A Framework to Demonstrate a DNP3 Interface With a CIM-Based Data Integration Platform

Preprint

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A Framework to Demonstrate a DNP3 Interface With a CIM-based Data Integration Platform

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***Abstract*—The contemporary electrical grid is characterized by its complexity and abundance of data. A control-rich environment supported by information and communication technologies within an Advanced Distribution Management System (ADMS) presents a viable and cost-effective option for utility companies aiming to implement advanced real-time analytical schemes for monitoring and remotely controlling distribution feeders. Modular platform-based approaches to distribution operations require a structured framework for acquiring field device measurements, performing analytics, converting the setpoint to the correct protocol, and sending it on the appropriate communications network to the field devices. We present the development and deployment of an application service to integrate an open-source standards-based platform with an ADMS test bed with field devices using the Distributed Network Protocol (DNP3) for data exchange. The step-by-step procedure for establishing the DNP3-Master service on an open-source distribution platform is outlined, comprehensively explaining the Master setup process. Moreover, sample use case results highlight the capabilities of the DNP3-Master service setup. Results demonstrate the scalability and configurability of the DNP3-Master service, making it adaptable for integration with other relevant applications, thus providing potential opportunities for real-world field trials and real-time assessments.**

***Index Terms*—Advanced distribution management systems (ADMS), Common Information Model (CIM), Distributed Network Protocol (DNP3), GridAPPS-D, supervisory control and data acquisition (SCADA).**

I. Introduction

The increasing speed of changes introduced by distributed energy resources (DERs) compels distribution system operators (DSOs) to deploy fast-sampled distribution-level synchrophasor devices and smart meters. Additionally, the advanced metering infrastructure (AMI) plays a pivotal role in grid modernization [1], aiming to establish two-way communication between customers and utilities. This involves coordinating smart meters, information and communication technologies, and advanced data analytics at the control center. The substantial amount of data generated by these devices alongside supervisory control and data acquisition (SCADA) measurements demands advanced data analysis skills for smart infrastructure.

Data exchange protocols such as the Distributed Network Protocol (DNP3) [2] are commonly used in distribution networks, where legacy devices exchange data within the grid service area. DNP3 communication involves a “Master” (typically SCADA or any system polling telemetry data from DNP3 devices) and an “Outstation” (any device or system producing data, such as voltage or current measurements from grid elements). This protocol [2], recommended for modern SCADA Master–Outstation communication links, exhibit features that significantly enhance robustness, efficiency, and interoperability compared to older protocols such as Modbus. While it introduces a higher complexity, DNP3 is adaptable for use with various devices including intelligent electronic devices (IEDs) or remote terminal units (RTUs).

Utilities need applications and software services that take advantage of all available data to implement advanced methods that operate and control these devices. A data-abstraction layer is required to efficiently develop services that support interoperability and can be deployed for different distribution networks and device protocols. A standards-based approach provides these benefits by having a common set of data models and functions that are used by the applications and services.

In this paper, we present a generic framework for the development and deployment of a DNP3-Master service based on the Common Information Model (CIM) [1] standard that interfaces with a standard-based open-source platform called GridAPPS-D [1] and the advanced distribution management system (ADMS) test bed [3] at the National Renewable Energy Laboratory (NREL). Previous research by a team from Pacific Northwest National Laboratory explored the DNP3 Outstation, focusing on the data exchanged between the commercial SCADA tool SurvalentONE SCADA and the GridAPPS-D platform [4]. The service starts with a “Master” agent from SurvalentONE SCADA, running on a single IP and port or multiple IPs and ports, with data polling from the “Outstation” (GridAPPS-D) to multiple masters simultaneously, enabling interoperability between CIM and DNP3 platforms. However, this paper describes the DNP3 workflow between GridAPPS-D acting as the “Master” and the ADMS test bed at NREL simulating the “Outstation.” A Colorado distribution feeder with 425 DERs, including 300 photovoltaics (PVs) and 125 battery systems, is simulated using OpenDSS. The setup

