Product Specification:

Distributed Control Module

Development of an Energy Services Interface for the EGoT

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Product Specification:

Distributed Control Model

Background

This product specification describes the architecture, implementation, and hardware descriptions of a Distributed Control Module (DCM) prototype. A DCM is an enabling technology for distributed energy resources (DER). DERs are grid-enabled generation, storage, and load devices that are owned by utility customers. DCMs enable information exchange between a distributed energy resource management system (DERMS) and DERs for the purpose of networking large numbers of DERs. DERMS are operated to reduce the cost of operating the grid; the customer benefits indirectly, and sometimes directly, through participation in grid service programs. The DERMS coordinates participation of DERs, which act in concert to provide essential reliability services for a grid operator.

The DCM prototype described within this document enables DER participation in a service-oriented aggregation system. A DERMS server provides IEEE 2030.5 smart energy resource services to DCM clients using a request/response information exchange process. DCMs serve as gateways between the DERMS and the DERs, and they act as agents on behalf of the DER owners to provide intelligent management of the DERs.

Portland State University (PSU) has built DCM prototypes for the purpose of both laboratory validation and field demonstration. Portland General Electric (PGE) and the Northwest Energy Efficiency Alliance (NEEA) have secured donations of grid-enabled water heaters from Rheem, AO Smith, and Ariston Thermal. These water heaters are deployed at residences within PGE's service territory, as well as within the PSU power engineering lab. Together, these units form a mini-network of DERs for the purpose of demonstrating PSU's service-oriented DERMS aggregation system.

Acronyms

CAD	Computer Aided Design
CSIP	Common Smart Inverter Profile
DCM	Distributed Control Module
DER	Distributed Energy Resource
DER	*Distributed Energy Resources* function set, defined by IEEE 2030.5
DERMS	DER Management System
DRLC	*Demand Response & Load Control* function set, defined by IEEE 2030.5
DTM	Distributed Trust Model
EGoT	Energy Grid of Things
ESI	Energy Services Interface
GO	Grid Operator
GSP	Grid Service Provider
HTTP(S)	Hypertext Transfer Protocol (Secure)
IEEE 2030.5	The open message DER protocol used in this project, aka SEP 2.0
IMM	Interoperability Maturity Model
MVoT	Metric Vector or Trust
NEEA	Northwest Energy Efficiency Alliance
PGE	Portland General Electric
PLA	Polylactic Acid
PS	Product Specification
REST	Representational State Transfer
SEP	Smart Energy Profile 2.0, aka IEEE std 2030.5
SGD	Smart Grid Device. ANSI/CTA-2045 term synonymous with DER
SPC	Service-Provisioning Customer: a utility customer and DER program participant
UCM	Universal Communications Module. ANSI/CTA-2045 term synonymous with DCM
UPS	Uninterruptible Power Supply
WH	Water Heater

Executive Summary: Getting DERs to Scale

The value of DERs to the grid as a resource is well understood; DERs have been used as a resource for more than 50 years. Two of many important resource use cases are: 1) mitigating the need to build generation to meet peak load, and 2) reducing the need for storage (by shifting load away from windless nights) as wind and solar generation increases and displaces fossil fuel generation. However, growth in demand response programs has been anemic, at best, over the past decade, and DR remains a small part of utility asset portfolios. As reported by the EIA[1], demand response (DR) resources have grown only very slowly in the last ten years; growth is slow despite the arrival of "smart" appliances in 2010. In 2013 6.6% of residential customers were enrolled in DR programs, compared to 7.4% enrolled in 2021. The 2021 actual peak demand savings used, 8.7 GW, is just 2.2% of the residential peak demand[2].

Two of the major barriers to expanding DERs at scale are the concerns of customers that remote control of their appliances will negatively impact their lifestyles (a loss of privacy of *agency*), and that they will be negatively impacted due to data being collected from their appliances via two-way communication (a loss of privacy of *information*). A major purpose of this DOE-funded project is to develop a system of control that addresses both of these privacy concerns.

This project implements a Distributed Control Module (DCM) at the customers premises. The DCM performs several key functions to remove these barriers. First, though it implements two-way communications with the appliance (or DER), these communications exist only between the DCM and DER and never with a third party beyond the customer's premises, thereby preserving the customer's privacy of information. Second, the DCM accommodates input from the customer about their preferences, which ensures the customer's privacy of agency is preserved subject to tradeoffs that the customer allows. Third, the DCM initiates queries defined under the open standard IEEE 2030.5, and as permitted by customer preferences, to the Grid Service Provider (GSP). These queries allow the DCM to see the grid services that the DCM may subscribe the DER to provide. The DCM understands the commitments it might make through information about the DER through its detailed communication with the DER. However, the GSP knows only about the characteristics of the service such as start time, quantity of energy, and duration of the service. In this method, the GSP knows nothing about the specific DER or how the DER is operated to achieve commitment to the GSP, again preserving privacy of information. Fourth, to develop a sense of trust between the service provider and the customer, the DCM participates in a Distributed Trust Model (DTM) system. A trust agent within the DCM monitors the metadata of information moving to and from the DCM. The method of the DTM is explained in detail below, but the result is to ensure the customer's connection to the outside world serves only the intended purpose.

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[1] US DOE Energy Information Agency:
Demand Response - Yearly Energy and Demand Savings, accessed September 2023
Number of Ultimate Customers Served by Sector, by Provider, accessed September 2023
[2] Residential demand is assumed to be 50% of summer peak demand stated in this EIA reference

The report that follows details the extensive and innovative work of this project, which defines, builds, and tests this end-to-end system. This specific method of DER control and its level of protecting customer privacy and lifestyle is a first, and also a notable achievement.

1 Introduction

An Energy Grid of Things (EGoT) is composed of multiple actors, each with their own responsibilities and objectives. Figure 1.1 shows the information exchange pathways between actors. Service Provisioning Customers (SPCs) own Distributed Energy Resources (DERs), which are customer-owned grid-enabled generation, storage, or load assets that can be aggregated en masse to provide grid-DER services[3]. SPCs register their DERs with a Grid Service Provider (GSP), which is responsible for aggregating DERs for the purpose of providing grid-DER services. A Grid Operator (GO) procurs grid-DER services from one or more GSP, with the objective of using these services to reduce the cost of grid operation, maintain power system reliability, and provide resilience.

The SPC's objective is to maximize their benefits from program participation, which may include financial, environmental, comfort, and/or convenience considerations. The SPC sets its desired participation preferences, which determine how aggressively or conservatively the SPC would like its DERs to engage in GSP programs. The Distributed Control Module (DCM) serves as an agent on behalf of the SPC to obtain the desired objectives through intelligent management of the DER.

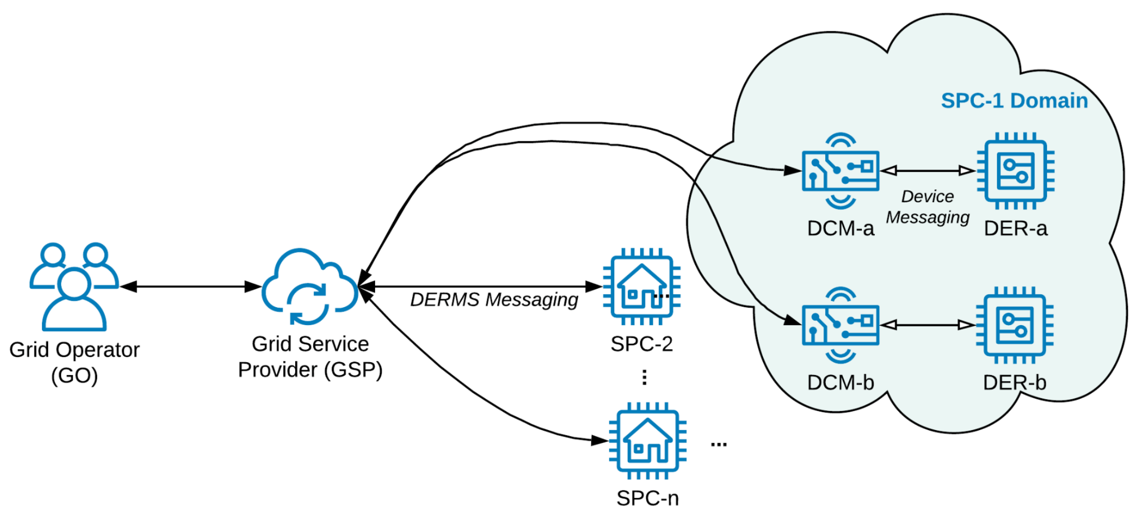

Figure 1.1 A simplified representation of the EGoT actors and the information exchange pathways between them. DCMs manage information exchange between GSPs and DERs, and intelligently manage DERs on behalf of SPCs.

[3] Grid-DER services are essential reliability services that can be provided through dispatch of DER aggregations. Grid-DER services fall into six categories: Energy, Reserve, Regulation, Blackstart, Voltage Management, Frequency Response. Grid-DER services definitions were proposed by the Grid Modernization Laboratory Consortium.
J. T. Kolln, J. Liu, S. E. Widergren, R. Brown, "Common Grid Services: Terms and Definitions Report," Pacific Northwest National Laboratory, PNNL-34483, July 2023.

1.1 Design Principles

The following principles have been used to guide the design and development of the DCM client.

1. Adopt existing and open protocols to ensure interoperability between the GSP and DCMs (ANSI/CTA-2045-B and IEEE 2030.5 in this product specification). Interoperability minimizes implementation costs and maximizes the number of DERs that can participate in grid-DER service programs.
2. Encourage large-scale SPC participation by addressing customer concerns regarding security, privacy, and trust. Specifically, apply the rules of the Energy Services Interface (ESI)[4] to check that these issues are addressed during design.
3. Expect DER capabilities to improve and adoption to increase over time. The system shall be extensible in anticipation of DER technology innovation and proliferation.
4. Encourage future innovation of the DCM user-agent functionality; this product specification focused on the gateway functionality, which enables GSP-DER information exchange. Anticipate that user interface and customer experience experts will innovate DCMs to enhance benefits by improving SPCs' interactions with their DERs.
5. Enable a DER aggregation system that accepts all interested parties; DER participation must not be limited to particular types of DERs.
6. Apply the principle of *layered decomposition* to actuation of the DER in response to messaging: the methods used by the DER to meet its participation commitments in response to messaging from the DERMS shall be determined by the original DER equipment manufacturer.
7. Expect revisions will be made to this product specification in future as its shortcomings become evident.

