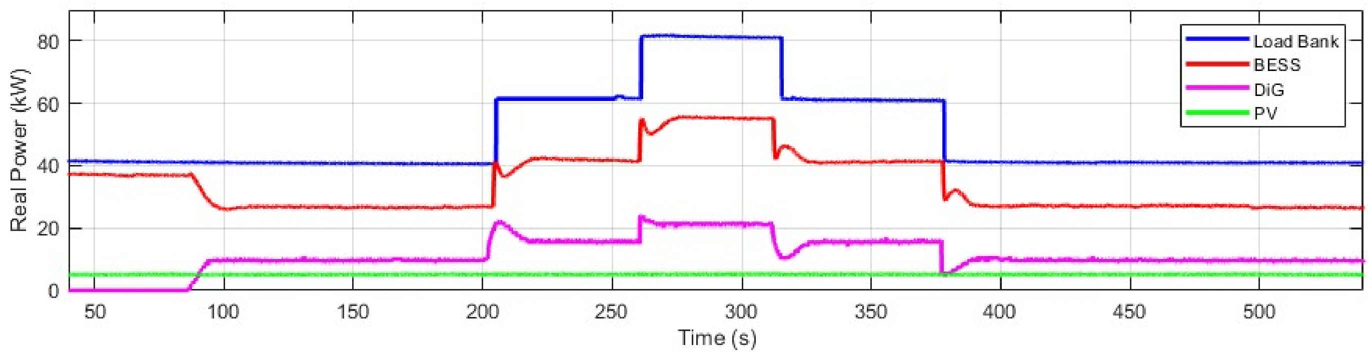

Fig. 4. Data captured through DDS of Resistive Load Balancing between a Diesel Generator (DiG), Battery Inverter (ESS), and PV Inverter

[4]. Once it has been accepted as the active controller for that device, it can send requests to change values of the device's registers such as real power, reactive power, frequency, and voltage depending on what is needed of the grid.

C. Real-World Testing

The research team at UST Center for Microgrid Research (CMR) first began testing the SBC stack converter with a Typhoon HIL606 simulation of the DiG through a Woodward easYgen control panel. This allowed for a safe environment to make sure that the code was working as expected and that safety checks were in place, so the device would not be able to accept values from the MC that were outside of its nominal bounds. Once simulation testing was successful, the team was able to move onto real-world testing of the DiG on the CMR microgrid.

After the success of real-world testing on the DiG, more devices were included until there were four functioning devices on the grid, each being run by a SBC, the DiG, load bank, ESS and PV array. The DiG, ESS, and PV are able to balance the loads demanded by the load bank in grid-connected mode and islanded-mode. The following results section will go over these devices load balancing in islanded-mode.

IV. Testing Methods and Results

Fig. 4 shows the load bank changing the resistive load on the CMR microgrid and how that load is balanced between three power devices. The PV inverter holds a constant active power at 5 kW throughout the entirety of testing, and the ESS holds the rest until about 85 seconds where the DiG comes onto the system. At this point, the DiG and ESS, both running in droop control, will balance the remaining load, not taken by the PV inverter. The DiG will take about 28% of the remaining load, and the ESS will take about 72%. This can be seen at the 100 second mark where the ESS is producing 25 kW, the DiG is producing 10 kW.

Continuing through the graph, the load bank increases resistive load to 60 kW at 200 seconds with the DiG taking about 15 kW and the ESS taking about 40 kW. At 260 seconds, the load bank increases the load to 80 kW with the DiG taking about 20 kW and the ESS taking about 55 kW. As the resistive load decreases between 310 seconds to 550 seconds down from 80 kW to 60 kW then down to 40 kW, we can see the balancing of the DiG and ESS reflect the same real power values they had at the same load values earlier.

The data used in creating the graph in Fig. 4 was caught using a DDS monitor software. The software can join the DDS domain our microgrid is connected to and capture the data published in specific topics. The topic used to create this figure was from the topic *tms::AcSummaryMeasurementUpdate* [4]. This topic requires devices to publish their current power values, real and reactive, along with their frequency and voltage values. Each device would publish its data to this topic in 100ms intervals, so the team was constantly aware of the changes in the devices as the different load values were applied to the grid.

Through the success of real-world testing, the team at the CMR has been able to increase the development of allowing TMGs to facilitate backwards compatibility with devices that were deployed before the standard was created [4]. Even though each device may be from a different manufacturer, they each have the same communication plug-and-play capabilities in the microgrid.

A. Challenges and Limitations

One major challenge the team encountered was the data publication times of each device to the TMS topics. To start, each device has a different manufacturer, so the time it takes data from the devices registers to travel from device, over TCP, and come to the SBC stack converter differs. These different time delays can be due to the internal gateway of each device translating from RTU/serialization to TCP. We took into account the time it takes data to travel from device to SBC and still noticed significant delays. For example, the topic *tms::AcSummaryMeasurementUpdate* requires devices to publish their data every 100ms +/- 10%. If a device was publishing on average every 120ms, then there must have been a bottleneck occurring which led to the discovery that there was more than just the devices code in its stack converter and communication to the device that was causing delays. The team began to see transaction delays when reading a devices register. This showed that there was another source reading the same registers as our team during real-world testing and

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requests for holding register reads were being denied. Once the source that was interfering with the device was disconnected, the team was able to see compliant publication times for the TMS topics.

V. Conclusion

The work presented in this paper showcases how legacy devices can become compliant with the MIL-STD-3071 protocol. The inclusion of the Woodward easYgen DiG (SRC), the Sigma2 Load Bank (LOAD), the Battery Inverter (STOR), and the PV Inverter (SRC) allows us to create a solid foundation for research into commercial-grade DERs enabled with TMS [11]. Future developments include working on the other devices, such as relays, and developing these to become TMS compliant devices.

Along with the relays, the Microgrid Controller (MC) and Microgrid Dashboard (MD) are also devices that will be developed to become TMS compliant. A MC device would allow for more complex behavior handling such as frequency and voltage droop correction, handling valid and invalid requests from the power devices, and keeping track of devices joining and leaving the network.

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