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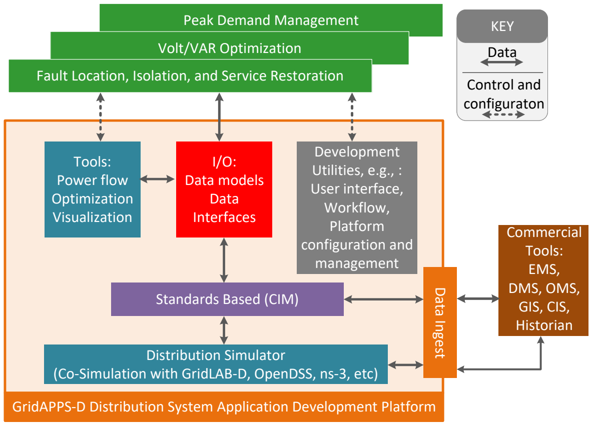

Fig. 1. Conceptual architecture of GridAPPS-D.

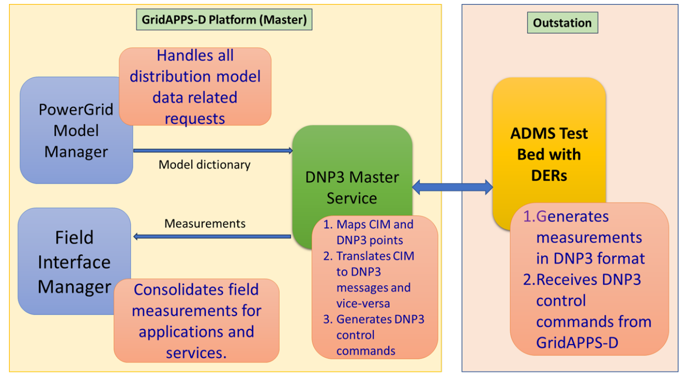

Fig. 2. Architecture for integrating the DNP3-Master service.

uses a Schweitzer Engineering Laboratories (SEL) real-time automation controller (RTAC) [5] as a protocol converter, communicating with GridAPPS-D. DNP3 data is transmitted from the SEL RTAC to GridAPPS-D, where control commands are activated by the GridAPPS-D algorithm and sent back to the SEL RTAC. Finally, data is received by the ADMS test bed. The details of this integration are presented in Section IV-A.

The subsequent sections of this paper are structured as follows. In Section II, we introduce the modeling and simulation environment, detailing the architecture of GridAPPS-D. Section III provides a description of the DNP3-Master application service. The example application and the results from tests conducted on NREL's ADMS test bed are presented in Section IV. Finally, Section V presents the conclusions and a discussion of future work.

II. GridAPPS-D Overview

Fig. 1 provides an overview of GridAPPS-D's architecture. GridAPPS-D uses the CIM [6] to standardize the representation of distribution feeder models. The CIM organizes data about different parts of power systems that control operations.

This platform comes with a range of important features. It helps manage various network models, related information, and data that change over time. One interesting feature is co-simulation, which allows application developers to simulate different behaviors in distribution systems. Another key feature is "Data Ingest," which makes it easy to exchange data with existing systems such as energy management systems (EMSs), distribution management systems (DMSs), outage management systems (OMSs), geographic information systems (GISs), and data storage systems.

As more DERs become part of the power grid, integrating them seamlessly becomes crucial. Using the CIM as a common standard allows applications to use a common application programming interface (API) regardless of the protocol used to retrieve the information [7]. The "Data Ingest" function acts as a service that can take in data from external devices or management systems. This paper focuses on one of the use cases for the application service: how GridAPPS-D exchanges data with an external distribution system simulation within the ADMS test bed. This test bed is hosted separately from the main GridAPPS-D platform. More detailed information about it is provided in Section IV.