[4] See subsection 1.2.4 for a brief description of the ESI.
For a more in-depth description, see *Energy Services Interface: Privacy, Security, Trust, Interoperability*, Portland State University PSU-ECE DOE-05, 2023

1.2 Participants & Definitions

The DCM product specification relies on specific definitions for many terms. An understanding of the system will best occur by studying the *functions & responsibilities* tables and the *definitions* tables presented in the following subsections, and then to refer back to these tables as new content is introduced. Tables 1.1 and 1.2 present the main participants that interact through information exchange to enable the dispatch of DER to provide grid-DER services. Participants are classified as *Actors*, which are persons or other external systems; and *Collaborative Objects*, which include interacting components other than Actors. The number of participants varies depending on the use case.

Table 1.1 Actors

Name	Type
Grid Operator	organization
Grid Services Provider	organization
Service Provisioning Customer	person or organization

Table 1.2 Collaborative Objects

Name	Type
Distributed Control Module	agent & gateway
Distributed Energy Resource	device
EGoT DER server/client management system (DERMS)	application

1.2.1 Functionalities and Responsibilities

This subsection presents the functionalities and responsibilities of the system actors and collaborative objects discussed within this document.

Table 1.3 Grid Operator

Functionality	A GO seeks grid services from GSPs in order to achieve operational objectives, which include 1) maintaining operations within the physical constraints that must be honored in order to prevent damage to grid components and equipment, and 2) operational goals associated with stable, reliable, economical delivery of power at nominal conditions.
Responsibilities	● Engage with GSPs to acquire grid services to achieve operational objectives. ● Design and fund incentive programs to attract GSP and/or SPC participation to implement operational objectives. ● Provide DER topological assignment information during the DER registration process

Table 1.4 Grid Service Provider

Functionality	A GSP provides grid services to a GO through the dispatch of DER that have subscribed to a GO program. Aggregation and dispatch are achieved using a DERMS. Grid services are the means by which a GO achieves operational objectives.
Responsibilities	● Provide grid services to GOs. ● Evaluate its aggregation of DER assets to determine a menu of grid services to offer to GOs, prioritized based on the priority operational objectives of GOs. ● Entice SPCs to subscribe to DER aggregation programs ● Exchange information according to the EGoT Server/client implementation profile.

Table 1.5 Service Provisioning Customer

Functionality	An SPC is an electric utility customer who owns one or more devices that can serve as a DER, and who is interested in providing those DER to a GSP through an aggregation program.
Responsibilities	● Subscribe to GO or GSP programs so that their DERs can be managed in order to provide value to the grid ● Ensure their DER are available to request services from GSPs ● Communicate prioritized operational objectives with the GO

1.2.2 Collaborative Objects Definitions

Below are definitions of collaborative objects that are required to properly interpret this document.

Table 1.7 Collaborative Object Definitions

Name	**Definition**
Distributed Control Module	A DCM is a [compute] client that requests resources from a DERMS server. It provides gateway service between communications protocols used by the DERMS and communications protocols used by DER. It serves as the SPC's user-agent to autonomously make resource service request decisions.
Distributed Energy Resource	DER are customer-owned generation, storage, and load assets that can provide grid-DER services. These resources are located behind a customer meter.
EGoT DER server/client management system (DERMS)	The EGoT server and client facilitate TLS and HTTP communications using the IEEE 2030.5 resource models. The client and server are also responsible for translating the common IEEE 2030.5 models into the specific DER and GO interfaces to implement controls and energy services.

1.2.3 Definitions: ***Resources*** and ***Services***

This product specification uses technical terms from two disciplines, electric power engineering and network engineering. Inevitably, common terms from these disciplines will have conflicting definitions. Two such terms that are particularly problematic in this document are “resources” and “services.”

Resources

Within a network engineering context, a “resource” is content within a server. This may be a static file such as an xml document, or a software program that provides a service such as a credit card payment. These resources are accessed from the server by the client through resource requests, and provided to the client by the server through resource responses. IEEE 2030.5 defines function sets, such as *Flow Reservation* and *DER*, that provide smart energy services using request/response resources.

In a power engineering context, “resources” are generation, storage, and load assets that can be used to serve some function. These may be large-scale utility assets like generators, or residential scale assets like customer appliances. The latter can be aggregated by a DERMS to provide grid-DER services. Within this document, “resources” refers to the network engineering definition, and electric power resources are strictly DER.

Services

Within a networking context, a “service” is a uniquely identified application provided by a server, which provides the application to clients via request/response resources. The EGoT DERMS has a service-oriented architecture, which transacts services between the DERMS server and DCM clients. IEEE 2030.5 defines smart energy resources that use a DNS-registered service instance called *smartenergy*. In this document, these network services are referred to as “resource services.”

In the power engineering context, “service” often refers to the electrical service provided to a customer. “Service” also refers to the use of an electrical system resource to provide a necessary grid function, such as a voltage support service or peak demand mitigation service. These are often called “ancillary services,” “essentially reliability services,” or simply “grid services.” Within this document, the terms “grid service” and “grid-DER service” are used interchangeably. “Grid-DER service” refers to any of the six grid service categories defined in Appendix A of the EGoT DERMS Implementation Profile document[5]. Grid-DER services transact between the GO and the GSP, and therefore are outside the scope of this document.

[5] *Implementation Profile: EGoT DERMS server/client System*, Portland State University, PSU-ECE-DOE-01, 2023

1.2.4 The Energy Services Interface

The Energy Services Interface is a set of rules meant to 1) ensure private, secure, and trustworthy information exchange between GSPs and SPCs, and 2) stimulate technological innovations within a large and dynamic EGoT ecosystem. Large-scale adoption of DERs will be necessary to dispatch effective grid-DER services, and to stimulate technological innovations in DER, DERMS, and grid service programs. The ESI promotes these objectives by advancing a set of rules and interoperability requirements that define bi-directional, service-oriented, logical interfaces between GSPs and DERs, with expectations for privacy, security, and trust[6].

The ESI rules and interoperability requirements establish boundaries between SPCs and GSPs that delineate the functions and responsibilities that must be implemented by the developers of EGoT ecosystem products. These rules impose constraints on the implementation of a DERMS, which enforce consideration of privacy, security, and trust.

By emphasizing private, secure, and trustworthy information exchange, and by mandating a service-oriented and interoperable architecture, the ESI promotes the development of an EGoT ecosystem that motivates SPC participation and technological innovation. Interoperability encourages innovation by reducing barriers to entry and increasing confidence of stakeholders. SPCs will be willing to participate in grid-DER service programs that establish trust and emphasize customer choice. Large-scale SPC participation ensures GSPs have ample DER resources to provide grid services that have significant impact on grid reliability and reduce electricity cost for consumers. This in turn signals economic opportunities that encourage innovation, resulting in the development of a robust EGoT ecosystem.

[6] S. Widergren, R. Melton, A. Khandekar, B. Nordman and M. Knight, "The Plug-and-Play Electricity Era: Interoperability to Integrate Anything, Anywhere, Anytime," in IEEE Power and Energy Magazine, vol. 17, no. 5, pp. 47-58, Sept.-Oct. 2019

2 DCM System Architecture

The DCM serves two roles, Figure 2.1. It serves as a user-agent on behalf of the SPC to moderate DER commitments as influenced by the SPC's preferences. And, the DCM serves as a gateway between the protocols used by the GSP and the DER, if those protocols are different. This product specification focuses principally on the gateway role, and less on the agent role, though the former is influenced by input from the latter.

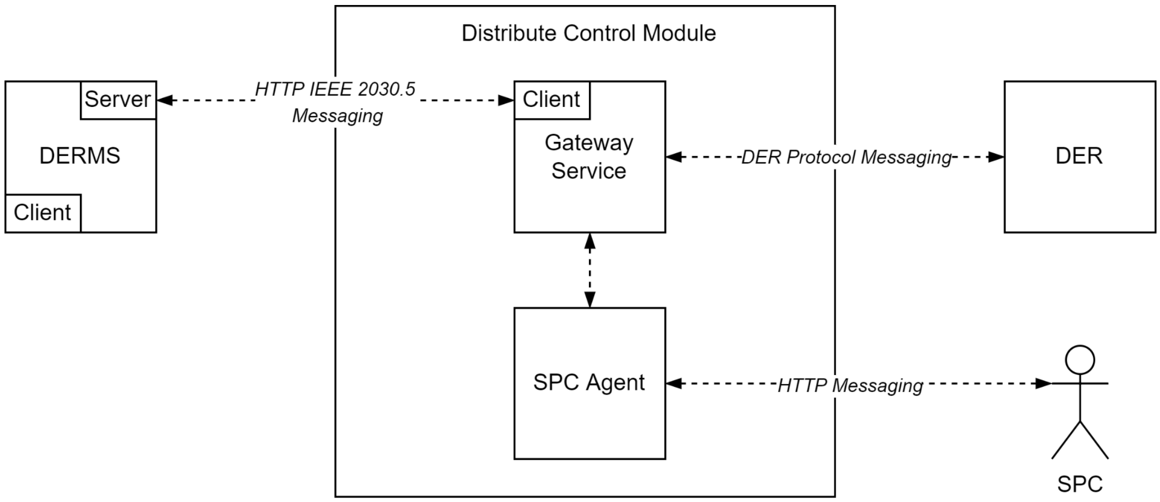

Figure 2.1 Block diagram of the Distributed Control Module showing the two principal services of the DCM: providing gateway service between the DERMS server and the DER, and acting as a user-agent on behalf of the SPC. SPC preferences influence the gateway service via the user-agent. The figure shows the SPC interacting directly with an agent in the DCM. An alternative embodiment may be that the user interface on the DER communicates SPC preferences through the DER protocol.

2.1 Scope of Communication: GSP-DCM

The GSP uses a server to aggregate DERs, herein called the EGoT DERMS server, or just the DERMS. The DCM is the client of the EGoT DERMS server. This server/client system is based on a REST architecture wherein the server hosts resources and the client acts on those resources via request/response information exchange. As the client, the DCM initiates all resource requests. The resources are defined by the IEEE 2030.5 Smart Energy Profile protocol[7]. In its gateway role, the DCM mediates the implementation of IEEE 2030.5 resource logic between the GSP and the DER.

Communication between the DERMS and the DCM uses the IEEE 2030.5 smart energy resource function sets. There are three such function sets: *Demand Response & Load Control* (*DRLC*), *Distributed Energy Resources* (*DER*), and *Flow Reservation*. To ensure the SPC's privacy, only the latter two of these are permitted by this product specification.

[7] IEEE Std 2030.5-2018 (Revision of IEEE Std 2030.5-2013) Standard for Smart Energy Profile Application Protocol, February 2018

2.1.1 Smart Energy Resource: *Flow Reservation*

For the Energy, Reserve, and Regulation grid-DER services, and some applications of the Blackstart service, the DERMS uses *Flow Reservation* resources. This is a consequence of the constraints imposed by the ESI pertaining to both privacy of information and privacy of agency. In contrast to the *DRLC* and *DER* resource services, the *Flow Reservation* resource services exchange a minimum amount of information during the request/response messaging between the DCM and the DERMS. The DERMS uses the *Flow Reservation request* and *Flow Reservation response* resources to estimate DER capacities to participate in grid-DER services. These estimates are conveyed through just four parameters: *energy*, *power*, *interval*, and *duration*.

Privacy of information is preserved since only the *energy* and *power* properties of the DER are required for *Flow Reservation* requests. The DCM uses the *Flow Reservation request* resource to indicate to the GSP a specific amount of *energy* that the DER will consume during the *duration*. The *power* property conveys to the GSP the peak power that the DER will require during the *duration*. No information related to the DER appliance or its unique topological location needs to be conveyed.

The SPC's privacy of agency is also preserved because the SPC's method of using its DER is not revealed within *Flow Reservation* requests. Concerning DER operation, only the *interval* and *duration* need to be communicated. The *interval* of the Flow Reservation request allows the DCM to indicate to the GSP a time period when the DER is available to participate. The *duration* is the amount of time the DER can participate during the *interval*. For example, consider an SPC that has registered its dishwasher for resource service participation. The differences between the "pots & pans", "quick clean", and "water-saver" cycles will have no effect on the ability to participate. Only the *duration* of the selected cycle and the *interval* of availability are communicated within the *Flow Reservation* request.

2.1.2 Smart Energy Resource: *Distributed Energy Resources*

For Frequency Response and Voltage Management grid-DER services, the EGoT DERMS server uses the 2030.5 *DER* function set, which enables four types of curve control. Curve control is a capability that inverter-based DER can provide. Frequency-Watt and Frequency-VAr curves enable a GSP to offer Frequency Response and Volt-VAr grid-DER services to a GO. Volt-VAr and Volt-Watt curves enable Voltage Management grid-DER services. Note, the *DER* function set requires the DCM to expose slightly more of an SPC's information than does *Flow Reservation*. For instance, an SPC's topological location information[8] is required for Voltage Management grid-DER service since voltage is a local electrical phenomenon.

The DERMS server offers the DERProgram, DERControl, DERCurve, and DERCapability resources. The DCM client uses the *DERCapability* resource to inform the DERMS server of its DER nameplate power ratings (Watts and VArs). Knowing the power rating allows the DERMS server to calculate aggregate power capacities when

[8] "Topological location information" is a utility's ID for the service transformer or tap line that serves the customer.

responding to Frequency Response or Voltage Management grid-DER service requests from the GO.

Curves are offered by the DERMS server to DCM clients as DERCurve resources. When DCMs request such resources from a DERMS server, the server responds by sending an appropriate curve to the DCM. The DCM then passes the curve on to the DER. Curve control is a feature of inverter-based DER, and requires the DER to accept curve data. This may be achieved using protocols such as DNP3 (IEEE 1815), SunSpec Modbus, or IEEE 2030.5. This product specification currently limits DCM-DER communication to ANSI/CTA-2045[9] messaging, which does not specify curve control methods. As such, the *DER* function set is outside of the scope of the present version of this document. However, future versions are likely to include this function set.

2.2 Scope of Communication: DCM-DER

The DCM is an IEEE 2030.5 resource-restricted client that simplifies participation and reduces the SPC's private data exposure to outside entities. The DCM serves as a logical interface between a DER and the DERMS server. The ESI interoperability rules allow DCMs to connect to a DERMS regardless of the communication protocol used by the DER. A DER may or may not accept IEEE 2030.5 messaging. If it does, the gateway service is not needed, though some means for mediating DER participation is still required such that the SPC's preferences are satisfied. Likely, the DER will accept some other protocol, such as BACnet, EcoNet, or ANSI/CTA-2045. This product specification addresses the latter protocol, independent of the 2045-A or -B designation.

2.3 Integration with a DTM System

An EGoT DERMS may be supervised by a distributed trust model (DTM) system[10]. In which case, a trust agent resides within the DCM. The DCM block diagram is modified to show this DTM functionality, shown in the lower left of Figure 1.2. A trust agent monitors transactions between the DERMS server and the DCM as well as transactions between the DCM and the DER. Characteristics of these exchanges, but not the messages themselves, are quantified and stored within a metric vector of trust (MVoT). The trust agent periodically forwards the MVoT to an external trust aggregator using an unspecified trust protocol.

The DCM includes an internal server/client pathway that allows the DCM to post messages to the trust agent via a limited, onboard server/client system. The client resides at the gateway while the server resides within the trust agent. HTTP methods are limited to just POST. As such, only the DCM may initiate transitions and no information may pass from the trust agent to the other components of the DCM.

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[9] *ANSI/CTA-2045-B, Modular Communications Interface for Energy Management*, Consumer Technology Association, 2020

[10] *Product Specification: Distributed Trust Model System*, Portland State University, PSU-ECE DOE-02, 2023

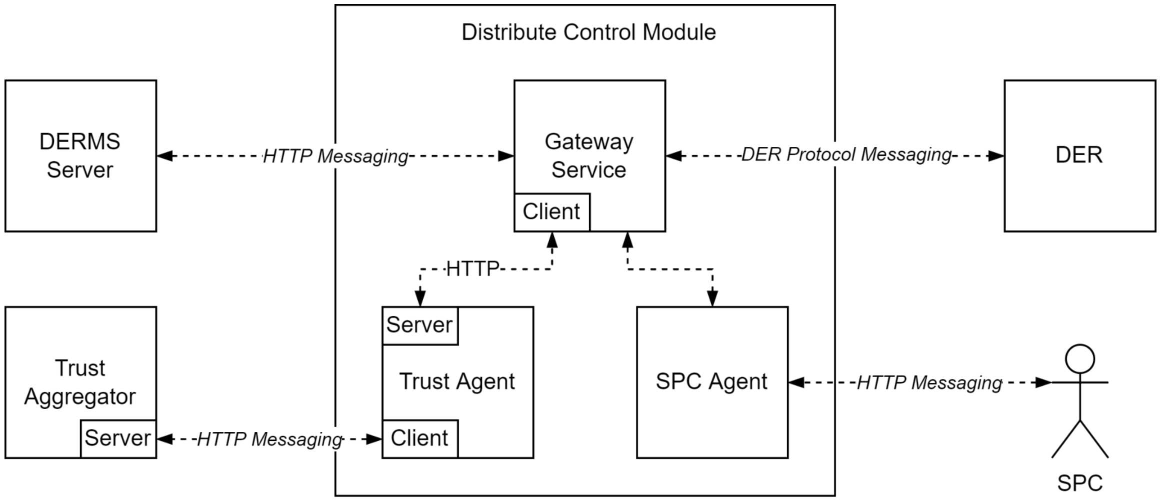

Figure 1.2 Block diagram of the DCM showing the DTM System components. A trust agent, which resides within the DCM, monitors DERMS-DCM and DCM-DER information exchange, the characteristics of which are quantified as MVoTs. A trust aggregator received the MVoT data from the trust agent.

3 Server & Client Implementation

The IEEE 2030.5 standard hosts a large number of resources and function sets. The EGoT server/client uses a subset of these function sets to reduce information exchange and protect SPC privacy. Table 3.1 shows this subset of function sets as well as the DERMS server and DCM client responsibilities required for implementation. The DERMS server must implement all these function sets. However, the DCM client can refuse to expose specific information to the EGoT server by not supporting specific function sets.

The primary function set the DCM client must support is *Flow Reservation*. The *Flow Reservation* function set is an element of the End Device resource, which allows the DCM to restrict a large portion of the function sets and still participate in the basic energy resource service.

Table 3.1 Required IEEE 2030.5 function sets

Name	**DERMS Server**	**DCM Client**
Device Capability	Mandatory	Mandatory
Self Device	Mandatory	Optional
End Device	Mandatory	Mandatory
Time	Mandatory	Mandatory
Function Set Assignment	Mandatory	Optional
Distributed Energy Resources	Mandatory	Optional
Meter	Mandatory	Mandatory
Log Event	Mandatory	Mandatory
Flow Reservation	Mandatory	Mandatory
Security	Mandatory	Mandatory
Subscription/Notification	Mandatory	Optional
Mirror Reading	Optional	Optional

3.1 GSP-DCM Information Exchange

This product specification specifies IEEE 2030.5 as the protocol for information exchange between the GSP and the DCM. The GSP is responsible for creating the required IEEE 2030.5 resources to achieve grid service commitments accepted by the GO. After the SPC registers its DER with the GSP through out-of-band channels, the DCM may submit resource service requests to the GSP. The DCM submits *Flow Reservation* requests, which the GSP uses to provide Energy, Reserve, Regulation, and some Blackstart services to the GO. In future product specifications, the DCM could submit *DER* requests to provide Voltage Management and Frequency Response services to the GO.

3.1.1 Registration

The SPC is required to work with their utility to create the *customer agreement* resource, which establishes the topological grid location associated with the DER. This also serves to ensure specific DER connection agreements are handled through the utility before connection to the grid. The submission of all registration information to populate the *end device, function set assignments, customer agreement*, and *ssl (secure sockets layer) certificate* are performed out-of-band between the GSP and the SPC.

Once all resources are populated, the DCM is given access to the DERMS server through its domain name. The DCM verifies that it is registered using the CSIP COMM-006 Basic Registration procedure, which uses IEEE 2030.5 to manage registration. CSIP COMM-006 provides an outline of the registration step.

3.1.2 Topological Assignments

The topological assignment of DER is designated by the GO during the registration process. The GSP is responsible for creating groupings as indicated by the GO. These groupings are used to manage DER participating in location-based grid services. For non-function set assignment resources such as *Flow Reservation* requests, the GSP is required to manage DER groupings internally to ensure desired DER participation.

3.1.3 *Flow Reservation* Resource Service Requests

The GSP accepts and aggregates requests for *Flow Reservation* resource services from DCMs, Figure 3.1. These requests are initially scheduled to complete at the latest time within the *interval* of the request, where *interval* is one of the four *Flow Reservation* parameters. The GSP commits these requests to a specific grid service advertised by the GO and reschedules the *Flow Reservation response* to satisfy the grid service requirements.