III. DNP3-Master Service

This work builds on our prior work [4], where the integration was between GridAPPS-D and an external commercial SCADA tool using the DNP3 protocol. The application service is known as "gridappsd-dnp3" within the GridAPPS-D environment. This service essentially acts as a translator between the CIM message bus and the external DNP3 Masters. These Masters can be SCADA systems or grid devices equipped with DNP3 capabilities, residing at different IP addresses and ports. In this next phase of the work, we are expanding this idea with "gridappsd-dnp3-master" service. It converts DNP3 measurements and messages from external devices. In addition, it generates DNP3 control commands from a CIM-based platform and sends them to the devices. However, there are a few key differences between these two services:

- In the "gridappsd-dnp3" service, the distribution feeder simulation takes place within a simulator on the GridAPPS-D platform (in our use case, it was GridLAB-D in Fig. 1). In contrast, the DNP3-Master service connects with externally located distribution feeder elements (in our use case, the NREL ADMS Test Bed).
- In the "gridappsd-dnp3", GridAPPS-D acts as an Outstation, handling incoming requests. In the DNP3-Master service, it takes on the role of a client, initiating actions. These agents are similar to specialized assistants managing communication tasks. The translation between CIM and DNP3 messages in this service is explained in Section IV.

Fig. 2 shows the flow of the data propagation and processing by each component of the system. The key functional elements such as GridAPPS-D, the DNP3-Master service, and the ADMS test bed are also illustrated. The interactions between components are explained in the remainder of this section.

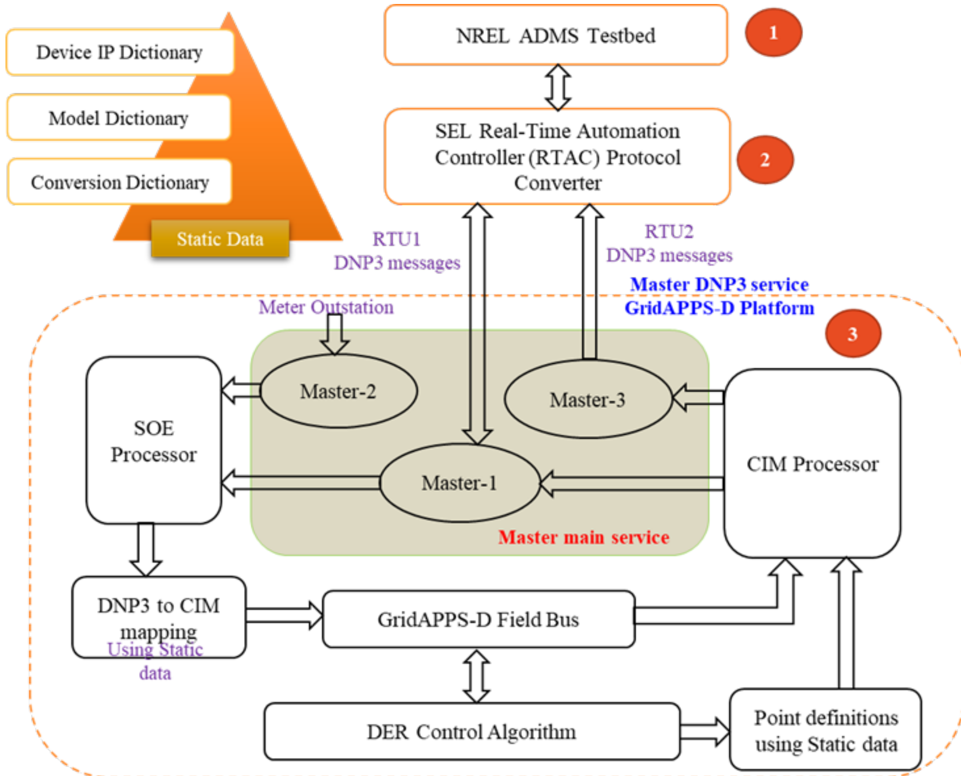

Fig. 3. Diagram showing the flow of data/messages for co-simulation at NREL.