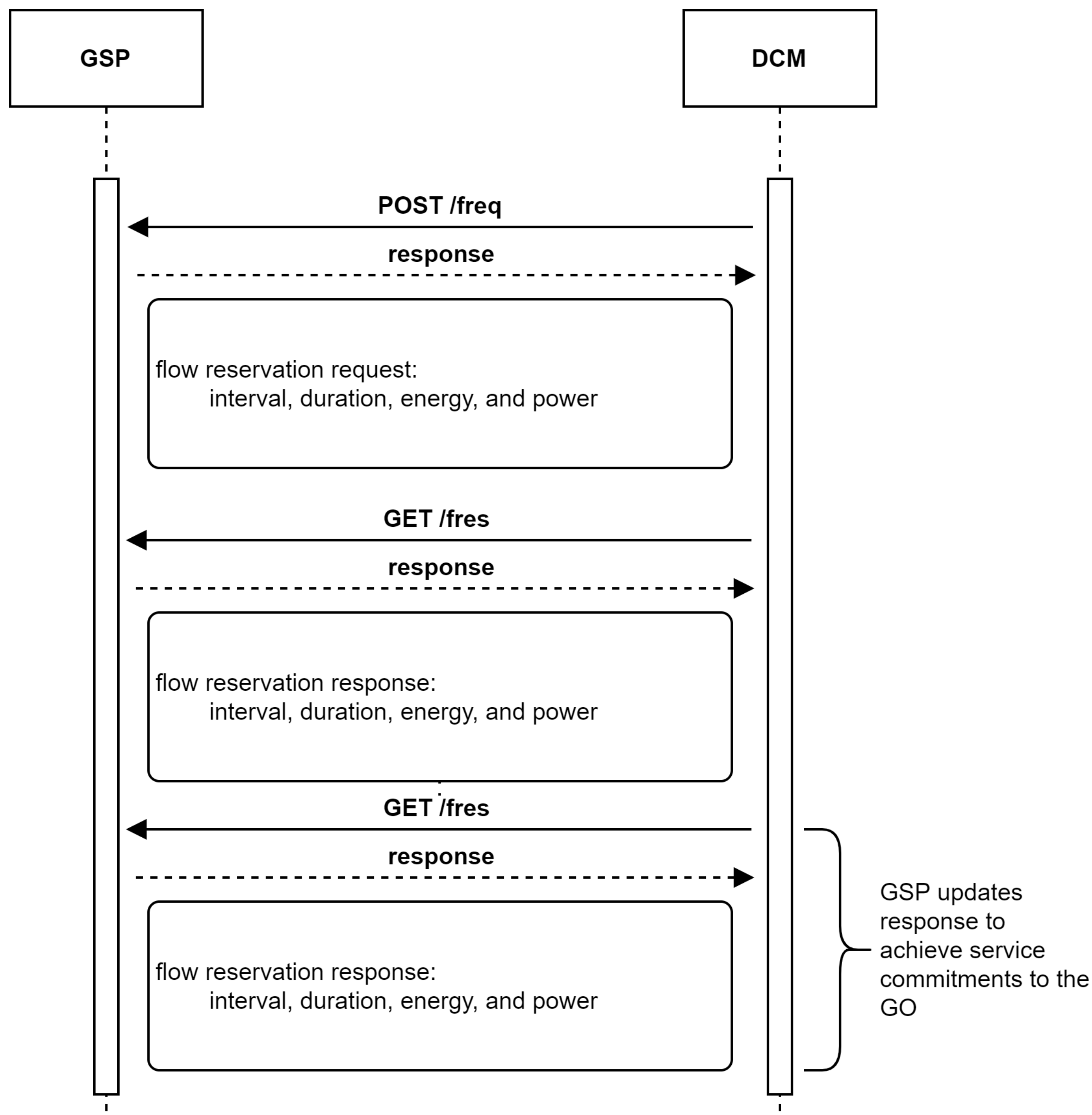

Figure 3.1 DCM *Flow Reservation request* to the GSP for resource service participation.

3.1.4 Resource Service Settlement

The GSP uses the *mirror reading set* resource to validate all DERs that participate in resource service commitments, Figure 3.2. After a DER has completed the *Flow Reservation response*, its DCM is responsible for submitting a mirror meter reading. The GSP uses the aggregated DCM *mirror reading set* to submit grid service settlement to the GO.

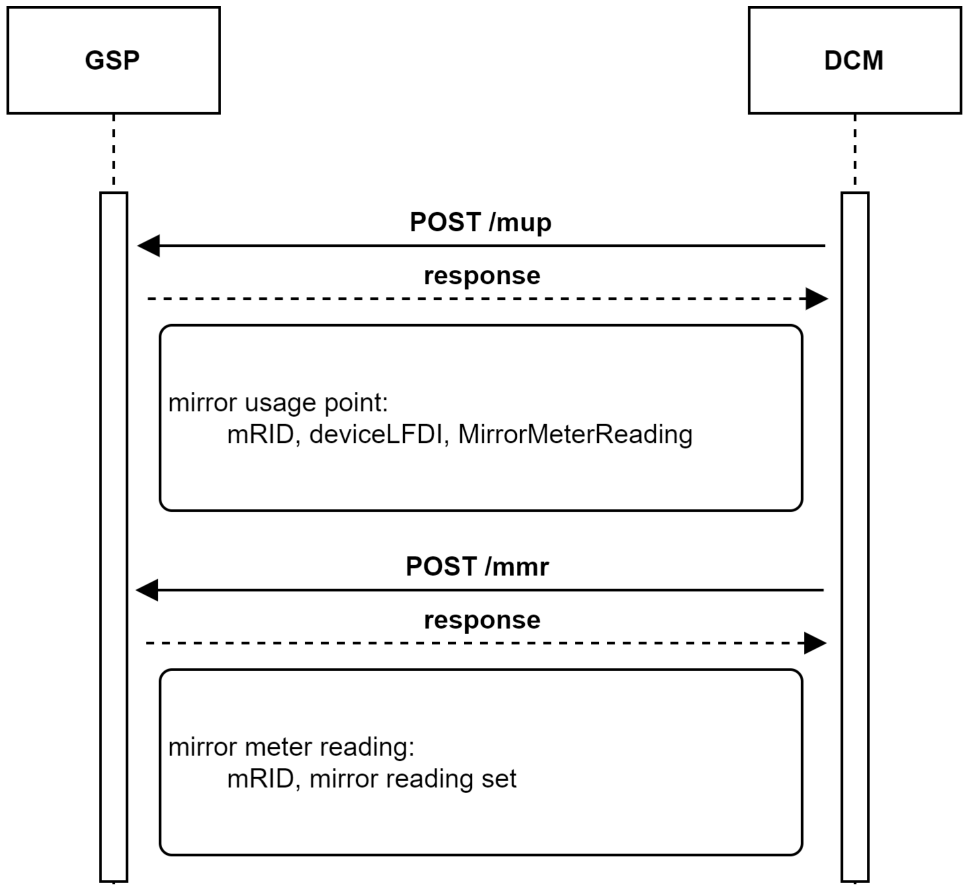

Figure 3.2 DCM mirror meter reading set for *Flow Reservation response* validation.

3.2 DCM-DER Information Exchange

The DCM serves as a gateway between IEEE 2030.5 messaging from the GSP and ANSI/CTA-2045 messaging to the DER. The DCM is responsible for creating *Flow Reservation requests* and abiding the *Flow Reservation response* terms sent by the GSP.

Figure 3.3 presents a simple example of information exchange between a DCM and a water heater (WH) DER. In this example, the DCM prepares the WH to consume a specified amount of energy at a later time. When that time occurs, the DCM instructs the WH to consume energy.

1. The DCM places the DER in a *Shed* mode to defer consumption to a later time.

   The DCM sends a *Shed* command to the DER, which effectively lowers the WH temperature setpoint thereby increasing its EnergyTake as consumers use hot water. EnergyTake is the amount of energy the DER will need to consume to return to its setpoint temperature.

   (From the GO's perspective, this *Shed* command may be sent at the beginning of a peak load event or in advance of a valley filling period.)

2. The DCM periodically queries the DER for its EneryTake.

   The DCM uses the *CommodyRead* request command from the ANSI/CTA/2045 "Intermediate DR Application" command set to query the DER for its *Present EnergyTake Capacity*.

   The DER responds with a *CommodityRead* reply that contains the EnergyTake value, in Whr. (a similar request/reply would have already occurred for the *Rated Max Consumption Level* (W), which for a WH does not change over time)

   The DCM uses these commodity reads to determine *energy* and *power* for an upcoming *Flow Reservation* request. It makes a *Flow Reservation* request once the DERMS creates a suitable resource.

3. The DCM receives a *Flow Reservation* response from the GSP, which includes a scheduled start time for the DER.

   The DCM starts the DER at the scheduled time by sending a *Load Up* command to the DER, which ends the *Shed* mode and effectively raises the internal setpoint of the water heater, resulting in the heating element turning on.

4. The DCM periodically checks the DER EnergyTake property using *CommodityRead* requests and stores the values, which will be sent to the GSP upon completion of the *Flow Reservation response*.

5. After finishing the operation, the DCM might return the DER to the *Shed* state so it may be used for another *Flow Reservation* resource service.

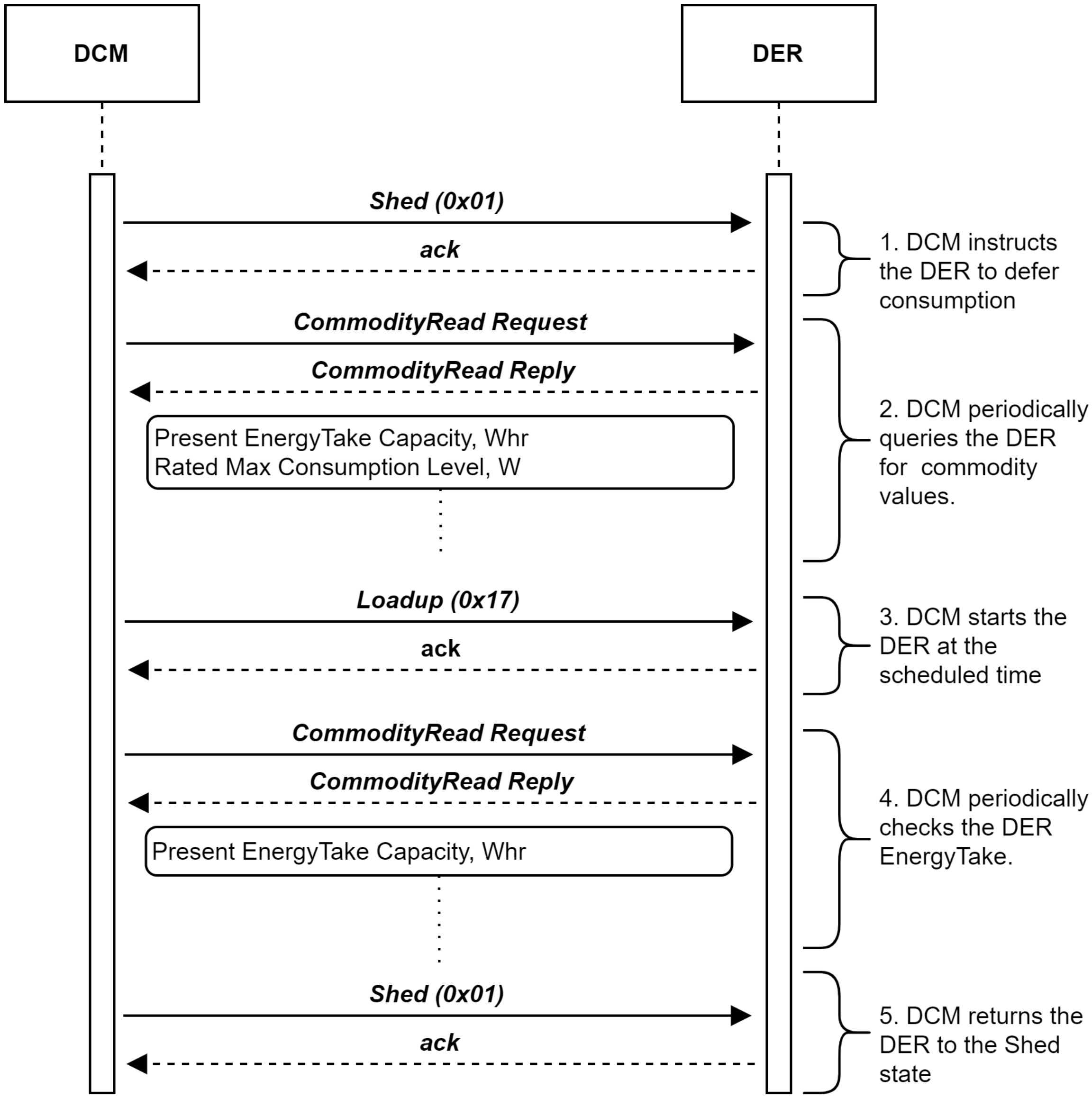

Figure 3.3 DCM *Flow Reservation* process implemented on the DER-side of the DCM gateway using ANSI/CTA-2045 commands.

Epilogue: Getting to DERs to Scale

The methods of DER control described in this Product Specification are not the only ways to protect customer privacy. Briefly, the next paragraphs describe an alternative approach. However, note that the approach requires a smart DER. As used here "smart" means the DER that has internal controls that permit it to perform operations useful to the grid when requested through a communication link. Very generally, "operations" means: to use (or generate) more, or less, energy in a specific period to accommodate a grid need. The specific appliances tested in this project were smart water heaters with a certified EcoPort, meaning the water heater accommodates the ANSI/CTA-2045 communication protocol to permit DER control and information flows. The EcoPort is a USB-like communication socket on the water heater. One embodiment of the project in this report would co-locate the DCM in the communication module that "plugs" into the EcoPort.[11] In the module there will be two distinct communication streams. Two-way communication between the DCM and water heater as defined by CTA-2045, and two-way communication between the DCM and GSP using a small, limited set of IEEE 2030.5 commands.

An equally valid means to achieve customer privacy and lifestyle is an embodiment that broadcasts commands from a GSP to the CTA-2045 communication module. Privacy under one-way communication is obvious, but impact on lifestyle requires a bit of knowledge about how an OEM implements CTA-2045 commands in the appliance. First, all commands via the EcoPort are left to the OEM for specific implementation. The appliance behavior will depend on the specific state the appliance is in. This implementation aspect is in the specification and desirable because the appliance design engineer is in the best position to program how to operate the appliance in each moment and situation to serve both the customer and grid. Second, the specification allows customers to provide lifestyle choices to the appliance; the appliance uses those choices together with grid signals, such as price signals or control signals, to determine how the appliance will alter its normal program.

One key difference in the two approaches is how validation of the appliance response to the service request occurs. In this project, validation occurs when the DCM initiates a settlement request via the IEEE 2030.5 standard. In the alternative embodiment, there are several tools that can be used alone or in combination. First would be to create an automated algorithm to examine smart meter data of a participant coincident with control events; the objective would be to determine the average response of a specific participant over a large number of similar events. Second would be to enroll a small sample of willing participants that allow for statistical collection of operational data from the appliance. A third tool requires linking the GSP control software with the SCADA system of the distribution utility. The electrical topological assignment that occurs during customer enrollment allows forecasting of control event impact by feeder, or feeder subsegment, and this impact can be compared to actual changes observed in the SCADA system.

---

[11] EcoPort is the brand name for ANSI/CTA-2045 certified products.

Appendix A: Prototype DCM Hardware Description

This Appendix describes the hardware components of a prototype DCM. The prototype was designed and built by Portland State University undergraduate engineering students based on a set of product requirements. Each product requirement is stated in italics, followed by a description of how that product requirement was realized.

In subsection A.1, we present the electronics hardware components, including computation, physical connectivity, power supply, backup battery supply, and electronics temperature testing. In subsection A.2, we discuss the DCM enclosure, including EcoPort compliance, and the enclosure design. The enclosure was subjected to multiple drop tests, which we report on at the end of this subsection. A bill of materials for the DCM prototype is included in subsection A.3.

A.1 Electronics Hardware

A.1.1 Computation

The DCM shall use a microprocessor with the ability to have 32 GB of memory or more.

The DCM prototype described in this document uses a Raspberry Pi 4 Model B[12] with 8 GB of built-in RAM, Figure A.1. A micro SD card provides an additional 32 GB of memory. This version of the Raspberry Pi uses a Broadcom BCM2711 SoC with a 1.5GHz 64-bit quad-core Cortex-A72 (ARM v8) processor.

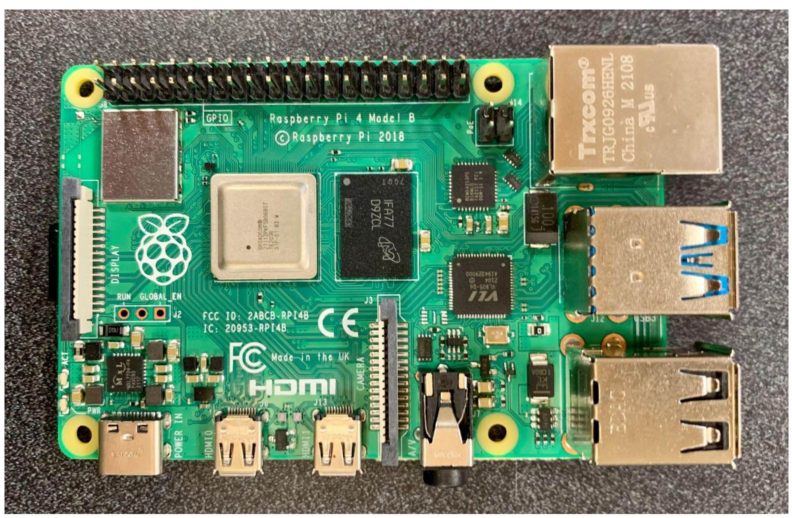

Figure A.1 Raspberry Pi 4 Model B used in the DCM prototype.

[12] Raspberry Pi 4 Computer Model B Data Sheet

A.1.2 Data Link Layer Connectivity

The DCM shall have a wireless LAN connection and shall be compliant with IEEE 802.11 Wi-Fi standards.

The Raspberry Pi 4 has built in wireless LAN capability. If wireless LAN is not built into the microprocessor being used, other means to establish wireless LAN connection shall be implemented.

A.1.3 Power & Backup Battery

The DCM shall use the 120 V AC supply from the DER EcoPort as its power supply.

A power converter shall be used to provide DC power from the DER to the DCM.

A battery pack shall be connected to the microprocessor to act as a backup in the case power is lost from the DER.

The DER provides 120 V AC power from the EcoPort connection. The Raspberry Pi requires 5 V DC power. The power converter conditions the 120 V AC supply to 5 V DC for the Raspberry Pi. A 10 Ah battery and provides pack up energy for the Raspberry Pi in the event of loss of AC supply from the DER. The battery and uninterruptible power supply (UPS) board are shown in Figure A.2.

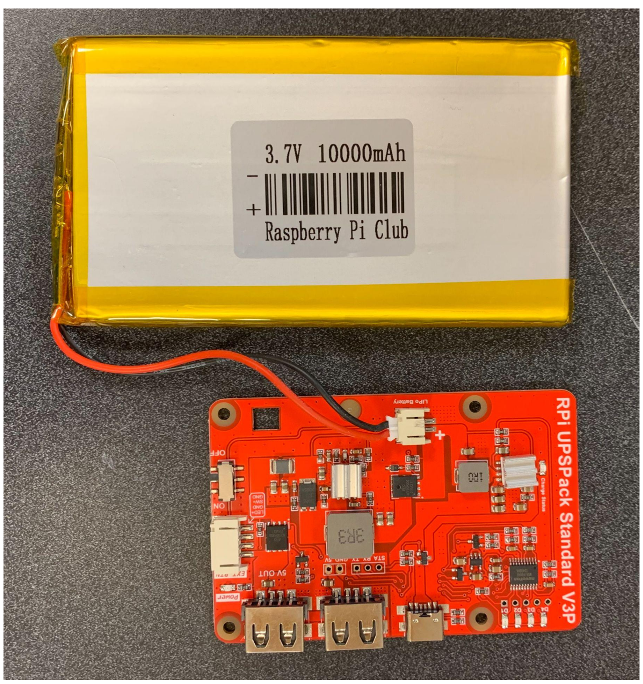

Figure A.2 Backup battery pack and UPS board, which attach to the Raspberry Pi.

A.1.4 Serial Communication

The microprocessor shall be equipped with hardware that enables RS-485 serial communications between the DCM and the DER.

An RS-485 CAN HAT, Figure A.3, enables serial communications between the DCM prototype and the DER. The CAN HAT mounts on the Raspberry Pi.

Figure A.3 An RS-485 CAN HAT provides serial communication between the DCM and the DER.

A.1.5 Electronics Temperature Testing

The temperature within the DCM enclosure shall not exceed 35°C and the temperature of the CPU of the Raspberry Pi shall not exceed 70°C.