A. PowerGridModel Manager

This is a core component of the GridAPPS-D platform that is responsible for handling all distribution model data-related requests. It receives a request from the DNP3-Master service to generate a CIM dictionary for the requested distribution model identification (ID). PowerGridModel Manager then queries the database and responds with the dictionary file that contains the distribution model details such as equipment and measurement name, ID, and properties.

B. Field Interface Manager

To bridge the gap between a field device's data model and its protocol, we employ the concept of a "field interface" (FI). This is essential for aligning the original DNP3 service's capabilities with different device functions. The introduction of an FI enhances modularity, ensures compliance with the data model, and provides a solid foundation for future updates. It receives the field measurements from device protocol services such as the DNP3-Master service, consolidates them, and publishes them to field output topics for other applications.

C. DNP3-Master Service

The DNP3-Master service, integrated with the GridAPPS-D platform, subscribes to DNP3 messages originating from the test bed or field devices. In this scenario, the GridAPPS-D platform is the Master, while the ADMS test bed acts as the Outstation. Every 60 s, the Master polls the Outstation for information (this interval is adjustable). This code establishes a connection with the Outstation, receives measurements, updates real-time values, and transmits control commands. This application service is composed of multiple Python scripts [8]. The conversion code extracts data from the CIM dictionary file, encompassing measurements for all model components. This data is then transformed into a JSON file containing information such as the datatype, magnitude, value, measurement ID, attribute, name, and description fields. Table I summarizes the data type, group, and variation of DNP3 points. These specifications adhere to the DNP3 standards, ensuring a consistent framework for communication.

TABLE I
DATATYPE, GROUP, AND VARIATION OF THE DNP3 POINTS

Data Type	**Group**	**Variation**	**Examples**	**Control/ Status**	***Sent From***
Analog Output	42	3	Solar Panel, Capacitors, Regulators	Control (Update set points)	Master to Outstation
Analog Input	30	1	AC Line Segment	Measurement Values	Outstation to Master
Digital Output	12	1	Switches, Reclosers, Regulators	Control, Enable, Disable	Master to Outstation
Digital Input	1	2	Breakers	Status	Outstation to Master

IV. EXAMPLE APPLICATION AND RESULTS

In this section, we provide a comprehensive overview of an illustrative application that involves the integration of

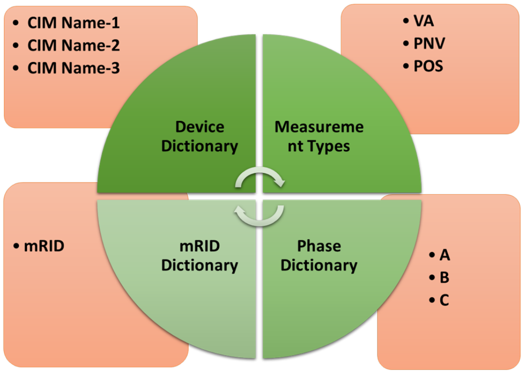

Fig. 4. Schema for the conversion dictionary.

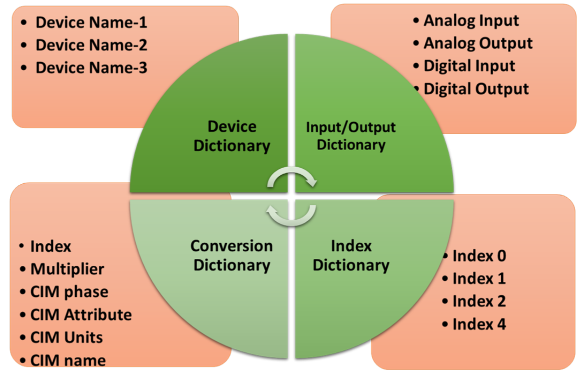

Fig. 5. Schema for the model dictionary.