The structure and cooling system of the DCM enclosure were designed such that the temperature within the enclosure does not exceed 35°C and the core temperature of the Raspberry Pi CPU does not exceed 70°C. Adjustments to these maximum values may be made based on the requirements of the particular microprocessor and hardware being used.

The structure of the DCM enclosure allows for air flow via ventilation cutouts on the enclosure sides and a small fan placed inside. A physical temperature sensor placed in the enclosure and the built-in CPU temperature sensor on the Raspberry Pi were used to temperature stress test the DCM.

The DCM's temperature was stress tested by running two CPU tests[13]. The first test was lighter and used the "Stress" package, which produced high-load usage across all of the Raspberry Pi's resources. The second test, "cpuburn-a53", is more intense and maxes out the workload on the Raspberry Pi's CPU. Each test lasted around 10 minutes. There were several hours in between the tests to allow the system to cool down to its average temperatures. The table below shows the highest temperatures when no tests are running on the Pi, and the maximum temperatures reached during the two stress tests. In future, more tests may be executed, such as an overclocking test.

Test Number	Maximum Temperature Inside the Enclosure (°C)	Maximum CPU Temperature (°C)

[13] Stress Testing Your Raspberry Pi

No Tests	22.0	37.0
CPU Stress Test 1	23.6	58.4
CPU Stress Test 2	24.3	65.2

Table A.1 Results from the two CPU temperature tests. In neither test did the CPU temperature exceed the specified 70°C limit.

Heat sinks could also be used within the DCM to provide additional temperature regulation, but our temperature tests indicate that additional measures are not needed.

A.2 Enclosure Hardware

A.2.1 ANSI/CTA-2045-B EcoPort Compliance

The DCM enclosure complies with the ANSI/CTA-2045-B physical AC Form Factor requirements, Appendix 18 of the standard, pg 117.

ANSI/CTA-2045-B 18.1.1 - Connector

> *In the case of 120 V devices, pin 12 (Line 1) shall be the hot connection and pin 5 (Line 2) shall be the neutral connection.*
>
> *The connector includes protective sleeves to cover the energized pins, has some circuits removed to increase clearance around the AC power, and is polarized so that the mating device can only be plugged-in one way.*
>
> *The connector part that would go on the SGD*[14] *is available from connector manufacturers in various types.*

In compliance with ANSI/CTA-2045-B 18.1.1, the DCM uses a 12-pin dual-row male vertical header for connecting with the DER adapter module. This polarized connector has protective coverings of the energized pins and is readily available from many different manufacturers. Figure A.4 shows a photograph and dimensional drawings of the connector.

[14] SGD, Smart Grid Device. SGD is the ANS/CTA-2045 term for the smart appliance. In this document, SGD is synonymous with DER.

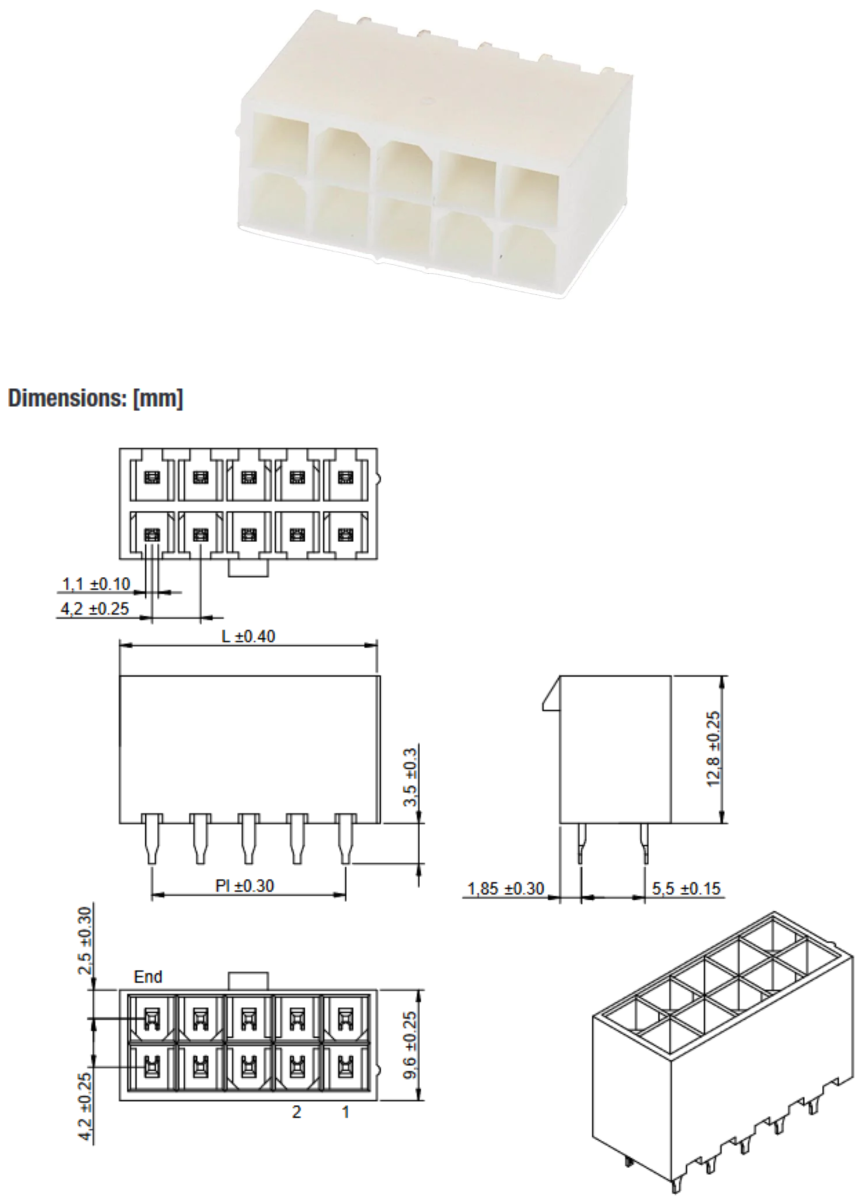

Figure A.4 12 pin dual row male vertical header connector, which connects with the female DER adapter module (Figure A.5). Photo (top). Dimensional drawings (bottom).

In compliance with ANSI/CTA-2045-B 18.1.1 for 120 V AC devices, the DCM connector uses pin 12 for hot connection and pin 5 for neutral connection. Figure A.5 shows a photograph of the female adapter module of the DER, which mates to the male header connector of the DCM.

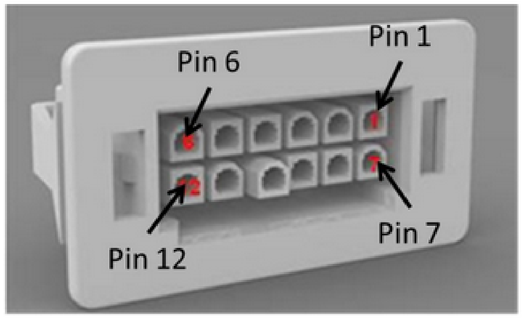

Figure A.5 A photograph and pinout of the female DER adapter module. 120 V AC is provided between pins 12 and 5.

ANSI/CTA-2045-B 18.2 - AC power

> *UCMs[15] must be designed to operate normally over a voltage range from 10% under the nominal service voltage to 20% over the nominal voltage.*
>
> *UCMs must be auto-ranging.*
>
> *Current consumption on the AC lines may not exceed the limits indicated in Table 9-3 [below].*

Power Level Indicator	DC Form Factor		AC Form Factor		
	Maximum Continuous Average	Maximum Peak	Maximum Continuous Average	Maximum Peak	Maximum Instantaneous
0x00 (default)	50[mA]	300[mA]	50 [mA,rms]	300 [mA,rms]	10 [Amps]
0x01	150[mA]	2[Amp]	N/A	N/A	N/A
0x02	250[mA]	2[Amp]	N/A	N/A	N/A
0x03	500[mA]	2[Amp]	N/A	N/A	N/A
0x04	750[mA]	2[Amp]	N/A	N/A	N/A
0x05 5 V Power Option (See Section 15.2.1)	1[Amp]	1.5[Amp]	N/A	N/A	N/A
0x06 to 0xFF (Reserved)					

Table 9-3 – Interface Power Level Indicator Codes

[15] UCM, Universal Communications Module. UCM is the ANS/CTA-2045 term for the module that connects to the SGD, Smart Grid Device. In this document, UCM is synonymous with DCM.

In compliance with ANSI/CTA-2045-B 18.2, the 10 W AC/DC power supply operates on roughly 30% under/over nominal voltage with an input voltage range of 85~305 V AC.

DCM loading on the 5 V DC bus:

Rasp Pi: 730 mA

Can Hat: 10 mA

Battery Pack UPS: The output current can reach: 5 V 3 A. After actual testing, when a Pi4 runs the official Raspbian system, the normal power consumption is about 5 V 1 A. When peripherals such as a camera and U disk are inserted, the power consumption increases to 5 V 2 A. Therefore, the use of UPS v3 to supply power to Pi4 has a large margin. This DCM implementation does not power anything except the Pi4. Therefore, actual output current is limited to what the Pi4 can draw, 730 mA.

Cooling Fan: 200 mA

Total maximum DC current estimate:

$$I_{DC\,Max\,Total} = \sqrt{I_1^2 + I_2^2 + \ldots\ldots I_n^2}$$

$$I_{DC\,Max\,Total} = \sqrt{(730\,mA)^2 + (10\,mA)^2 + (200\,mA)^2} = 760\,mA$$

Total maximum AC current estimate:

$I_{AC\,Max} = \frac{P_{DC}}{\eta 120V}$, where η is an assumed AC-DC conversion efficiency, 80%.

$$I_{AC\,Max} = \frac{(5\,V)(760\,mA)}{(0.8)(120\,V)} = 40\,mA$$

The estimated maximum AC current draw is below the 50 mA limit for maximum continuous average current specified by CTA-2045 18.2 Table 9.3.

ANSI/CTA-2045-B 18.2 - AC power (cont.)

The serial communications link (Data-, Data+, Signal Ground) shall have at least 1500 V AC isolation from the AC Power connections (Earth Ground, Line 2, Line 1) through the power supply Serial Electrical Interface to assure good communication.

Although no datasheet for the specific power supply exists, similar 10 W AC/DC power supplies provide 3000 V AC/1min isolation in compliance with ANSI/CTA-2045-B 18.2.

A.2.2 Enclosure

The DCM prototype enclosure was designed to accommodate the hardware elements described within this section. These are components of a *prototype* system; a commercial DCM would use customized components designed to minimize the size of the DCM enclosure.

A perspective CAD drawing of the DCM enclosure is shown in Figure A.6. Figures A.7 and A.8 show the enclosure cover and bottom, respectively, with dimensions. The enclosure body includes multiple design features:

1. Vent slots to permit inlet convective cooling
2. Vent slots to permit outlet convective cooling
3. Two thru-hole posts for the #8-32 mounting screws
4. One rectangular cutout for the 12 pin dual-row male vertical header
5. Two inset pockets and thru-holes for the #6-32 nuts for mounting 12 pin pcb
6. Three rectangular cutouts for dataport access on the Raspberry Pi
7. Thru-holes for mounting the cooling fan and vertical header (not shown)

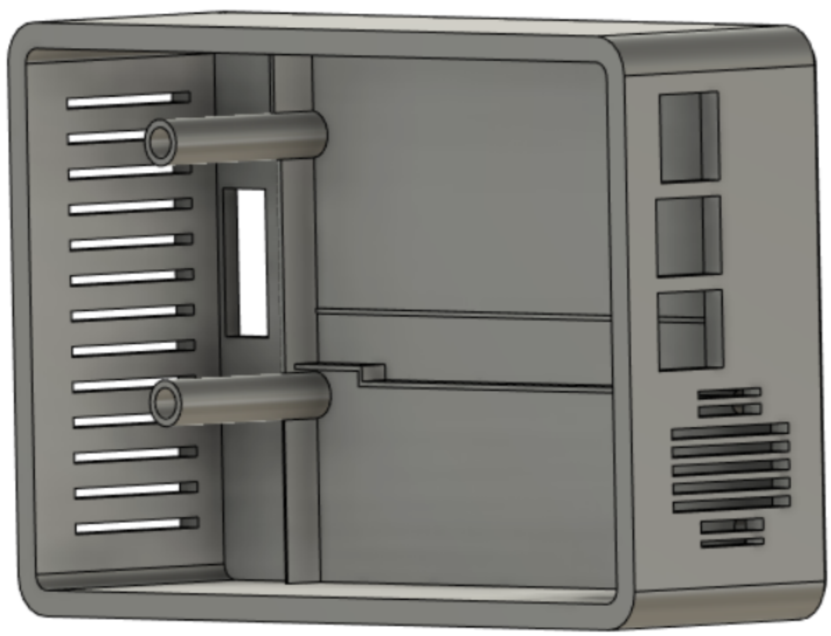

Figure A.6 Enclosure CAD drawing, body, perspective projection.

The DCM prototype enclosure is manufactured using a 3D printer, a PLA (poly lactic acid) corn-based filament, and a 0.4 mm extrusion nozzle. The enclosure is printed via an additive layer technique with a layer height set at 0.2 mm. Using an infill density of 20%, each enclosure (body and lid) takes a total of about 26 hours to complete. This process results in a product with a +/- 0.15 mm tolerance.

Figure A.7 Enclosure CAD drawings, cover. Top views (top) and bottom view (bottom).

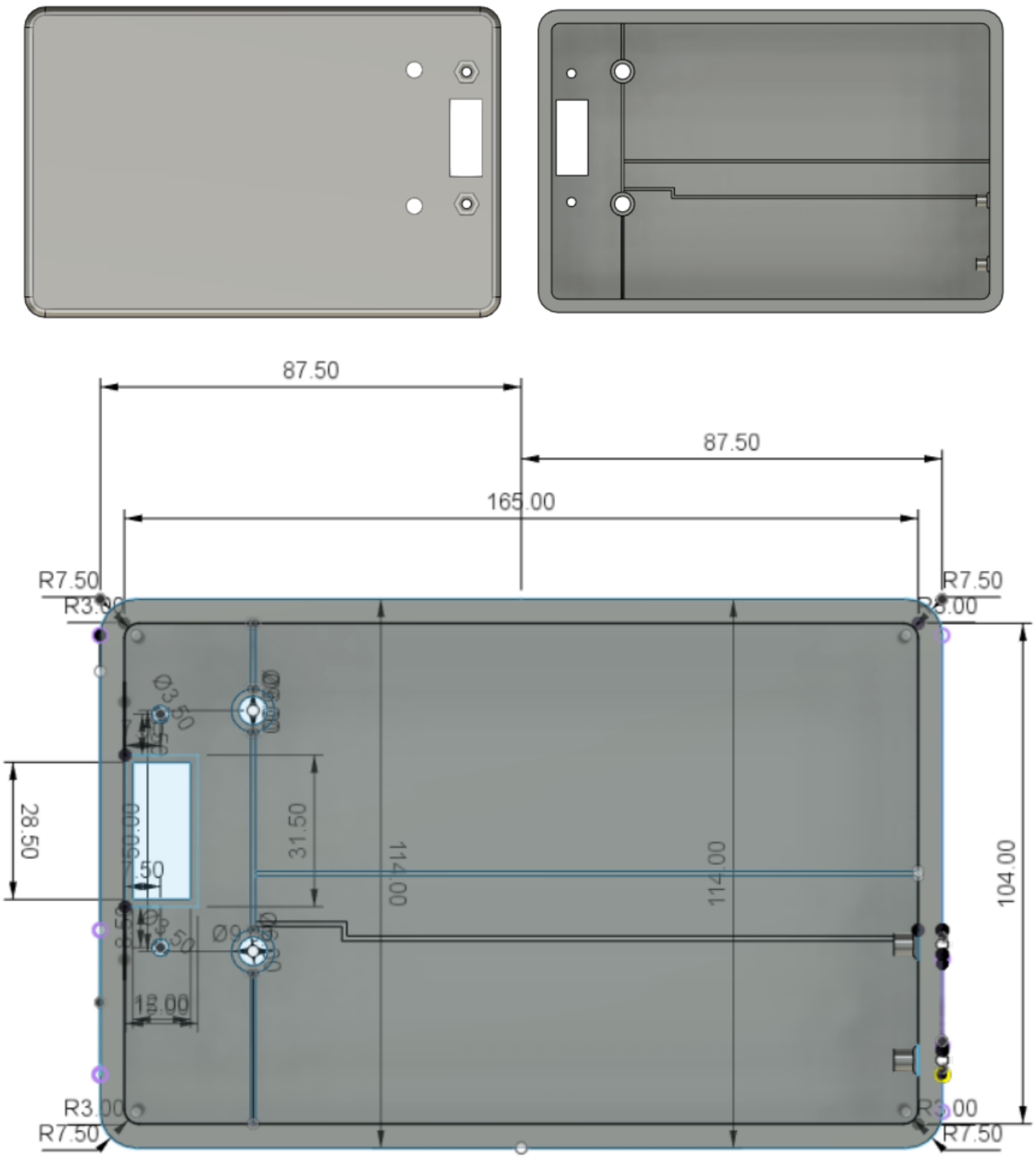

Figure A.8 Enclosure CAD drawing, body. Bottom view (left), top view (right) and dimensions (bottom).

A.2.3 Physical Testing

The DCM enclosure shall be made of a plastic type material that is able to protect the internal contents when dropped from heights between 30 and 65 inches.

As mentioned, the prototype enclosure is made with a 3D printing material, PLA. In future production of the DCM, a more robust material should be used to improve the protection and performance of the enclosure.

The 3D printed DCM enclosure was subjected to four drop tests, listed in Table A.2. The tests show that, although the enclosure took some damage being dropped from two different heights, it was sturdy enough to protect the internal hardware.

Another form of physical tests that can be explored is torque testing. Applying pressure to the end of the DCM that is not bolted into the DER causes some movement. Any light bumping or tugging does not break the enclosure, but more intentional forces could cause damage.

Drop Test Number	**Height (inches)**	**Orientation of the enclosure**	**Results**
1	~ 65	Parallel with the floor, connection side facing down	● Lid popped off ● One of the outside corners took damage ● Contents inside did not come loose
2	~ 65	Perpendicular to floor, USB/fan side facing down	● Lid popped off and took damage ● Outside corner that hit the floor shattered ● Contents inside were fine and did not leave the unit
3	~35	Parallel with the floor, connection side facing down	● Lid popped off ● Only slight damage in splitting an outer corner of the enclosure
4	~35	Perpendicular to floor, USB/fan side facing down	● Lid popped off ● Slight damage to the outer corner that made impact with the ground

Table A.2 Drop test conditions and observations.

A.3 DCM BoM

Bill of materials for the DCM prototype module.

Part Name	Description	Quantity	Vendor	Part No.
Raspberry Pi 4 Model B	Raspberry Pi 4 B Kit 8 GB	1	Vilros	VR4B8GBBK005
Raspberry Pi Battery Pack	Backup power supply for the Raspberry Pi in case power goes out or it gets disconnected from the WH	1	Amazon	B07Y213F8S
SanDisk Ultra Micro SD Card 32 GB	hard drive for raspberry pi	1	Vilros	VILP118
RS485 Raspberry Pi Hat	Adaptor for Raspberry Pi to allow for communication using the RS485 standard	1	Amazon	B07VMB1ZKH
USB C to USB A cable	4 inch 90 degree	1	Amazon	B07X8QV4NL
PLA filament	1.75mm for 3D print prototypes	1	Amazon	B07Q82HVTT
Connector Header Male 12 Pin	WR-MPCA, 4.20mm	1	Mouser Electronics	64901221122
Power supply 120V to 5V	AC to DC converter 120-230V to 5V	1	Amazon	B07SGQ6XXR
5V Small cooling fan	Miniature 5V Cooling Fan for Raspberry Pi	1	Adafruit	3368
USB C to 22 AWG wires	USB C to wires	1	Amazon	B09C7SLHFP
4" Length, Partially Threaded, #8-32	DCM mounting hardware	2	Amazon	B009168JTI
#4 x 1/2" Pan Head Phillips	Screws for mounting fan	4	Amazon	B01MFAIS08
Double Sided White PE Foam Tape	tape for securing internal parts	1	Amazon	B07PNG8ZSG
12 pin PCB	custom PCB for 12 pin male connector	1	OSH Park	N/A
24 ga wire	24 ga stranded conductor	1	Amazon	B087TJNJZS
rubber feet	rubber feet for spacing and mounting	2	Amazon	B093RH258Z
Steel Pan Head Machine Screw #6 - 1/14	PCB mounting hardware	2	Amazon	B00F3599ZE
Hex Nuts, #6-32	PCB mounting hardware	2	Amazon	B07JPFTTJW

Appendix B: Draft DCM Installation & Connection Manual

This Appendix is a draft Installation Manual intended for homeowners to use when connecting a prototype DCM to their water heater. Subsect B.1 describes the procedure for manually mounting the DCM to homeowner's water heater EcoPort. Subsection B.2 describes the procedure for connecting the DCM to the homeowner's wifi network. Note that the wifi connection procedure is more complicated than is appropriate for a homeowner due to the prototype nature of the DCM and DERMS at the time of this publication.