GridAPPS-D with the ADMS Test Bed at NREL.

A. ADMS Integration

Fig. 3 shows the flow of data/messages of the DNP3-Master service inside GridAPPS-D in a co-simulation setup at NREL, consisting of three stages: the ADMS test bed, the SEL RTAC, and GridAPPS-D. The details of each stage are as follows:

- **ADMS Test Bed**: NREL's ADMS Test Bed [3], funded by the U.S. Department of Energy, employs multi-timescale co-simulation (using HELICS [9]) to evaluate grid control architectures. It integrates hardware seamlessly, collecting data through various communication protocols and aiding the power industry in testing existing/future control systems.
- **SEL RTAC**: The SEL RTAC [5] serves as a protocol converter with cybersecurity features. In the ADMS test bed setup (Fig. 3), OpenDSS is used for power flow simulation. As OpenDSS lacks the required communication protocols, the SEL RTAC protocol converter enables the DNP3-Master service for demonstration.
- **DNP3-Master Service in GridAPPS-D**: This setup involves the preparation of static data in a CSV file and the assignment of names/indexes to the measurements (analog/digital) of the RTAC devices (RTU1, . . . , RTUn). The DNP3-Master setup (Fig. 6) utilizes Python scripts, opendnp3, and pydnp3 libraries [10], [11] to create conversion, model, and device port configuration dictionaries.
  - **Conversion Dictionary**: Fig. 4 depicts the schema for the conversion dictionary. It stores the device names, input/output measurement details (digital/analog), and CIM-identifiable data. The index dictionary provides dedicated indices for RTAC measurements.
  - **Model Dictionary**: Fig. 5 shows the schema of this dictionary.
  - **Device IP/Port Configuration Dictionary**: This stores the IP and port addresses of devices to be polled.

Initially, the main Master service initiates multiple Masters capable of simultaneous data exchange every 30 s (configurable). This approach enhances user flexibility, as not all Masters need to engage in bidirectional RTAC-to-GridAPPS-D data exchange. For instance, in Fig. 3, Master-1 performs bidirectional DNP3 data packet exchange, employing both analog input and output channels. In contrast, Master-2 exclusively transmits data through an analog output channel, while Master-3 solely utilizes an analog input channel for data polling from the meter Outstation. In this paper, Master-1 exclusively handles the exchange of DNP3 data packets to the sequence of events (SOE) Processor/Handler class, managing the DNP3 values received from the Outstation. It bridges the application layer and SOE callbacks from the Master.

Subsequently, DNP3 packets from the SOE are converted into the CIM format using static data and transmitted to the GridAPPS-D field bus output topic. Any application requiring these data can subscribe to the field output topic. The application can then process the received data and send the control commands back to the "Outstation" via the DNP3-Master service. Static data define point definitions, which are then sent to the field input topic. Refer to Table I for detailed information on the point definitions, including the data type, group, and variation, conforming to DNP3 standards. More details on DNP3 mapping can be found in the previous paper [4]. Finally, CIM-to-DNP3 conversion occurs within the CIM Processor, which manages application commands and sends values to the Outstation through the Master.

B. Integration Results

In this section, we discuss the results of a demonstration of the DNP3-Master service and validate the DNP3 data exchange framework using Wireshark [12]. The objective is to control 425 DERs inside a feeder using active power set points received via DNP3 communication from the DER control algorithm on GridAPPS-D. For demonstration, RTU1 is used from the RTAC, and Master-1 facilitates bidirectional data exchange. The RTAC serves as an aggregator, providing situational awareness of the electrical network and DER status as a DNP3 input to the algorithm within GridAPPS-D. The calculated set point is output by the DNP3 master to the RTAC for simulation incorporation. This data transfer is similar to other observed DNP3 master SCADA systems. Fig. 6 illustrates DNP3-to-CIM mapping using static data (such as