B.1 Mounting the DCM

Physical connection between the DCM and DER

1. With the DCM flat on its back, the 12 pin male dual vertical header can be seen protruding from the enclosure, Figure B.1. This is the communication connection between the DCM and DER adapter module.

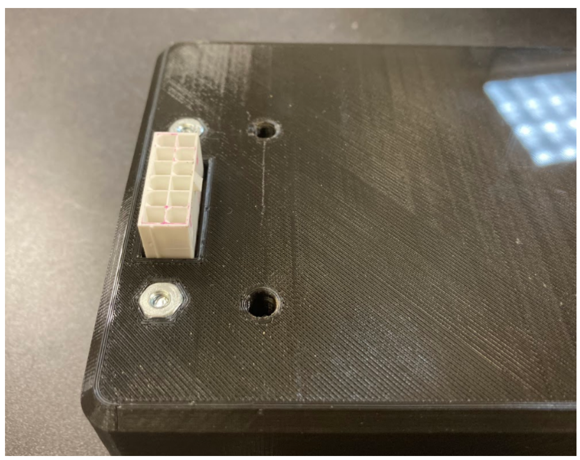

Figure B.1 Male 12 pin connection located on DCM.

2. Locate the female 12 pin header of the adapter module on the appliance. This is typically mounted on the side or top of the appliance, as shown in Figure B.2. Take note of the brass nut inserts located on the adapter module. These are the mechanical mounting points for the #8-32 machine screws used in a later step.

Figure B.2 Female 12 pin connection located on the adapter module

3. Using the empty through holes on the enclosure as a guide, orient the DCM correctly and align the female and male 12 pin connections between the DCM and appliance adapter module.

Figure B.3 Through holes on DCM aligning with brass nut inserts on the adapter module for correct orientation.

4. Place a hand on the back of the DCM and apply light pressure to correctly seat the male connector into the female connection. When the DCM will go no further, an acceptable connection has been established.

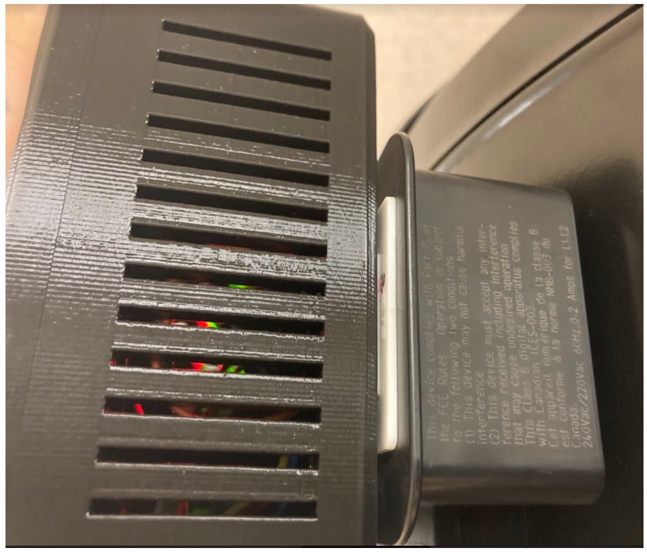

Figure B.4 Male 12 pin connection (DCM side) correctly seated into the female connection (adapter module side)

5. Using the provided #8-32 machine screws, Figure B.5, the DCM can now be mechanically fastened to the adapter module of the appliance.

   Note: Continue to support the DCM by hand until the mounting hardware has been installed, Figure B.6. Failing to do so could cause damage to the 12 pin connector. It may be necessary to slightly adjust the position of the DCM in order for mounting hardware to align exactly with the brass nut inserts.

Figure B.5 #8-32 machine screws (mounting hardware)

Figure B.6 Supporting the DCM by hand while installing mounting hardware

6. Using a Phillips head screwdriver, tighten the machine screws until the screws are seated all the way into the countersunk holes, Figure B.7.

   Note: These do not need to be tightened very much. Overtightening the mounting screws will lead to damaging of the DCM enclosure. Because of this, using a drill or other electric tool is not recommended.

   The DCM should now be correctly connected to the adapter module of the DER.

Figure B.7 Tightening mounting hardware with phillips screwdriver

B.2 Connecting the DCM

B.2.1 Connecting to WiFi

For this version of the DCM prototype, the WiFi connection will be set up before the homeowner receives the DCM. The homeowner will provide us with their WiFi network name and password. Once the DCM is installed to the water heater and has power, it will automatically connect to the WiFi.

In future, alternative options for connecting to WiFi will be explored, such as an app that connects via Bluetooth or using the WPS button on the homeowner's router.

B.2.2 Setting Homeowner Preferences

In future, an area of focus will be allowing the homeowners to have easy control of updating preferences for Flow Reservation request durations and intervals. At this time, these preferences will be communicated and set up prior to the homeowner receiving the DCM.

B.2.3 Connecting to Servers

The prototype will be preconfigured to connect to two servers: one that communicates with the DCM and another that communicates with the DTMC. The homeowner will not need to do anything to set up this connection, as it will happen automatically when the prototype is connected to WiFi.

On the server computer, open terminal and type the command as follow:

```
~ % ssh sonali@psuegotderms.ece.pdx.edu
```

PASSWORD: blackberry

Once you log in, type the command "ls" in the terminal and ensure derms.py it is present. Then type "python3 derms.py" to activate the derms program.

```
[sonali@psuegotderms:~$ ls
derms_server.py  doe-egot-system  temp
[sonali@psuegotderms:~$ python3 derms_server.py
```

Once it it activate, it should look like this. This means the server it is listening.

```
[sonali@psuegotderms:~$ python3 derms_server.py
DERMS started on https://127.0.0.1:8080
```

B.2.4 DCM to DERMS Server

The connection between the DCM and DERMS server will be preconfigured, allowing the prototype to start communication as soon as the device is connected to WiFi.

When DCM device is connected to the WiFi, navigate to the CTA2045 by executing the command "cd water_heaters_testings/dcs/build/debug/" then type the command "./sample2" to activate the commodity commands. it should look like these 2 pictures.

```
[pi@dcm-number7:~ $ ls
Bookshelf  Documents  Music      Public     Videos
Desktop    Downloads  Pictures   Templates  water_heaters_testings
[pi@dcm-number7:~ $ cd water_heaters_testings/dcs/build/debug/
[pi@dcm-number7:~/water_heaters_testings/dcs/build/debug $ ./sample2
```

```
[pi@dcm-number7:~/water_heaters_testings/dcs/build/debug $ ./sample2
2023-08-29 12:25:25,391 INFO  [default] starting commodity service...
2023-08-29 12:25:25,554 INFO  [default] ack received: 16
2023-08-29 12:25:25,707 INFO  [default] message type supported received: 2
2023-08-29 12:25:25,707 INFO  [default] commodity response received.  count: 4
2023-08-29 12:25:25,707 INFO  [default] commodity data: 0
2023-08-29 12:25:25,707 INFO  [default]         code: 0
2023-08-29 12:25:25,707 INFO  [default]   cumulative: 157000
2023-08-29 12:25:25,708 INFO  [default]    inst rate: 0
2023-08-29 12:25:25,708 INFO  [default] commodity data: 1
2023-08-29 12:25:25,708 INFO  [default]         code: 8
2023-08-29 12:25:25,708 INFO  [default]   cumulative: 0
2023-08-29 12:25:25,708 INFO  [default]    inst rate: 4500
2023-08-29 12:25:25,708 INFO  [default] commodity data: 2
2023-08-29 12:25:25,708 INFO  [default]         code: 6
2023-08-29 12:25:25,708 INFO  [default]   cumulative: 10325
2023-08-29 12:25:25,709 INFO  [default]    inst rate: 0
2023-08-29 12:25:25,709 INFO  [default] commodity data: 3
2023-08-29 12:25:25,709 INFO  [default]         code: 7
2023-08-29 12:25:25,709 INFO  [default]   cumulative: 1813
2023-08-29 12:25:25,709 INFO  [default]    inst rate: 0
2023-08-29 12:25:25,913 INFO  [default] ack received: 13
2023-08-29 12:25:26,036 INFO  [default] operational state received 0
c- CriticalPeakEvent
e- Endshed
g- GridEmergency
l- Loadup
o- OutsideCommunication
s- Shed
q- Quit
enter choice: s
```

Once the commodity command has activated, Then DCM will gather the flow reservation parameters values (Power, EnergyTake, Duration, Interval) and send it to the DERMS via XML, Once the DERMS receive the message it will respond with the status code: 201, and the DERMS can send out service via XML to the DCM as well. The following pictures shows the DCM sent flow reservation parameters data and DERMS request of service to the DCM.

DCM View

```
pi@dcm-number8:~/client $ python3 dcm_client.py
/usr/lib/python3/dist-packages/urllib3/connection.py:455: SubjectAltNameWarning: Certificate for psupwrlabderms.ddns.net has
 no `subjectAltName`, falling back to check for a `commonName` for now. This feature is being removed by major browsers and
deprecated by RFC 2818. (See https://github.com/urllib3/urllib3/issues/497 for details.)
  warnings.warn(
Response from server:
HTTP/1.0 200 OK
Server: BaseHTTP/0.6 Python/3.8.10
Date: Tue, 12 Dec 2023 22:39:30 GMT
Content-type: text/xml
Content-length: 52

<Response>Service Status: Service Started</Response>HTTP/1.0 200 OK
Server: BaseHTTP/0.6 Python/3.8.10
Date: Tue, 12 Dec 2023 22:39:30 GMT
Content-type: text/xml
Content-length: 36

<Response>Service Type: 1</Response>
Status Code: 201
```

DERMS View

```
sonali@psuegotderms:~$ python3 derms_1.py
Server started on http://127.0.0.1:8080
127.0.0.1 - - [12/Dec/2023 14:39:30] "POST / HTTP/1.0" 201 -
Received Order ID: 78913
Received Customer: SPC_3
Received Interval: 3600.0
Received Duration: 0.0
Received Power: 0.0
Received EnergyTake: 225.0
Received Timestamp: 2023-12-12 14:39:30
Received Service Message: Start Service?
127.0.0.1 - - [12/Dec/2023 14:39:30] "POST / HTTP/1.0" 200 -
Sent Response: Service Status: Service Started
127.0.0.1 - - [12/Dec/2023 14:39:30] "POST / HTTP/1.0" 200 -
Sent Response: Service Type: 1
```