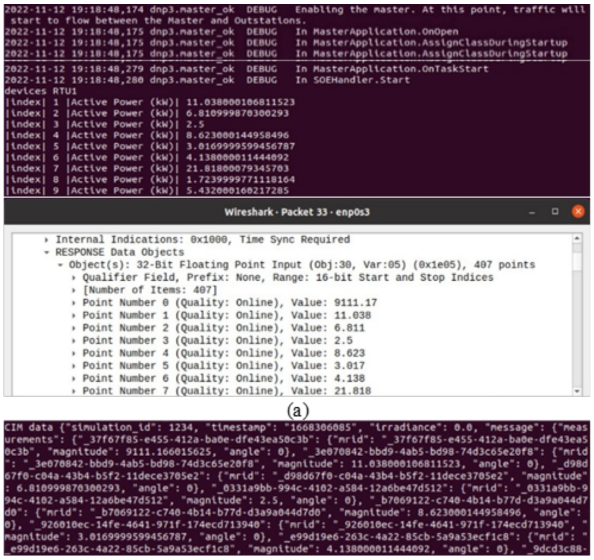

Fig. 6. DNP3-to-CIM mapping: (a) SOE processor raw DNP3 data from the SEL RTAC and (b) CIM message.

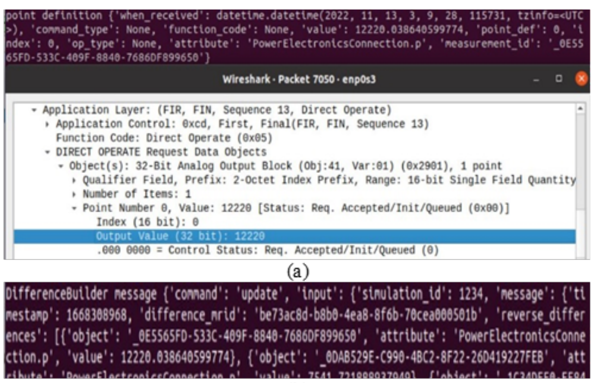

Fig. 7. CIM-to-DNP3 mapping: (a) point definitions and (b) difference builder message.

device IP, model dictionary, and conversion dictionary). In this case, Fig. 6(a) shows the raw DNP3 data from the SEL RTAC received from the SOE handler or processor, matching the Wireshark [12] 32-bit floating-point input data. Fig. 6(b) displays the CIM message corresponding to the raw DNP3 data, converted and sent to the field output topic. The DER control algorithm, developed by NREL, subscribes to the field output topic to further process the data and generate actual set points for the DERs. These set points are fed to a Python script [8] defining point definitions, as shown in Fig. 7(a). Subsequently, the GridAPPS-D python builder generates forward- and reverse-difference CIM messages [1], as shown in Fig. 7(b). The evaluation used a configuration polling every minute for integrity, without assessing latency. The latency for a collocated system is in the milliseconds, minimizing the impact to the optimization performance with a time step of one second.

V. Conclusions and Future Work

In summary, this paper described the development and deployment of an application service aimed at seamlessly integrating GridAPPS-D, a robust open-source software platform adhering to industry standards, with an ADMS Test bed hosting a complex distribution feeder incorporating 425 DERs. Our focus included explaining the integration architecture and its careful implementation and presenting empirical results from rigorous functional testing, affirming the ability to facilitate two-way communication across different protocols [7]. With these successfully demonstrated examples, we believe the DNP3-Master service offers flexibility in configuring and scaling the integration of numerous DERs and legacy devices, with minimal file configurations. This could involve real-world field trials and real-time assessments.

Looking ahead, we plan to extend this work to integrate an EMS (GE e-terra) with GridAPPS-D. In this setup, Hypersim will simulate the distribution model, emulating voltage measurements transmitted to GridAPPS-D via the Transmission Control Protocol within DNP3 packets.

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